THE UNIVERSITY OF STIRLING

ROBERTSON RESEARCH FELLOWSHIP

A TECHNOLOGICAL ECONOMIC APPROACH TO LONG TERM MINERAL RESOURCE DEVELOPMENT:

illustrated by the case of Highland Dolomite

by

Jonathan Richard Morgan

A thesis presented to the Board of Studies for Technological Economics for the Degree of Doctor of Philosophy

Stirling, Scotland, October 1974

ABSTRACT

An interdisciplinary study in technological economics is undertaken of various factors of determining importance in the long term development of minerals resources.

Contributions to a theory of minerals development, and three empirical studies of minerals consuming industries are brought together in a simple network approach to the structuring of opportunities for long term development called opportunity planning. The empirical and planning studies are illustrated with reference to a particular mineral, dolomite, which is in geologically plentiful supply in the Highlands of Scotland. This region provides a focus for the application of the technological economic studies.

From the outset attention is drawn to the essentially interdisciplinary definition of mineral resources as distinct from minerals deposits. Various aspects of this definition are examined including the implications of changes in the patterns of minerals demand. It is suggested that much greater attention to the analysis of such patterns is required even though they may develop at stages relatively distant from extractive and primary processing operations. This is because such changes may be crucial in the shaping of a compromise between the technical potential of a minerals deposit and the economic role of the derived products. As a convenient method of relating the relevant technological and economic variables the simple production function is used to provide a preliminary hypothesis describing the incentives necessary to stimulate minerals

development. And on the demand side several hypotheses of the diffusion of innovations are critically examined and an evolutionary model for the diffusion of new materials is proposed.

The empirical studies examine an industry in each of the three major divisions of the proposed minerals classification: a metals industry (magnesium), industrial minerals industry (basic refractories) and the bulk materials industry. The industries examined may all have the study mineral, dolomite, as a raw material in common. Each industry is examined under the following headings: structural analysis, technological background, end use analysis and market behaviour. The analysis conifrms that assessment of minerals prospects in terms of current end use specifications, established technology and current market prices may be an insufficiently enterprising means of assessing minerals potential.

In subsequent sections, therefore, a method of planning for minerals development is proposed which is sufficiently flexible to incorporate alternative technologies, the particular technical advantages of individual minerals deposits and possible changes in end uses and their functions. The method, called opportunity planning, advocates a simple network approach for the structuring of opportunities which can subsequently be applied to specific minerals deposits. Two strategic divisions are proposed, labelled interventionist and non-interventionist opportunity planning. The opportunity planning network is applied to the three case study industries and complements long term development forecasts based solely on the extrapolation of current supply and demand configurations.

development. And on the demand side several hypotheses of the diffusion of innovations are critically examined and an evolutionary model for the diffusion of new materials is proposed.

The empirical studies examine an industry in each of the three major divisions of the proposed minerals classification: a metals industry (magnesium), industrial minerals industry (basic refractories) and the bulk materials industry. The industries examined may all have the study mineral, dolomite, as a raw material in common. Each industry is examined under the following headings: structural analysis, technological background, end use analysis and market behaviour. The analysis conifrms that assessment of minerals prospects in terms of current end use specifications, established technology and current market prices may be an insufficiently enterprising means of assessing minerals potential.

In subsequent sections, therefore, a method of planning for minerals development is proposed which is sufficiently flexible to incorporate alternative technologies, the particular technical advantages of individual minerals deposits and possible changes in end uses and their functions. The method, called opportunity planning, advocates a simple network approach for the structuring of opportunities which can subsequently be applied to specific minerals deposits. Two strategic divisions are proposed, labelled interventionist and non-interventionist opportunity planning. The opportunity planning network is applied to the three case study industries and complements long term development forecasts based solely on the extrapolation of current supply and demand configurations.

Finally the empirical and theoretical studies are used to suggest a checklist of the constraints on minerals development in the Highlands of Scotland. The planning model is used to arrive at a range of specific opportunities worthy of fuller investigation in each of the industries studied.

PREFACE

This study originated as a practical problem in minerals development encountered by the Robertson Research Company. The problem concerned the furthering of the development of the mineral deposits of the Highlands of Scotland. In their work on minerals assessment undertaken for the Highlands and Islands Development Board and other bodies, the company frequently found that, whilst the results of their exploration work recommended exploitation according to current prices, markets and technical specifications, it was impossible to assess the long term prospects for such development and hence encourage the necessary commitment of capital at the critical stages. A Robertson Research Fellowship was therefore instituted to investigate "The technological economics of Highland Minerals".

As a first attempt to analyse the interactions between technology and economics in minerals development the familiar problems of interdisciplinary research have been encountered. Three methodological problems in particular were encountered. The first problem was that of establishing a level of effective communication which could adequately convey the significance of specialist areas of study. Wherever possible therefore no prior acquaintance with the technologies studied is assumed and where economic phenomena are examined only simple hypotheses are used. While the end result may involve a synthesis which is selective and possibly disquieting to some specialists, I believe that misrepresentation has been avoided and that such selectivity is vital in the invitation of criticism. However wherever appropriate I have tried to make explicit the values which have guided selection.

A second problem experienced concerned working in an area bounded by the intensely practical problems of the minerals industries on the one hand, and somewhat abstract economic theory on the other. Thus it was found difficult to investigate a theoretical problem in the classical manner of hypothesis testing and corroboration. In the event two compromises were adopted: a number of contributions to a theory of minerals development were proposed and used to aid in the explanation of specific development problems in later chapters, and secondly three major industry studies were prepared and circulated to interested parties for comment. Their contribution and those of the many others who were interviewed were invaluable in shaping the study.

Finally there was the general issue of relevance. Whilst the present study may contribute to a much needed general theory of minerals development, its value will ultimately lie in its relevance to the practical problems of minerals development. Wherever possible therefore emphasis has been placed on the positive implications of the theoretical analysis and empirical investigations. And here particular attention is paid to the problems and prospects for minerals development in the Highlands of Scotland.

ACKNOWLEDGEMENTS

I gratefully acknowledge the Board of Directors of the Robertson Research Company for the award of a Robertson Research Fellowship in the Department of Industrial Science at Stirling University. Acknowledgements are also due to the Highlands and Islands Development Board for their generous contribution towards the expenses of the project.

This study could not have been completed without the untiring assistance and advice freely given by my supervisors, Mr M S Makower, (Industrial Science) and Mr R W Shaw (Economics). I am sincerely grateful for the guidance received in our innumerable discussions.

Thanks are also particularly due to Dr R H Cummings (Managing Director, Robertson Research Company)for acting as my industrial supervisor and to Dr P Ibbotson of Robertson Research for enabling me to continue my liaison with the company.

Miss N Walker (Industrial Science) is thanked for her secretarial help during the course of the Fellowship and Mr S Jones for assistance in data computing.

It would be impossible to adequately acknowledge all those who have assisted in the development of this study. May I therefore thank all those who have freely given of their time and in particular acknowledge material assistance from the following:

Robertson Research Company: Chemistry division for carrying out analyses on dolomite samples.

Highlands and Islands Development Board: Dr G L Adams, Mr D R Fasham.

Institute of Geological Sciences: Mr A A Archer, Mr R A Healing, Mr G S Johnstone, Mr I N Thomas.

G R Stein and Co., the Steetley Company, Pilkington Bros., and the British Steel Corporation for carrying out analyses on dolomite samples.

and

Mr J Bailey (BSC)
Dr J D Bailey (The Steetley Company)
Mr G Bull (G R Stein & Co)
Mr T S Busby (British Glass Industry Research Association)
Dr J H Chesters
Mr C I Dixon (Imperial College)
Mr A G Edwards (Building Research Establishment)
Mr P A Fisher (Magnesium Elektron Limited)
Mr C Hardy (BSC)
Mr I Hatfield (G R Stein & Co)
Mr A Highfield (G R Stein & Co)
Mrs E C Hill (British Road Federation)
Mr J Laming (Pickford Holland Co)
Mr G O Lawson (Scottish Development Department)
Miss N MacLeod (Ross and Cromarty County Council)
Mr W McGrane (E.C.C. Quarries Ltd)
Mr J G Morgan-Jones (Tarmac Ltd)
Mr R H Peters (Hoare & Co., Govett)
Mr G Skelton-Smith (Kings & Co)
Mr D C Stafford (Exeter University)
Mr P Thompson (G R Stein & Co)
Mr C V Underwood (Derbyshire County Council)
Mr W Ward (Pilkington Bros)
Mr J Williamson (The Steetley Company)

And my friends and colleagues in the Departments of Industrial Science and Economics.

CONTENTS

CHAPTER THREE: CASE STUDIES IN TECHNOLOGICAL ECONOMICS: INDUSTRY ANALYSES

CHAPTER FOUR: LONG TERM GROWTH PROBLEMS AND PROSPECTS

CHAPTER SIX: MINERAL RESOURCE DEVELOPMENT IN THE HIGHLANDS — PAGE

LIST OF TABLES

TABLES Ctd. PAGE

Appendices (ctd) Page

LIST OF FIGURES

FIGURES Ctd. PAGE

APPENDICES / FIGURES PAGE

CHAPTER ONE

TECHNOLOGY, ECONOMICS AND MINERAL RESOURCE DEVELOPMENT

1. INTRODUCTION AND OBJECTIVES

This study is a first, preliminary attempt to investigate the development of mineral resources, from deposit to end consumer, in terms of the interaction between technology and economics. As such it is necessarily concerned with long-term development and the commercial evaluation of specific projects is not included. The overall objective is to stimulate a broader appreciation for the range of opportunities that should be considered by the resource developer. Three minerals consuming industries are studied empirically and in relation to a number of relevant theoretical concepts. For this purpose the mineral dolomite was chosen (c.f. Appendix A) to illustrate the sharply contrasting problems involved in the development of the same raw material for three different types of primary processing industry. Finally a simple method of structuring alternative opportunities is proposed and applied to the case study industries, ultimately in terms of the problems of, and prospects for, development of mineral resources in the Highlands of Scotland.

In the present chapter the central theme of the changeability of the definition of resources is introduced. As a convenient method of relating technology, economics and raw materials the concept of the production function is also introduced. The absence of precedent for theoretical analysis in this interdisciplinary area, leads finally to the abstraction of a number of relevant issues for more detailed discussion in Chapter Two. The chapter closes with a brief review of related work.

2. THE DEFINITION OF MINERAL RESOURCES AND END USES

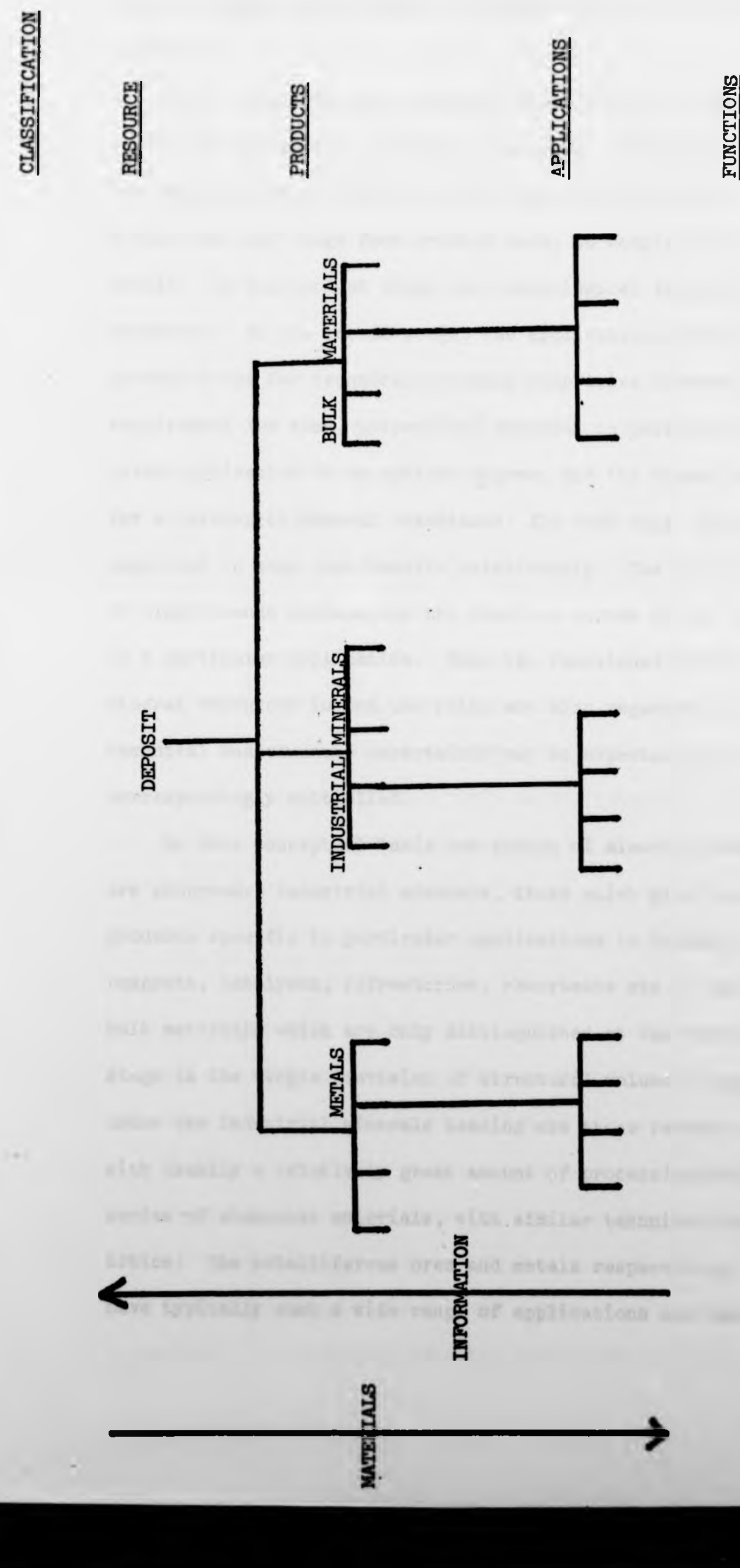
2:1 The classification and definition of mineral resources

A first problem in the analysis of the relations between technology, economics and mineral resource development is the definition of a mineral resource. The common confusion between the terms deposit and resource has created considerable misapprehension in the literature[1] and lies at the centre of many minerals development problems. A mineral deposit is an accumulation of minerals in a strictly technical sense. Minerals have the same relation to deposits as trees to forests or water to lakes. The technical delineation of a mineral deposit is determined by the establishment of a physical boundary between it and the surrounding materials. A mineral deposit may be a vein of chrome ore, or a mountain of limestone: both represent concentrations of minerals by geological processes to yield accumulations which may, or may not have economic significance.

A deposit becomes a resource if there is both a demand for the materials which can be derived from the deposit, and if there exists a means by which the usable materials can be extracted from those which are not required. The interplay between these two factors is such that often no clear conclusion can be reached as to whether a technology preceded the emergence of a demand or vice versa. In formulating a classification of mineral resources therefore it appears inadvisable to attempt a

FIGURE 1

A MINERALS CLASSIFICATION



division solely on the basis of either technical or economic criteria.

It is suggested that there are three areas of significance in the classification of mineral resources. Firstly there is the product which, depending on the length of the chain of production, may range from crushed rock, to complex die cast metals. At the product stage the technological imperative seems uppermost. At the second stage, the application, there may be greater scope for technical/economic compromise between the requirement for some, unspecified material to perform in a given application to an optimum degree, and the demand resulting for a particular mineral 'candidate' for that role, as may be expressed in some cost/benefit relationship. The third area of significance encompasses the function served by the product in a particular application. When the functional aspects of mineral resources in end use roles are also regarded as variable, technical and economic uncertainty may be expected to be correspondingly multiplied.

On this conceptual basis two groups of mineral resources are proposed: industrial minerals, those which give rise to products specific to particular applications in industry (as reagents, catalysts, refractories, absorbents etc.), and the bulk materials which are only distinguished at the functional stage in the simple provision of structural volume. Subsumed under the industrial minerals heading are those resources which with usually a relatively great amount of processing yield a series of elemental materials, with similar technical characteristics: the metalliferous ores and metals respectively. Metals have typically such a wide range of applications and variety of social functions that they are commonly distinguished at the product level. This tripartite classification is summarised in figure 1.

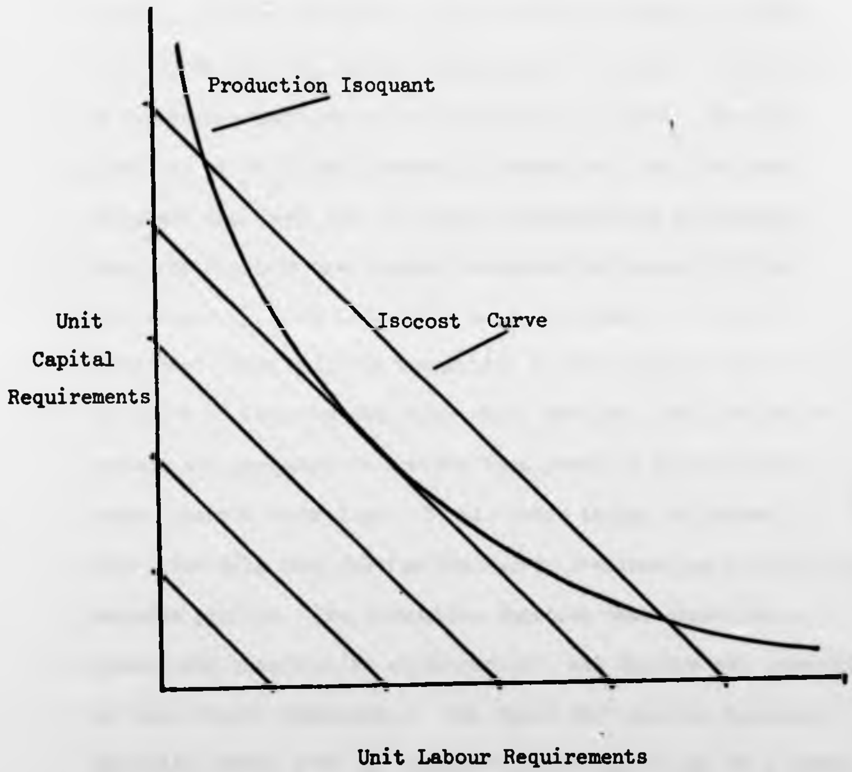
It is important to stress that whereas materials flow, as it were, down the chart, information on the type, grade and quality of mineral, product and application flow back from the functional stage and is eventually deducible as raw material specifications. Also although the terms level, stage and area are helpful in conceptualising the minerals classification it is important to note that there is no prior hierarchical ordering in the sequence product:application:function. The three are usually mutually self-determining.

2.2 The minerals production function

As may be anticipated from the previous section some of the perennial problems of mineral resource development lie in the difficulties of, on the one hand, monitoring changes in end use patterns and interpreting these as raw material requirements, and on the other of innovating raw material characteristics and estimating possible demand configurations. If technology remained constant and if the prices of the factors of production and growth in homogeneous demand were known, then the evaluation of minerals deposits could be derived from production function theory allied with an overall nett present value calculation for discounted cash flow over the life of the project.

To begin therefore with the simple production function.[2] This relates, in strictly technical terms, to the physical quantities of materials, labour, capital and any other inputs that are necessary to yield a given output under constant technology. It is assumed that the factors of production are

FIGURE 2: THE SIMPLE PRODUCTION FUNCTION



infinitely substitutable for one another and that the law of diminishing returns applies.[3] Accordingly the most convenient method of representing this relationship, the production isoquant, is a curve convex to the origin which in the extreme case of infinite equality of substitution of factors would appear as a rectangular hyperbola or its n-dimensional equivalent (see figure 2). This curve is analagous to the consumer indifference function in that the firm is, in a strictly technical sense, indifferent to which factor combinations are used: all result in the same (quantitative and qualitative) output. However, given the price of the factors of production, the firm can calculate the total cost of various combinations of factors. These costs points are usually connected as isocost curves (see figure 2), such that for a given isoquant, the lowest total cost curve which is tangential to the isoquant will at the point of tangency determine which physical combinations of factors are necessary to achieve best practice productivity under constant technology. If all other things are equal this point will also provide the factor combinations necessary to maximise profits. The production function thus stated is an essentially quantitative relationship: all factors are regarded as individually homogeneous. But where the minerals producer is typically remote from end consumer markets there may be a number of discrete stages in the total production function each with its own optimised sub-function. The problem for the mineral resource developer therefore is to abstract from such sub-optimised quantitative relationships overall implications for the quantity and quality of raw materials that will be required over the life of a proposed project. Under constant technology, and other things being equal, this determination of "cut-off grades" appears feasible given sufficiently accurate forecasts of demand and an adequate quantitative statement of the various input-output relations included in the total production function.

In practice of course technology does not remain constant. It is a vital, although in the industries examined in the present study, a discontinuous source of opportunity for innovation. There are also considerable difficulties in establishing homogenous end use categories: social and political change in particular giving rise to technological and economic uncertainty. Thirdly, since minerals development projects frequently require long gestation periods, the general movements in factor costs and shifts in demand may be difficult to forecast on a sufficiently long term basis. Finally within the technical confines of the production function itself there may be substantial inhomogeneities reflecting the limited potential for factor substitution. And even where the law of diminishing returns does not apply, economies of scale may be achievable.[4] Together these factors lend an unusually high risk element to mineral resource development projects even when the implications of possible geological uncertainties are ignored.

2:3 The contribution of the present study

In the light of such important real world problems it would be irresponsible to suggest that the present study seeks to develop a comprehensive theory of minerals development. Even if such a theory could be postulated its corroboration through the medium of controlled experiment would be a highly impractical aspiration. Industries are, of course, complex social systems in which it is impossible to hold all variables, except those of immediate interest, constant in an attempt to measure, in the classical manner, the system's response to changes in the value of the chosen variable. Furthermore, as complex systems industries often exhibit the principle of equifinality[5] or simply, they can achieve a given objective via a number of alternative routes.

Whilst advocating an essentially empirical approach, therefore, for the purposes of industry analysis to gain a wider appreciation for the general determinants of mineral resource development, it would nevertheless be inadvisable to overstate the deficiencies of a parallel theoretical approach to the extent of total abandonment. By way of compromise it is proposed to analyse in some detail in Chapter Two three theoretical aspects of the minerals development problem which may be of qualified assistance in the structuring of the empirical material of later chapters.

Firstly, in spite of its noted inadequacies, the production function may yield important qualitative information on the circumstances which lead to the decision to invest in a minerals development project. In particular the replacement/net investment model as developed by Salter (1966)[6] and some of its implications for development strategy are formulated as a background to the interpretation of case study information. Secondly the rather wider issue of the diffusion[7] of new materials is examined. The object here is to suggest a generalised characterisation of the spread of innovation of new materials (which may include minerals with previously unexploited properties or products for new applications, etc). The underlying aim of the theory is again to guide the resource developer in his choice of strategy for development. The third aspect of theory chosen for more detailed analysis is the important issue of forecasting.

The previous section introduced the problems of long term uncertainty in minerals development in both technological and economic areas. Clearly therefore an improved understanding of the problems of long term forecasting could help reduce the risks involved in minerals development.

Before proceeding to a discussion of these three important aspects of theory however, it may be first appropriate to summarise the various unidisciplinary approaches to minerals development. Although a great deal of research has been directed at various aspects of the problem, ranging from technical evaluation of deposits to end consumer market research, such work has almost invariably been restricted in scope. In particular little effort has been devoted to interpreting disaggregated demand characteristics in terms of minerals requirements or to the effects of technological change in consuming industries on raw materials demand.

3. REVIEW OF RELATED WORK

3:1 Economic approaches

The economics of non-renewable natural resources includes three related specialisms. Firstly economic theorists have been concerned to demonstrate the applicability or otherwise of the law of diminishing returns to mining operations. The classical background to this area of study produced a celebrated but intermittent dialogue dealing with what might be broadly termed the theory of exhaustible resources.[8] Recently concern over the implications for economic growth of ultimate limits to resource exploitation has attracted a great deal of renewed speculation and the particular role of technological change in offsetting the disadvantages of mining lower grades of resources has been widely debated, if not very thoroughly examined.[9] So far as can be seen however this literature provides very little positive guidance on the detailed, practical, relationships between technology and economics in minerals development.

The second aspect of theoretical economics related to minerals development is the field of mineral economics. Mineral economics is a fairly narrow specialism primarily concerned with the estimation of minable reserves in newly discovered deposits. By estimation is usually meant an evaluation, frequently a nett present value calculation, of the most economically attractive method of mining proven, and marketable reserves. The long term is usually viewed as an extrapolation of short term conditions and evaluation does not generally involve assessment of the influences of market structure/behaviour, end use substitution or technological innovation. The methods are therefore useful, usually static, appraisals based on current marketable value.[10]

The third aspect of economic approaches to mineral resource development includes industry studies. Surprisingly few of these have evidently been undertaken.[11] This may partly reflect the position of minerals at one end of a long production chain, the other links of which generally provide a greater proportion of total value added. Indeed it is only either in time of sudden, perhaps artificial, scarcity or of competing claims for the use of natural resources[12] that the fundamental role of minerals in the national economy becomes apparent.

3:2 Geological Approaches

Geological theory is interested in mineral deposits in so far as they contribute to a fuller understanding of the earth, its genesis, and development. The professional geologist is typically equipped to evaluate mineral potential primarily as an explorer. Economic geology is largely concerned with the methods of discovery, description and classification, and origins of mineral deposits. For the geologist the terms 'economic mineral' or 'commercially exploitable ore' are based on considerations typically outwith his area of concern. Similarly the assessment of technology and its impact on mineral resource development is an area of analysis considered inappropriate for the earth sciences in general. It should also be noted that the traditional role of governmental institutions in mineral resource development has been analagous to that of academic analysts: the collection of factual information concerning the physical disposition and mineralogical content of deposits.

3:3 Industrial Approaches

A considerable amount of effort is probably devoted to long term planning by the major mining houses, and consumers of primary raw materials, in itself implying an interdisciplinary approach to minerals development. Most of this work is considered to be of competitive value and it is therefore rare for such information to be published.[14] The Journal of the Institute of Mining and Metallurgy for example concerns itself exclusively with advances in techniques of exploration, extraction and processing in the minerals industries. The industry has, in the face of such secrecy, often had its motives interpreted by an ill-informed public.

In conclusion then it is suggested that whilst a great deal of dispersed interest in the problems of minerals development has been recorded in the various literatures, an essentially interdisciplinary approach having due regard for the dynamic of technological and economic change has not so far been undertaken.

4. CONCLUSIONS

In this chapter the central theme of the changeability of the definition of mineral resources in terms of technological and economic variables has been introduced. It was concluded that a more flexible attitude to the problems of long term minerals development may be made possible by exploring the theoretical and empirical implications of this definition. Three aspects of theory were accordingly selected for immediate attention in Chapter Two. And in particular the key problem of persuading minerals using companies to change to alternative sources of materials or even to alternative materials was seen as an issue requiring urgent, if preliminary, theoretical formulation.

Concerning the subsequent empirical investigations it was concluded that the proposal and assessment of relevant hypotheses in industrial situations is generally impractical in view of the difficulty in achieving controlled experimental conditions. A pragmatic approach appeared to offer a practical alternative. As such therefore the industry case studies of Chapter Three effectively parallel the contributions to a theory of long term minerals development (Chapter Two). Finally it was observed that the disciplines relevant to minerals development have in general adopted a fairly narrow viewpoint. The contribution of such unidisciplinary backgrounds must therefore be to frame the minerals development problem as a compromise between what can be seen as technically feasible and what appears to be economically expedient. Against this background an interdisciplinary approach to the technological economics of long term mineral resource development may evolve.

CHAPTER TWO

MODELS RELEVANT TO A THEORY OF MINERAL RESOURCE DEVELOPMENT

1. INTRODUCTION AND OBJECTIVES

A number of aspects of a theory of minerals development are examined in this Chapter with a view to assisting the subsequent analysis of long term growth problems and prospects for the study industries in Chapter Four. These aspects of theory are intended as contributions to the understanding of a small number of critical issues in minerals development. No attempt is made to construct a comprehensive theory in the present study.

Possibly one of the most important problems facing the minerals developer is the interpretation of the conditions under which his product may be innovated by new consumers or accepted by established consumers of the material. The first part of this Chapter attempts an analysis of this problem using the production function model introduced in Chapter One as a starting point. The model is refined to include the replacement/net investment criterion which offers the opportunity to relate the nominal advantages associated with a technical innovation such as 'superior' raw materials, with the costs involved in changing to the new source of supply. This simple model, as proposed originally by Salter (1966)[1] is also used to interpret the effects of monopoly and oligopoly on the potential for technological economic development and the case of market segmentation is also briefly introduced.

CHAPTER TWO

MODELS RELEVANT TO A THEORY OF MINERAL RESOURCE DEVELOPMENT

1. INTRODUCTION AND OBJECTIVES

A number of aspects of a theory of minerals development are examined in this Chapter with a view to assisting the subsequent analysis of long term growth problems and prospects for the study industries in Chapter Four. These aspects of theory are intended as contributions to the understanding of a small number of critical issues in minerals development. No attempt is made to construct a comprehensive theory in the present study.

Possibly one of the most important problems facing the minerals developer is the interpretation of the conditions under which his product may be innovated by new consumers or accepted by established consumers of the material. The first part of this Chapter attempts an analysis of this problem using the production function model introduced in Chapter One as a starting point. The model is refined to include the replacement/net investment criterion which offers the opportunity to relate the nominal advantages associated with a technical innovation such as 'superior' raw materials, with the costs involved in changing to the new source of supply. This simple model, as proposed originally by Salter (1966)[1] is also used to interpret the effects of monopoly and oligopoly on the potential for technological economic development and the case of market segmentation is also briefly introduced.

The simple Salter model is not primarily concerned with the determinants of demand which is, at least initially, assumed to be homogeneous and constant. However the anticipation of the character and dynamics of demand patterns is of considerable interest to the minerals developer who is, aside from demonstrating the profitability of his project, concerned to discover the conditions under which his products may be expected to diffuse in established, non traditional, or totally new end use areas. The second part of this chapter therefore attempts to characterise the diffusion of new materials by adapting and expanding two contrasting approaches to a theory of diffusion: the Rogers and Schon models respectively.[2]

Thirdly and finally the minerals developer is invariably concerned to improve his foresight through employing quantitative long term forecasting techniques as an aid to planning. This is because specific minerals projects may involve gestation periods of up to ten years or even longer for full market development. Therefore in the last part of this chapter the problems and potential of long term forecasting are critically reviewed. A parallel between economic and technological techniques is drawn and some of the particular problems of minerals development as they affect the usefulness of forecasting exercises are introduced.

2. THE ECONOMICS OF TECHNOLOGICAL CHANGE: THE SALTER MODEL

2:1 An introduction to the model

One of the fundamental problems confronting the mineral resource developer, in common with entrepreneurs in general, is to estimate under changing technological and economic conditions,

FIGURE 3: UNIT LABOUR REQUIREMENTS FOR GIVEN TECHNOLOGIES

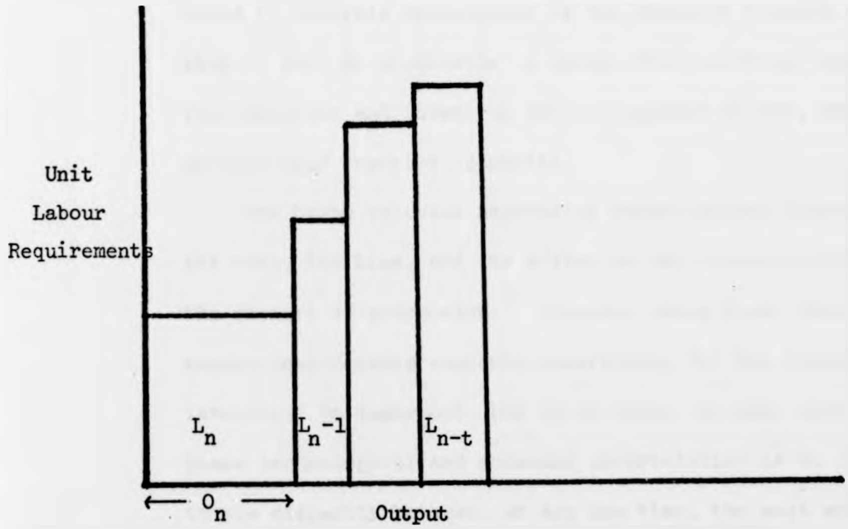
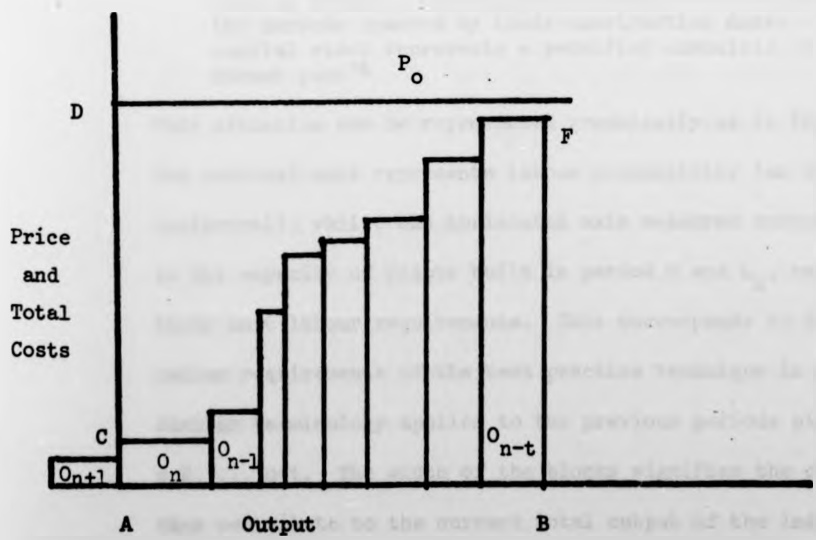


FIGURE 4: CROSS SECTION OF INTRA INDUSTRY EFFICIENCIES



Source: Salter W.E. (1966), pp. 53 and 59 when it will be profitable to invest in a project which embodies the most recent technical advances. A common question also asked in minerals development is the directly related one of when it will be profitable to change from existing sources of raw materials and invest in the development of new, possibly geologically superior, deposits.

The three relevant aspects of technological innovation are its rate, its bias, and its effect on the substitutability of the factors of production.[3] Together these three factors create considerable economic uncertainty for the intending investor. An important, but by no means the only consequence of these technological and economic uncertainties is to contribute to the disparity between, at any one time, the most modern plants manufacturing a given product to the highest current levels of efficiency and those that reflect historic levels of technological economic efficiency. The range of plants in operation at any one time:

> "are in effect, a fossilised history of technology over the periods spanned by their construction dates - the capital stock represents a petrified chronicle of the recent past"[4]

This situation can be represented graphically as in Figure 3. The vertical axis represents labour productivity (as its reciprocal), whilst the horizontal axis measures output. O_n is the capacity of plants built in period n and L_n, represents their unit labour requirements. This corresponds to the unit labour requirements of the best practice technique in period, n.[5] Similar terminology applies to the previous periods plants, n-1, n-2, ... n-t. The width of the blocks signifies the output they contribute to the current total output of the industry. The height of the blocks reflects the techniques embodied in the plants. As Salter concedes there are no prior reasons why younger plants should have the lowest unit labour requirements. But there are two strong reasons why other situations would be rare: first few innovations do not save labour absolutely, and secondly the pressures for substitution generated by technical progress in capital goods industries tend to encourage progressively greater savings of labour.

To restate the investment problem: it is desired to assess-

(i) when it will be profitable to invest in a project embodying current best practice productivity standards

(ii) when existing projects will cease to be profitable

In assessing potential profitability three factors are uppermost:

(i) Present and expected price of product

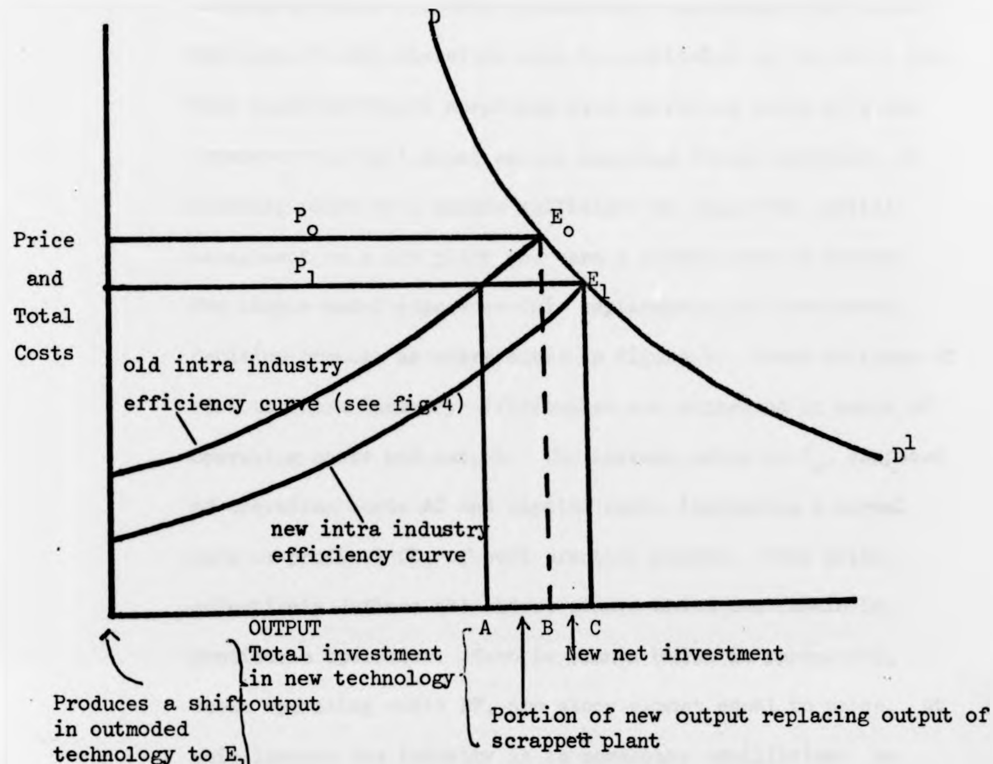
(ii) Present and expected prices of factors of production

(iii) Quantities of factors of production required to produce a unit of output.

Technological advance determines (iii) directly, but it also indirectly affects (ii) and (i) in perfectly competitive industries.[6] If (ii) and (i) remain constant even though total production costs are lowered as a result of technological innovation, this would lead to the accumulation of excess profits. In these circumstances additional projects also taking advantage of the technical advance would be enacted. As a result output will be expanded and prices lowered to a level at which supernormal profits are eliminated.

At the other end of the efficiency scale are the outmoded plants which embody historic technology. These plants can still remain in operation (that is to say are not rendered obsolete),

FIGURE 5: THE CYCLE OF COST REDUCING TECHNICAL ADVANCE



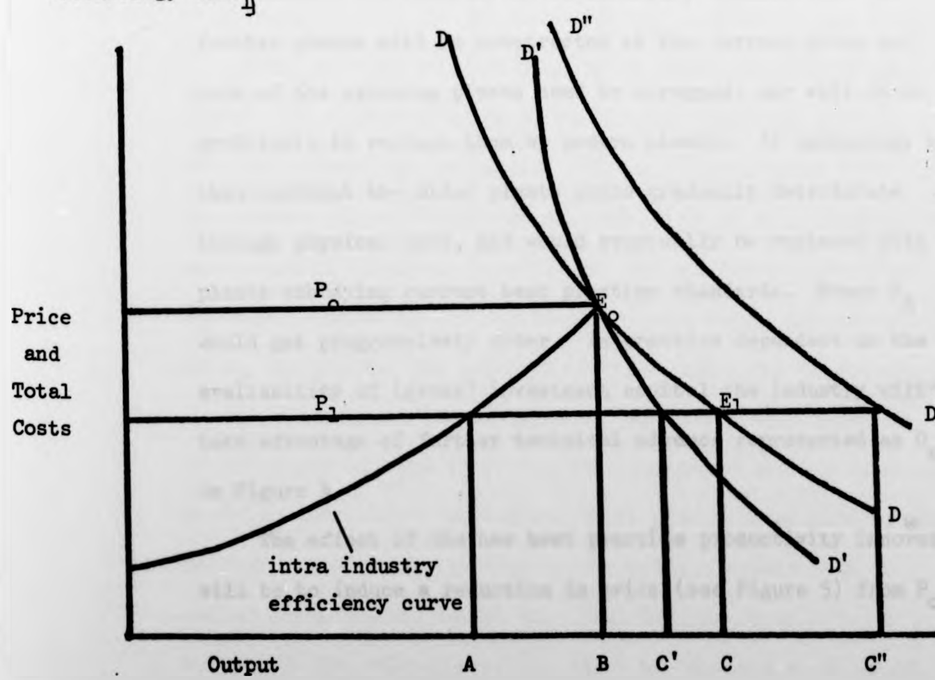


FIGURE 6: THE EFFECT OF DEMAND

Source: Salter W.E. (1966), op.cit., pp. 76 and 81 as long as their revenues exceed their operating costs alone. Replacement will therefore only be profitable at the first date that expected future surpluses over operating costs of a new 'state-of-the-art' plant exceed expected future surpluses of existing plant by a margin sufficient to repay the initial investment on a new plant and earn a normal rate of return. The simple model expresses this replacement/net investment decision process as represented in Figure 4. Cross sections of various intra industry efficiencies are expressed in terms of operating costs and output. The current price is P_o, composed of operating costs AC and capital costs (including a normal rate of profits) CD, of best practice plants. This price effectively defines the oldest plants which can remain in profitable operation. That is plants built in period n-t, whose operating costs BF, are alone almost equal to price. At this instant the industry is in momentary equilibrium: no further plants will be constructed at the current price and none of the existing plants need be scrapped, nor will it be profitable to replace them by modern plants. If technology were then constant the older plants would gradually deteriorate through physical wear, and would eventually be replaced with plants embodying current best practice standards. Hence O_n would get progressively wider. In practice dependent on the availability of (gross) investment capital the industry will take advantage of further technical advance represented as O_{n+1} in Figure 4.

The effect of the new best practice productivity innovation will be to induce a reduction in price (see Figure 5) from P_o

to P_1, rendering a certain portion of outmoded plant (AB) obsolete. These may be replaced in projects using the new innovation as firms install more best practice plants until price falls to P_1, and there will, in such circumstances, be an additional increment (BC) to total output. Total new investment is given by AC, and its incorporation in the industry's scheme of output will be as shown in Figure 5: the new technology is included as a block closest to the origin whilst the outmoded blocks shift until the segment closest to obsolescence approaches E_1. A new instantaneous industry equilibrium is established and the process repeats itself. However as Salter suggests:

> "Although price movements are closely linked with rates of improvements in best practice techniques, output movements reflect in addition the influence of (externally determined) demand"[7]

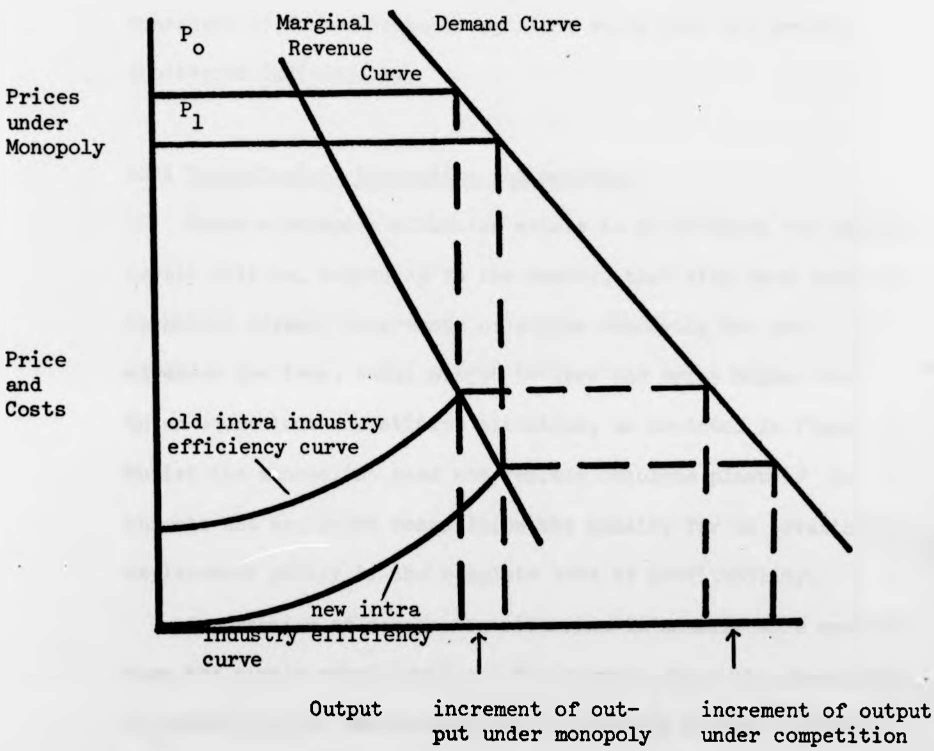
Two aspects of such externally determined demand are considered to influence the scope for technological innovation (see Figure 6). These are the price elasticity of demand and shifts in demand. As a general guide it can be seen that the greater the price elasticity of demand (DD as compared with $D'D'$) the greater the net expansion of output (BC vs BC') possible in each round of technical innovation. The effect of shifts in the demand curve to $D'D'$ is similar: the larger the positive shift, the greater the potential for net additions to output.

This concludes the analysis of Salter's simple model of the relations between technological innovation and the investment decision. The following section deals with a relaxation of the critical assumptions involved in the model, notably that of perfect competition, whilst the final section on this issue deals with the relevance of the model to minerals development.

2:2 Relaxation of assumptions involved in the simple model

There are a number of assumptions inherent in the construction of the simple model which are difficult to impose in practical analysis. They may be divided into two groups of which only the second is of present importance. The first group of assumptions relates to the technicalities of abstraction and includes the assumptions of homogeneous plant and equipment, industry/technology-specific plant, homogeneous products, and constant management and labour efficiency. The effects of any barriers to the diffusion of knowledge or advantageous geographical location, or the presence of infrastructural services and trade goodwill should also be included in this group. The effects of a relaxation in at least some of these assumptions would be largely quantitative: that is they could be theoretically incorporated in a more complex model. For the rest Salter remarks that: "Their most significant effect is to introduce an element of ambiguity into the idea of best practice costs"[8] But overall they do not alter the conceptual basis of the model, even when there are admittedly great practical difficulties in ascertaining their individual influences. For some, such as the barriers to the diffusion of knowledge the adjustment of prices to the new levels implied by technological innovation will be dampened, partly by creating gestation period delays, and partly through stimulating wider investment uncertainty. For others, such as inhomogeneities in plant and equipment, it is a question of ascribing relevant accounting conventions to determine the practical influence of any resale or scrap value as well as the isolated marginal product attributable to a particular piece of equipment.

FIGURE 7: TECHNOLOGICAL INNOVATION AND MONOPOLY



Source: Salter W.E. (1966), op. cit., p.91

The other group of assumptions relates more closely to the doctrine of perfect competition assumed in the construction of the simple model. Salter considers three areas where departures from perfect competition may affect the operation of his simple model. These are monopoly, market segmentation, and oligopoly. As each of these three concepts has important consequences for subsequent empirical study they are briefly considered individually.

22:1 Technological innovation and monopoly

Where a monopoly situation exists in an industry the general result will be, according to the theory, that with each round of technical advance increments of output embodying the new advances are less, total output is less and price higher than in an equivalent competitive situation, as depicted in Figure 7. Whilst the monopolist need not replace obsolete plant if he chooses not to, under competition the penalty for an irrational replacement policy is the complete loss of profitability.

In practice of course the situation is usually more complex than the simple model implies. For example where the elasticity of demand permits the monopolist may actually welcome technical advance since the scope for price/cost disparity could be increased still further. The exact interpretation of this mechanism will depend however on many other factors including the existence of any barriers to entry or the diffusion of knowledge. Furthermore the monopolist may wish to avoid attracting attention, or he may, through inertia, have developed an unnecessarily conservative replacement policy. Both these factors could lead the monopolist into a non profit maximising strategy. Under these circumstances the monopolist may even appear to earn a 'normal' rate of return since he could be producing less at a higher price using obsolete equipment with higher operating costs. Care therefore has to be exercised in concluding that simply because a highly concentrated industry has grown at a'normal'rate and that a reasonable price/cost disparity has been experienced that this is not in fact evidence of a much retarded growth potential which could have been realised in a more competitive situation. In particular the arbitrary control of price as an entry deterrent is illustrated in a case study in the following chapter.

22:2 The case of market segmentation, the principle of complementarity

Salter and otherssuggest that market segmentation may be used by inefficient firms who wish to avoid or are unable to compete solely on price grounds. Common strategies are product differentiation, advertising and emphasis on service or quality. But it is also recognised that similar tactics could be employed by competitive efficient firms facing a downward sloping industry demand curve who wish to take advantage of those customers who are willing to pay more for the product than in the 'equilibrium' case where price is equal to marginal cost.

Brunner (1974)[9] has suggested a development of the neo-classical interpretation which finds considerable support in the industry analyses of the present study. She suggests that in many industries there is, in effect, an emerging division of productive effort. At the one extreme are the small number of large manufacturers producing standard products in capital intensive plants enjoying economies of scale both at the manufacturing and distributional stages. These large firms typically support high overhead costs including servicing, and research and development facilities. At the other extreme, is the small local specialist who manufactures products to non standard specifications and entertains low volume orders. The specialist has typically lower overhead costs than his larger counterpart and may be in a better position to regard other portions of his total cost schedule as variable during adverse trading conditions. The specialist typically charges a higher price for his product and he may use appropriate alternative manufacturing techniques. Brunner suggests that these two types of participant have essentially complementary roles in the overall structure of demand in particular industries and as such they are interdependent. The principle of complementarity is explored in greater detail as a possible entry strategy in subsequent chapters.

22:3 Oligopolistic rivalry

The analysis of oligopoly is especially problematical, but its growing importance in many industries including the minerals sector necessitates some interpretation of the operation of the Salter model in an oligopoly situation. The simple model suggests that new low cost capacity tends to reduce the financial surpluses of existing high cost capacity. The individual firm has no control over price and in theory the cycle of innovation, price lowering and demand increase is endless. In an oligopoly situation the producer typically has a limited control over price and demand. Placing this responsibility for the size of the market partially on the producer will tend to inhibit the unilateral pursuit of a monopoly situation through ruthless price cutting as a result of technological innovation. For there is the possibility that new capacity may be unable to earn even a normal profit whilst existing capacities surplus will be drastically reduced. This relatively risky strategy may be rendered unnecessary in an oligopoly situation where instead of ruthless competition with the express aim of achieving a monopoly, the individual producer attempts to grow relative to competition through the capture of any market increase. The means of capturing this increase, or even creating it, will vary according to the individual situation but in general price competition through successfully innovated technological advance may still be the most important single factor.

The case of oligopoly combined with market segmentation is of particular interest in the minerals industries. At the one extreme are the handful of large diversified manufacturers who concentrate on producing standardised products for mass markets, and at the other are the small specialist producers who serve residual typically local market areas, entertain low volume orders, have typically higher operating costs, but are able to operate in a rather more flexible manner in relation to overall industry demand characteristics and general trading conditions, than their larger counterparts.

2:3 The place of the Salter model in minerals industry analysis

Although mineral raw materials were not explicitly included in the simple model, there is in principle no especial problem in treating them in a manner analogous to other factors of production. Thus as technological advance is implemented, as well as improving labour (and possibly capital) productivity, resource productivity may also be improved since new techniques may result in less wastage from a given deposit or alternatively permit the exploitation of lower 'grades' of material. Barnett and Morse (1963), have shown how in their view, diminishing returns from minerals exploitation has been averted over the past century in the U.S.A. through continuous improvement in extractive techniques.[10] Labour productivity has in many cases been dramatically improved.

Perhaps the most valuable contribution of the Salter model however lies in its cautionary approach to indiscriminate innovation. The criterion that change cannot be profitably undertaken unless the costs of change plus the new total operating costs are less than the old total operating costs alone, is of fundamental importance to minerals development. As such the model is best applicable where there is an accumulated fund of precedent such that development involves improvement rather than initiation. The model is less easily applicable to situations involving totally new developments or alternatively where there is considerable future technological uncertainty. Thus whilst the model may indicate a satisfactory level of profitability with a new method in a given year, there may accrue even greater benefits through postponement until major breakthroughs are achieved in subsequent years, and vice versa.[11] Again, in minerals development, it is frequently the case that innovation in one area cannot be profitably accomplished unless accompanied by associated innovations which enable the maximum overall benefit to be achieved. This "scheduling of innovation" problem is to be encountered in several areas of the empirical analysis.

Finally it is important to note that the Salter model is very largely concerned with the effect of technical advance on the industry supply curve under the various structural regimes. Demand is assumed to be wholly exogeneously determined. It is obvious however that innovation and the diffusion of innovation may also have important consequences for demand patterns. In the next section therefore two theories of innovation and diffusion are examined and a model of the diffusion of new materials is proposed.

3. THE DIFFUSION OF INNOVATION: THE ROGERS AND SCHON MODELS

3:1 Introduction

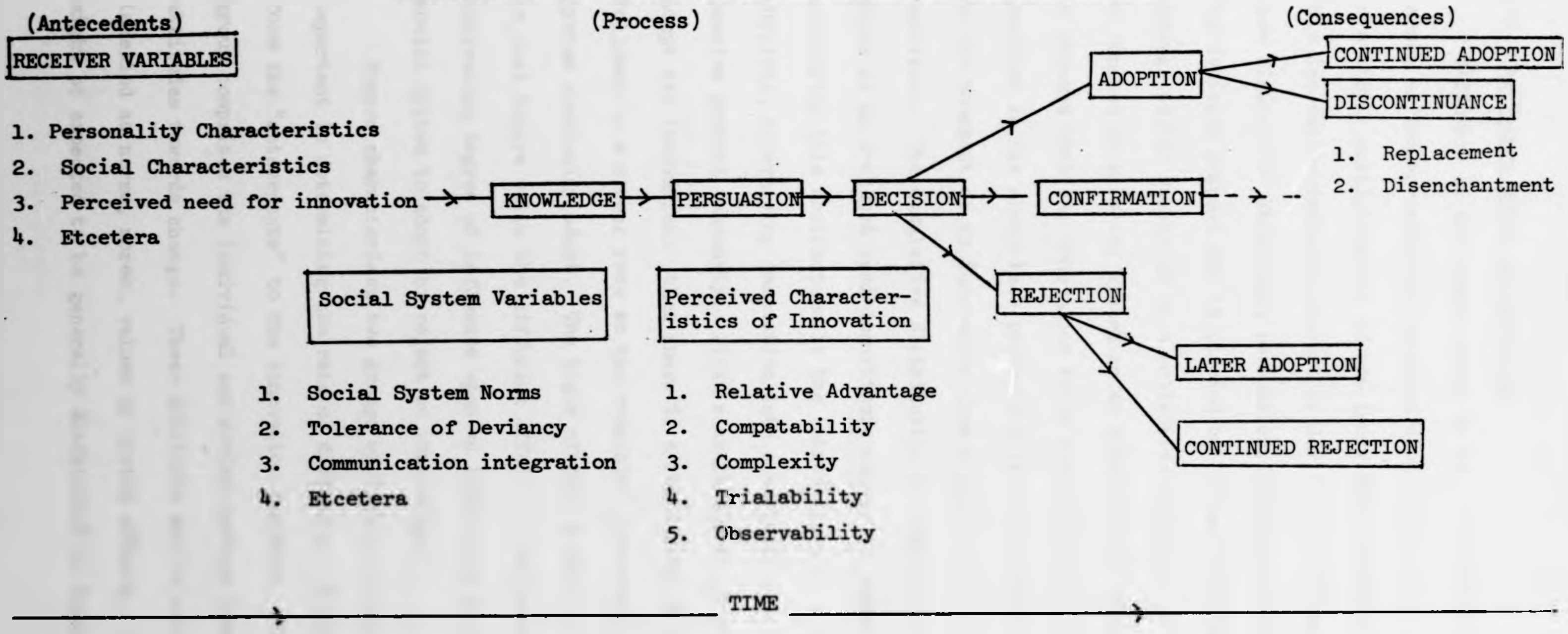
Although it is convenient to evaluate the merits of an innovation in financial terms as a measure of economic resource allocation, it is rarely possible to comprehensively express the overall net benefit of a development project in such a manner. For in the diffusion (or spreading of adoption) of innovations be it the introduction of a new product, process, technology, management technique or whatever, it is the individual or collective perception of net benefits on the part of potential adopters that is of ultimate determining importance. The relevance of an analysis of the diffusion of innovations to the present study is therefore twofold. First it may aid the understanding of the various barriers to innovation and diffusion that constrain development in the industries to be studied. And secondly through an attempt to abstract a generalised schema for the diffusion of new materials, the entrepreneur may be guided in his choice of strategy for minerals development as discussed in Chapter Five.

The minerals producer is located at one end of the production chain. For him the homogeneities of production and product assumed in the previous section do not exist. In general he can do relatively little to stimulate consumer demand for the products which contain his materials at the other end of the chain. From an innovative viewpoint therefore, the minerals producer must concentrate on capturing externally determined increments of demand however and whenever they arise; in whatever market areas (totally new, traditional or non traditional); and by whatever means are perceived as acceptable. Because of his distance from end consumer markets the minerals producer may also be involved in a considerable amount of peripheral innovation with the aim of making his material more compatible with existing products.

Much of the early work in the study of diffusion was carried out in fields remote from industrial development.[12] Sociological studies of modernising innovations introduced into primitive communities, or of the spread of agricultural innovations such as hybrid corn, gave rise to many generalised abstractions of the diffusion process. In most cases the innovation, although not always the consequence of its introduction, were well defined at the outset. The study of diffusion therefore concentrated typically on analyses of communication within the receiving system and individual sociopsychological characteristics.[13]

More recent work in the field of industrial innovation has recognised that it is frequently difficult to establish firm boundaries between innovation (as introduction) and diffusion (as spreading).[14] Indeed the very definition of the innovation may be subject tocontinuous modification long after its introduction. In this section therefore two contrasting, but possibly complementary, hypotheses of the process of diffusion are examined: the first with a 'traditional' background, the second attempting to incorporate the fluidity of the diffusion processes internal boundaries. The section concludes with a preliminary hypothesis of the diffusion of new materials.

FIGURE 8: ROGERS' PARADIGM OF THE INNOVATION DECISION PROCESS



Source: Rogers, E and Shoemaker, F.F. (1971), op.cit. p. 102

3:2 The Rogers model of diffusion

Diffusion in the Rogers model is seen in the traditional manner as the spreading of adoption of an innovation. Diffusion is a simple multiplication of the individual innovation decision. This innovation-decision process is divisible into four stages (see Figure 8): knowledge, persuasion, decision and confirmation. The decision process may be carried out by an individual, through social concensus as a collective decision, or it may be imposed on a social system as an authoritarian decision. It is assumed that the innovation to be adopted exists fully realised in its essentials prior to diffusion and that diffusion is the movement of an innovation from a centre to its ultimate receivers. The cumulative distribution of adopters over time plots as an S-shaped semi-logarithmic curve. A common example underlying this abstraction is the introduction of a simple, physical, modernising innovation into a backward but essentially passive peasant community. First a small number of individuals adopt the innovation: then there is a rapid rate of adoption followed by a slower rate as the remaining individuals in the system eventually adopt. The logic of this scheme is captured in what Rogers calls the diffusion effect: "the cumulatively increasing degree of influence upon an individual within a social system to adopt or reject an innovation".

Rogers characterises two groups of factors which are important in determining the rate of diffusion. Together they form the "antecedents" to the innovation decision. The first group comprises the individual and social systems general attitudes towards change. These attitudes may be variously labelled as norms, mores, values or system effects. Innovations might be expected to be generally disfavoured in organisations which

TABLE 1

THE CHARACTERISTICS OF INNOVATIONS

1.	RELATIVE ADVANTAGE:	the degree to which an innovation is perceived as being better than the idea it supercedes (138)*
2.	COMPATABILITY:	the degree to which an innovation is perceived as consistent with existing values, past experiences and the needs of the receivers (145)
3.	COMPLEXITY:	the degree to which an innovations form, function or meaning is perceived as relatively difficult to understand
4.	TRIALABILITY:	the degree of relative commitment that is necessary before the innovation can be tested to the receivers satisfaction
5.	OBSERVABILITY:	the degree of tangibility of the perceived benefits of an innovation

Source: Rogers, E. and Shoemaker, F.F. (1971), op.cit.

*refers to page number

lack a favourable general orientation to change, are not technically sophisticated, minimise contact with their external environments, and lack the ability to transpose the relative advantages of a proposed innovation to their particular situations. Similar parallels can be drawn at the individual level. The second group of antecedents to the innovation decision describes the five major attributes of an innovation which affect the individual decision and subsequent diffusion process. These attributes are summarised in Table 1. All innovations can be classified according to the net cumulative subjective perceptions of these five attribute categories as an innovations form, its function and its meaning. The form of an innovation is its directly observable physical appearance and substance. For many innovations this is the most easily diffused feature. The function of the innovation lies in its potential utility to the receiver(s). Function is rather easier to misconstrue than form since maximum (intended) utility from a given innovation can usually only be achieved where the meaning of the innovation is adequately perceived. Meaning "is the subjective and frequently unconscious perception of the innovation by the members of the social system" and, as an intangible property particularly susceptible to interpretation it is the most difficult property of innovations to diffuse.

The beginnings of an innovation decision are especially hard to specify. At the knowledge stage "the individual is exposed to the innovations existence and gains an understanding of how it functions".[16] The difficulty with thissimple definition, and one that is crucial to the issue of perceiving and exploiting opportunity, is what determines "exposure":

how is the individual (or organisation) exposed. He may in fact be surrounded by potential innovations but it is not until their potential utility, or until a need for the innovation arises that they become meaningful (form + function = meaning). Equally the need may develop as soon as the meaning of the innovation is perceived. It is vital therefore that any proposed innovation be either a response to established need, or alternatively, be accompanied by a convincing demonstration of its potential utility to the end user.

Although Rogers' largely sociological approach to the diffusion of innovation is drawn mainly from an agricultural background, recent work by Mansfield (1968a)[17] who carried out an econometric study of diffusion in three basic processing industries indicates that on the limited evidence available, some aspects of industrial innovation proceed in a similar manner to agricultural, and other sociological phenomena. In particular however Mansfield underlines the length of the innovation and diffusion period citing other studies[18] to show that long pre-production, planning, development, and market establishment delays may occur. As in Rogers' study Mansfield concludes that relative advantage, compatability, complexity, trialability and observability of an innovation influence its rate of diffusion.[19] Mansfield also found from his empirical studies that as an innovation diffuses there is a cumulative pressure on non-adopters to adopt, secondly that the probability of adoption is directly related to an innovation's 'profitability' and thirdly that for equally profitable innovations the probability of adoption is smaller for innovations requiring relatively large investments. And finally like Rogers, Mansfield regards the diffusion process primarily as one of communication: "The profitability of an investment opportunity acts as a stimulus, the intensity of which seems to govern quite closely a firm's speed of response."[20] However Mansfield does concede that the innovation and diffusion processes may be difficult to separate:

> "Early versions of an innovation often have serious technological problems, and it takes time to work out these bugs. During the early stages of the diffusion process, the improvements in the new process or product may be almost as important as the new idea itself."[21]

Rogers' model of the innovation decision and the diffusion of innovation implies an essentially smooth process of awareness, evaluation and adoption of a well defined product, idea, or technique which is gradually radiated to and accepted by most members of a social system without serious realignment of the values and norms of either individual or society. Crisis is only twice mentioned by Rogers:[22] In the first instance crisis is cited as a promoter of the relative advantage of a new idea: "A crisis emphasises the relative advantage of an innovation and hence affects its rate of adoption --- Other studies show that a decisive event may retard the rate of adoption of an innovation. However members of a social system may make up for lost ground as soon as the crisis is past." In the second instance Rogers cites a research study which examined the idea of decentralised organisation within a large industrial firm. In three cases "it took a sizeable crisis to bring action. Yet all three presidents had received proposals for reorganisation before that crisis made their usefulness apparent."

The present study suggests that the process of diffusion is characterised by an interplay between those who are favourably disposed to innovation and those who are actively hostile to it. Under circumstances which do not promote simple compromise or concensus achievement it may require a severe test of attitude such as a crisis to pass to the decision stage in the innovation process. Crises may affect also the antecedents of innovation: organisational structure or personal security may be threatened calling for drastic measures. Under such circumstances a measure of the organisation's durability is the degree to which change can be accommodated without threatening the overall stability of the organisational structure.

3:3 The Schon Model of Diffusion

Diffusion is seen in the centre-periphery model[23] as being a function of communication: the source emitting a stimulus which is perceived by the receiver eliciting an appropriate response. Schon attempts to incorporate the following features of the innovation/diffusion process not adequately covered in the centre-periphery model:

(i) The innovation may not antedate the diffusion process: it evolves and is subject to redefinition significantly throughout the diffusion process

(ii) Innovation typically elicits positively antagonistic reaction to its diffusion: defined as dynamic conservatism

(iii) The diffusion process does not look like the fanning out of an innovation from a single source. Many sources of related and reinforcing innovations are likely to be involved

(iv) The diffusion process does not consist primarily in centrally managed dissemination of information.

Schon's concept of the diffusion process, including the innovation decision, contrasts sharply with that of Rogers. Here the primary concern is not with a communication/decision process abstracted primarily at an individual level, but with the dynamic evolution of an innovation movement, and the wider systems adaptive or suppressive mechanisms which either accommodate or inhibit its diffusion.

At the outset there are a number of products, ideas, techniques, policies, etc., which are perceived by an individual or organisation as constituting a potential innovation. Certain elements of the innovation, the ones that contrast with current values and norms, will attract a degree of what Schon calls dynamic conservatism ('A tendency to fight to remain the same').[24] Other elements of the innovation, because of their apparent non-controversiality will be allowed to develop "at the margin". Gradually the loosely defined and constantly changing package which constitutes the innovation movement, through conflict with dynamically conservative elements, attracts a wider, non-esoteric audience. At the same time conflict serves to sharpen the definition of diffusion:

> "Diffusion leads to conflict and conflict nourishes diffusion"[25]

As the process of conflict and resolution progresses there eventually arises a piece of evidence or other attribute of the innovation (such as a vital technological breakthrough) which serves as a focus for both the dynamically conservative elements and the protagonists of the innovation. This crisis enables a number of key objectives in the diffusion process to be achieved:

(i) A structural realignment of the elements of the innovation to form a coherent transmissible unit

(ii) A struggle for control over the focal elements of the innovation: the rise of authority and the beginnings of institutionalisation

(iii) A concentration of dynamically conservative elements at the crisis point, thereby releasing previously suppressed elements of the innovation to catalyse the general process of realignment.

If the crisis is to result in successful innovation and further diffusion, the movement as a whole must be legitimised. Legitimisation in its simplest form would involve the decision to adopt by opinion leaders (as with the Rogers model) in the social system. The subsequent development of the innovation may be characterised as follows:

(i) It can be further diffused in "package" form possibly along similar lines to the conventional model

(ii) The potential for the conflict of new innovation movements in opposition to, or in furtherance of the now visible, acceptable, innovation arises, perhaps attracting dynamic conservatism from those who fermented the initial innovation movement

3:4 <u>A generalised characterisation of the diffusion of new materials</u>

Having contrasted the Rogers and Schon models of the diffusion process it remains to discuss their theoretical relevance to minerals development by proposing a model of the diffusion of new materials.

Later chapters in this study indicate a variety of key growth problems, neglected market areas, technological gaps and so on, but the entrepreneur in minerals development should also be interested in the underlying factors that might influence the diffusion of his product were he to capitalise on a selected opportunity. The immense variety of applications that minerals can fulfil and their general adaptability suggests that in

FIGURE 9: A CHARACTERISATION OF THE DIFFUSION OF PRIMARY MATERIALS

EMERGENCE →	EARLY PIECEMEAL ADAPTATION →	LATER PIECEMEAL ADAPTATION →	CRISIS →	GENERALISED DIFFUSION
1. Specific, possibly technically unique, end use applications	1. Wider range of related applications	1. Broader range of applications beginning to be influenced by non-technical considerations	1. The innovation takes on a 'packaged' form	1. Diffusion becomes self sustaining
2. Specialised area of communication of innovation	2. Beginnings of diffusion through antagonism with dynamically conservative elements	2. Wider but still specialised communication of innovation	2. Crisis brings the innovation to the attention of a general non-specialist audience	2. The inherent potential of the material is explored and exploited by an essentially non-specialist audience
3. Innovation determined by technology of application	3. Diffusion dominated by technology of application	3. The combination of material with application becomes mutually self determining	3. The concept of function (needs) is introduced	3. The concept of function is finally regarded as changeable: function ⇅ material ⇅ application

practice the diffusion of new materials cannot proceed in the same manner as for novel consumer goods. Minerals are, of course, remote from end consumer markets such that the producer is in a relatively poor position to influence final demand for (or direct the diffusion of) minerals products:(i) because of the variety of end use applications and (ii) because of end consumers' general insensitivity to the properties of the raw material constituents of the end product.

Nevertheless there does appear to be a sufficient number of common features in the diffusion of new materials to merit a preliminary generalised characterisation. Five stages are proposed although there may be omissions or transitional phases. The phases are emergence, early adaptation, later adaptation, transitional crisis and generalised diffusion. The schema is outlined in Figure 9. The general features of the model are as follows:

(i) Emergence

Many materials appear to be initially exploited for a particular, perhaps unique, property or combination of properties which they possess. For magnesium metal the new art of photography provided such an opportunity as a flashlight powder[26] whilst aluminium was once reserved for expensive tableware. Dolomite first found application in refractory brick manufacture in the second half of the nineteenth century as a uniquely suitable material for lining the convertors of the newly developed basic Bessemer process.[27] Many other materials are still used predominantly in highly specific industrial applications which often arose as the result of an unrelated innovation in process technology. Nevertheless the mineral need not be limited to one specific application at this stage. A more general pattern would tend towards a range of unrelated uses requiring raw materials with highly specific properties.

(ii) Early piecemeal adaptation

The important feature of this stage is the beginnings of a process of popularisation of the materials potential, albeit in a fairly narrow range of applications. This may result from competition with existing products to fulfil a particular function to a superior technical standard or technological economic optimum. Recent trends in refractory manufacture in Japan have led other manufacturers to consider dolomite and magnesia as end members of the same raw materials spectrum rather than naturally exclusive raw materials.[28] Magnesium metal's original application in photography was soon expanded to include basically similar applications in fireworks, star shells and rocket signals.[29] Titanium is still regarded as a promising new material but one which is currently reserved for special high temperature structural roles especially in aircraft.[30] It may be important that technical rather than economic considerations dominate the adoption process at this stage.

(iii) Later piecemeal adaptation

This stage is characterised by the exploration of the broader potential of the material in non-specific applications. A common prerequisite for the beginnings of this process would appear to be cost reducing innovation which is passed on in the form of lower prices. Until the beginning of this century both aluminium and magnesium would normally be bought by the pound or ounce. With improved technology substantial cost reductions could be implemented in both industries although these tended to be passed on more readily in the case of the former.

As a possible over-simplification this stage marks the beginnings of creative exploitation of the material in non-traditional end uses which reflect its inherent potential. A classic example of the transition involved can be seen in the contrast between the early Ironbridge in Derbyshire which merely replicates a similar design in wood and later types of girder design in structural iron and steel work. Concrete buildings also initially replicated earlier brick-built structures but as the design potential of the material diffused, imaginative, appropriately economical, designs emerged. This process also appears to have occurred in Germany in the 1930's where magnesium was promoted as 'Germany's Metal' and the transition from simple technical substitution to creative innovation gave the material applications in many non-traditional uses.[31] However at this stage, the diffusion process is still adaptive: the combination of material with application becomes mutually self-determining but the material does not influence the social function fulfilled by the application.

(iv) The role of crisis

The theoretical model of diffusion (Schon), suggested a key role for crisis.[32] It may have a positive or negative effect on diffusion but its role is usually decisive in providing for a closer specification of the previously fragmented elements of the innovation 'package'. The crisis need not be of major proportions: for example the critical role of the combined tests on roof failure in open hearth furnaces yielded decisive evidence in favour of high magnesia composite basic refractories.[33] At the other extreme the intervention of the Second World War did much to conclusively retard the diffusion of magnesium as a general purpose engineering material and stimulated much of the still prevalent psychological prejudice against the material. The energy crisis will no doubt have long term implications for the diffusion of nuclear technology and its raw materials, whilst the recent pollution crisis may have spread doubts about further innovation of mercury. The decisive role of crisis is fundamentally associated with the communication of innovation to a wide and essentially non-esoteric audience.

(v) Generalised Diffusion

The creative exploitation of the inherent potential of a raw material beyond the limits of its initial applications characterises this final stage in the diffusion process. At this stage material and application are not the only variables: the changeability of the concept of function is also introduced. The generalised diffusion of plastics beyond the "bakelite and nylons" stage is a conspicuous example. Plastics are now used to create as well as fulfil new areas of social need. As will be discussed subsequently, none of the industries studied has yet reached this stage, the attainment of which appears to offer the considerable advantage of self-sustaining subsequent diffusion.

4. LONG TERM FORECASTING MODELS

4:1 The function and purpose of long term forecasting

A number of factors establish the need for long term forecasting as an aid to planning for minerals development. Amongst these are:

(i) Minerals development involves high costs of entry entailing positive returns only after considerable delay. A long term view is vital if opportunity costs are to be realistically assessed.

(ii) Even for present participants success is increasingly dependent on long term capital commitment to service growth such that future cash flow assessments must be based on long term industry forecasts.

(iii) Distortions of ideal market mechanisms are common in minerals industries notably through the exertion of monopoly or oligopoly power, political intervention, technological monopoly etc.

(iv) Over the long term market definitions are themselves flexible either as a result of fundamental shifts in demand or through technological/social innovation.

All forecasts are probability statements about the future. The more remote the future and the greater the inherent instability in the object of the forecast the stronger the basis for rejecting formal forecasting techniques becomes. In particular those who place ultimate reliance on the market mechanism as a long term equilibrator envisage a self-regulating regime dominated by, in the industrial context, the desire to maximise profits, social benefits or other singular factors.[34] But whilst it cannot be denied that change and uncertainty are hallmarks of many minerals industries it is clear that unless a long term view is promoted short term imperfections may escalate into major long term instability.[35] The purpose of long term forecasting should therefore not be to provide an 'accurate' projection of current trends alone but rather to suggest in addition how such forecasts may be influenced either positively through a resolution of current problems, or negatively through the intervention of external factors. Such models will still be far from comprehensive but they may serve as a realistic basis for planning in minerals development.

4:2 Economic and technological forecasting models

Economic forecasting is a widely practised, but in a formal sense, fairly recently established discipline which has achieved a high degree of sophistication.[36] It has found its widest fields of application as an adjunct to short term (quarterly to biennial) planning. Long term economic forecasting (two years upwards) has not achieved comparable acclaim and indeed its very necessity has been questioned. Technological forecasting emerged in the late 1950's against the background of the American space effort. As a body of more loosely related techniques[37] its methodological base nevertheless has much in common with economic forecasting and the two are therefore discussed together. In one important respect however technological forecasting includes a methodology not formally practised in economic forecasting. This is normative forecasting or to use Gabor's phrase, Inventing the future.[38] Normative forecasting may range from the construction of a self-fulfilling prophecy at one extreme to the "creation of conditions to ensure that a maximum variety of individual incentives can be followed" at the other. As Table 2 indicates the other classes of forecasting models are based on intuitive and exploratory methodologies.

(i) Intuitive forecasting methodology

Intuition has provided a strong undercurrent to the development of many forecasting techniques.[39] Amongst economic techniques market surveys, business indicators, diffusion indices and so on may provide useful short term barometric indicators of trading conditions.[40] There is clearly great emphasis here on judgment in the framing of the data collection and in its

TABLE 2

Complementary Approaches to Forecasting: A comparison of methodology

CLASS	ECONOMIC	TECHNOLOGICAL
EXPLORATORY	Naive methodologies: linear extrapolation, time series analysis etc.	Functional Trend extrapolation including Envelope Curves and Historical Analogy
EXPLORATORY	Correlation and Regression Analysis	Contextual Mapping
EXPLORATORY	Econometric Modelling	Exploratory Simulation
	-	Morphological Analysis
INTUITIVE	Diffusion indices, business indicators, market surveys etc.	Delphi and other consensus techniques
INTUITIVE	Intuitive Economic Forecasting	Scenario Writing, SOON charts
NORMATIVE	-	Network/Relevance Analysis Matrix Analysis

interpretation. In technological forecasting an attempt to structure expert opinion in the anticipation of technological and other innovations was pioneered in the Delphi technique. This is a simple development of the panel of experts method in which the results of each round of responses is iterated until a concensus is achieved. Jantsch (1967) and Quinn (1968) discuss the methods in detail. Alternative intuitive methodologies include scenario writing which in its more refined form seeks to explore technological branching points dependent upon critical choices, and historical analogy which explores the technological equivalent of a product life cycle for related technologies. Refinements of the basic intuitive methodology have produced interesting results, through the importation of gaming techniques and integrated structural models permitting variable simulation.[41]

(ii) Exploratory forecasting methodology

Exploratory methodology starts from an assured basis of historical knowledge and seeks to justify its probabilistic forecasts on the basis of historical consistency. Although inertia may be a sufficient guarantee for short term forecasts one of the common aims of long term forecasts is improved anticipation of departures from present trends and on this basis the scaling up of essentially static short term projections may be logically qustionable (see Appendix B). Three categories, in order of increasing complexity, of exploratory forecasting are commonly recognised. These are naive or extrapolatory models, correlation and regression models, and full scale econometric models. Technological forecasting is developing along closely parallel lines to economic methodology in this area but has yet to develop an equivalent branch of econometrics. Roberts (1969) has suggested that such a development could lead to undesirable intellectual rigidity.[42]

The first group of methods is distinguished by the computation of forecasts solely from the historical values of the variables to be forecast. This may apply equally to sales forecasting as to simple extrapolation of some technical variable such as aircraft speed. Models may be of the general form:

$$\hat{X}_t+1 = X_t \quad \text{i.e. no change in the level X from t to t+1}$$

$$\hat{X}_t+1 = X_t \, (X_t - X_{t-1}) \quad \text{i.e. same change}$$

or

$$\hat{X}_t+1 = X_t \cdot \frac{X_t}{X_{t-1}} \quad \text{i.e. same rate of change}$$

Underlying all the many permutations, including data smoothing, that are possible is the principle that an historical consistency has been recognised in the selected data and that such a consistency exists is a sufficient justification for its future continuance.

Correlation and regression models seek to identify at the outset an a priori causative relationship between the forecast or dependent variable and some other variable whose movements are essentially independent. It is of course vitally important that the independent variable can be more easily forecast than the dependent. The basic methodology of regression concerns the adjustment of a line, or n-dimensional curve to various data observations such that the computed expression describes the relationship between the data more closely than any other curve. Regression analysis is paralleled in exploratory technological forecasting where it is known as time independent contextual mapping.[43] As in economic analysis an independent theory of causation is postulated and then correlation is attempted between the chosen technical parameters. Such extrapolation may provide insight into future technological capabilities if inventive and innovative processes continue at their historical levels.

The difference between correlation and regression studies and econometric modelling is one of degree rather than kind. Both require a preliminary theory of causation, which can be tested against the historical conformity of the data to the retrodictions of the theory. If the two are sufficiently well corroborated there may be an incentive to incorporate other aspects of the theory as a quantitative statement which will render the theory better testable. Simple econometric models have been constructed for a number of basic materials industries such as steel, plastics and aluminium. Rosenzweig's (1957) study of the latter is typical of the role of trial and error in econometric modelling which can result in a confusion of the objectives of corroboration of a theory of causation with an inductive approach to improving retrodictive correlative efficiency.[44] It is important to stress that there is no inherent logic in pre-existent correlative sequences which render greater plausibility to a 'point' forecast with a low 'standard' error in preference to one with a high error. The consolationof a relatively low standard error is of little value to the planner who has not the opportunity to repeat his plan in the event of a low probability 'inaccuracy'. Nevertheless econometric models are achieving some successes in short term forecasts of gross national product and other macroeconomic variables.

(iii) Normative forecasting methodology

Although true normative forecasting in the sense previously defined (see page 47) has not yet developed as a formal technique, its more limited use for the purposes of resource allocation is established. The basis of such forecasting models as PATTERN, PROFILE, and MAPTEK is the use of relevance trees as an aid to the structuring of decisions.[45] The preparations for such a relevance tree analysis are crucial: clear cut objectives, broad strategies for achieving these objectives, and formal tactical methods, must all be identified. Through the assignment of weights to the appropriate criteria on the basis of contribution to the overall objective, quantitative assessments may be achieved and alternative strategies evaluated.[46] Such models may be extremely expensive and time consuming to construct and will understandably reflect the value configurations of their engineers.

4:3 Conclusions on long term forecasting

There appears to be three major problems with long term forecasting which suggest caution in its application to planning for minerals development:

(i) Exploratory methods of technological and economic forecasting have not achieved a satisfactory level of long term credibility in the fields of interest. There are fundamental methodological limitations which may confuse correlation with causation.

(ii) Normative methods have developed primarily as a means for project selection based on current preferences. Relaxation of this constraint leads to a proliferation of objectives with no prospective arbiter.

(iii) Quantitative forecasting methodology relies heavily on statistical inference, in turn derived from the calculus of probability. The application of such methods to infinite time series analysis is, at best, logically questionable (see Appendix B).

For the entrepreneur who may be anticipating long term investment in minerals development, two sorts of information are required. Firstly he needs to know what opportunities may be presented on the basis of a continuation of present trends. As such therefore there is some merit in simplicity in the full understanding that such forecasts are ideal abstractions. Secondly the entrepreneur would need to know what possible implications departures from present trends could have for investment prospects. Many of these departures will be conditional on factors which will remain outwith the control of the entrepreneur and at least some will always be unpredictable. However it is suggested that careful analysis of the subject industry may reveal a number of key growth problems and ways in which these problems could be resolved. The aim of the entrepreneur in these circumstances therefore is to keep under continuous review as broad a range of opportunities as possible. When those random and unforseeable events which are beyond the scope of his plan combine to create an individually favourable opportunity or range of opportunities he will accordingly be in an advantageous position to capitalise on selected projects. Such a method of opportunity planning is developed further in Chapter Five. In conclusion it is clear that sophisticated long term forecasting techniques are expensive, insufficiently 'accurate', and may be unnecessary where the overall objective is to maintain an attitude of readiness to profit from specific opportunities which may arise where departures from simple trend forecasts occur. But it is important to add that such a flexible planning approach inevitably incurs the costs of being continuously ready to innovate and as will be seen the attitude may be impractical in certain situations.

5. MODELS AND EMPIRICISM: CONCLUSIONS

Earlier sections of this chapter have attempted a preliminary abstraction of some aspects of a theory of minerals development. The models discussed are intended to form a frame of reference in analysing the empirical studies of three selected minerals consuming industries in the following chapters. In particular the following issues are again reviewed in the light of the empirical analyses:

(i) The replacement/net investment hypothesis as a constraint on innovation

(ii) The effect of monopoly in the creation of barriers to entry to markets and production

(iii) The complementary role of producers in segmented markets

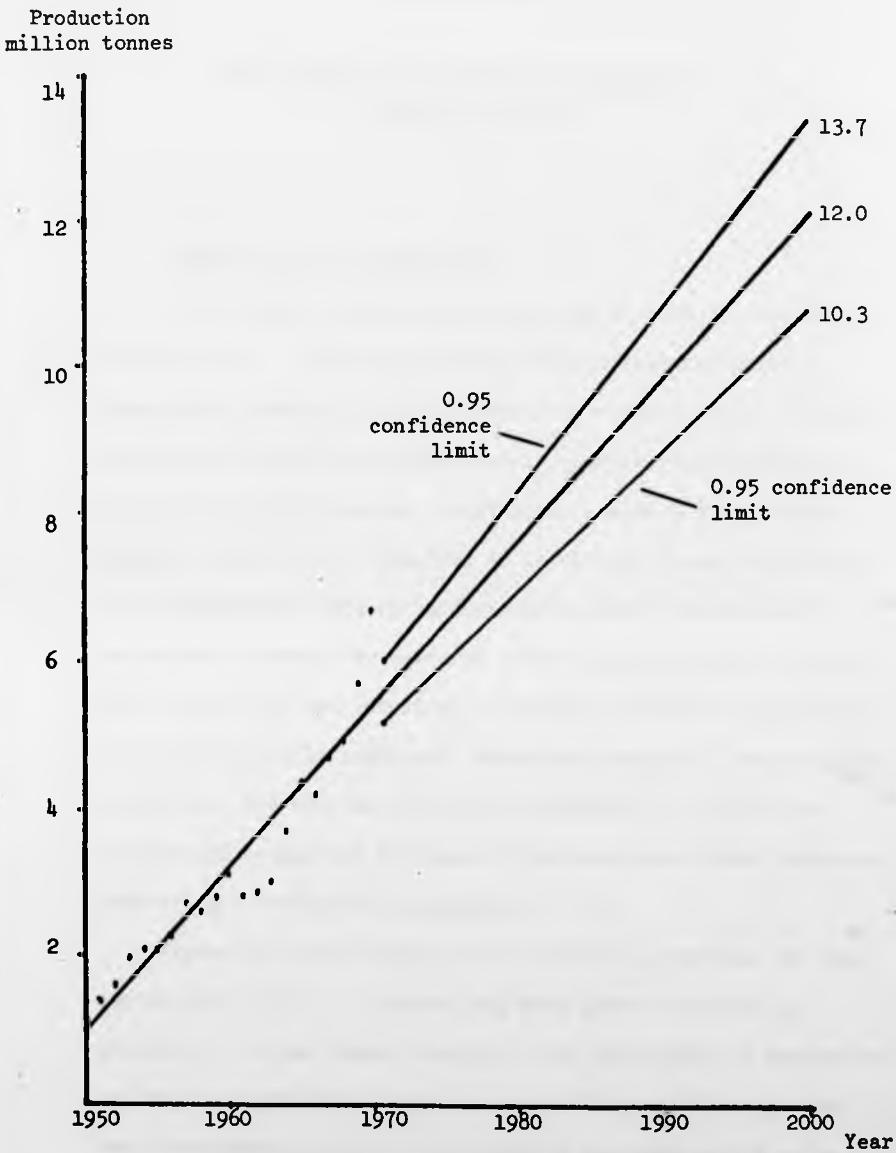
(iv) Oligopolistic rivalry

(v) The 'scheduling' of innovation

(vi) The barriers to diffusion

As was earlier stated the classical method of hypothesis testing cannot be applied to the empirical studies in an ideal manner. The approach adopted is therefore to present under the same topic headings relevant background information on the industries concerned including their structure and technology as well as a survey of end uses and market behaviour. In subsequent chapters efforts are made to determine how the long term growth problems of the three industries differ by referring back to, and where relevant refining, the theoretical contributions of the present chapter.

FIGURE 10: U.K. DOLOMITE PRODUCTION AND PROJECTION TO 2000



Equation: Y = 0.22X-10.02 where Y = production, million tonnes and X = year

Regression coefficient of correlation: $R^2 = 0.900$

Confidence limits (0.95) on coefficients A = 0.22(0.19→0.25), B = 10.02(-7.94→ -12.11)

CHAPTER THREE

CASE STUDIES IN TECHNOLOGICAL ECONOMICS : INDUSTRY ANALYSES

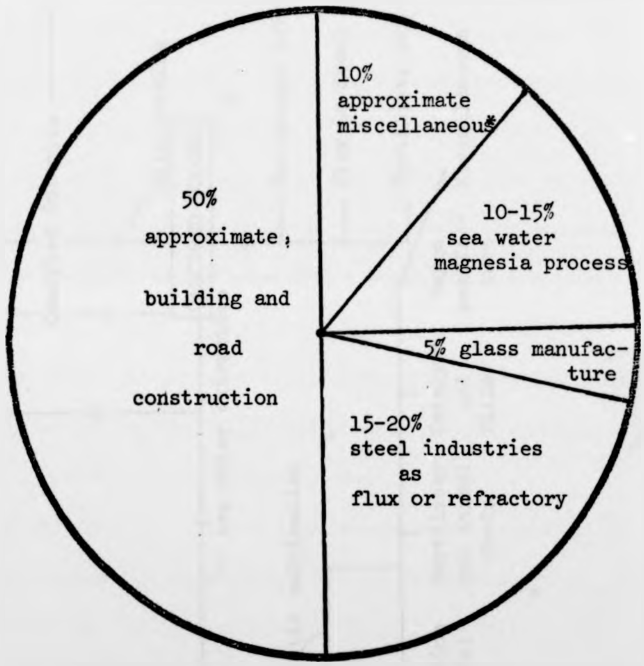
1. INTRODUCTION AND OBJECTIVES

This chapter includes three industry studies in technological economics. Each study deals with one selected primary processing industry in the raw materials classification: metals, industrial minerals, bulk materials. Particular attention is paid in this and subsequent chapters to the role of the study mineral dolomite (c.f. Appendix A) in each of these categories. As is demonstrated the technological economic determinants of raw material demand for dolomite differs significantly in each. And so each selected industry is therefore considered separately under the following headings: structural analysis, technological background, end use and behaviourial analyses. Much of the statistical background and some of the more specialised technical material are contained in Appendices C - H.

Figure 10 records overall U.K. dolomite production for the period 1950 - 1972. A broad long term growth trend is in evidence. In the first, simplest, case this trend is indicative of long term potential growth in demand for the mineral. But for the minerals developer the trend is too aggregative to be employed as a reliable indicator of the wide range of opportunities for development in the three minerals categories mentioned. Reference to figure 11 indicates that 'low value' bulk material applications of dolomite comprise half the annual total consumption whereas the remainder is divided between a wide range of

FIGURE 11: END USES OF DOLOMITE, U.K. 1968

TOTAL PRODUCTION: 4.98 million tonnes

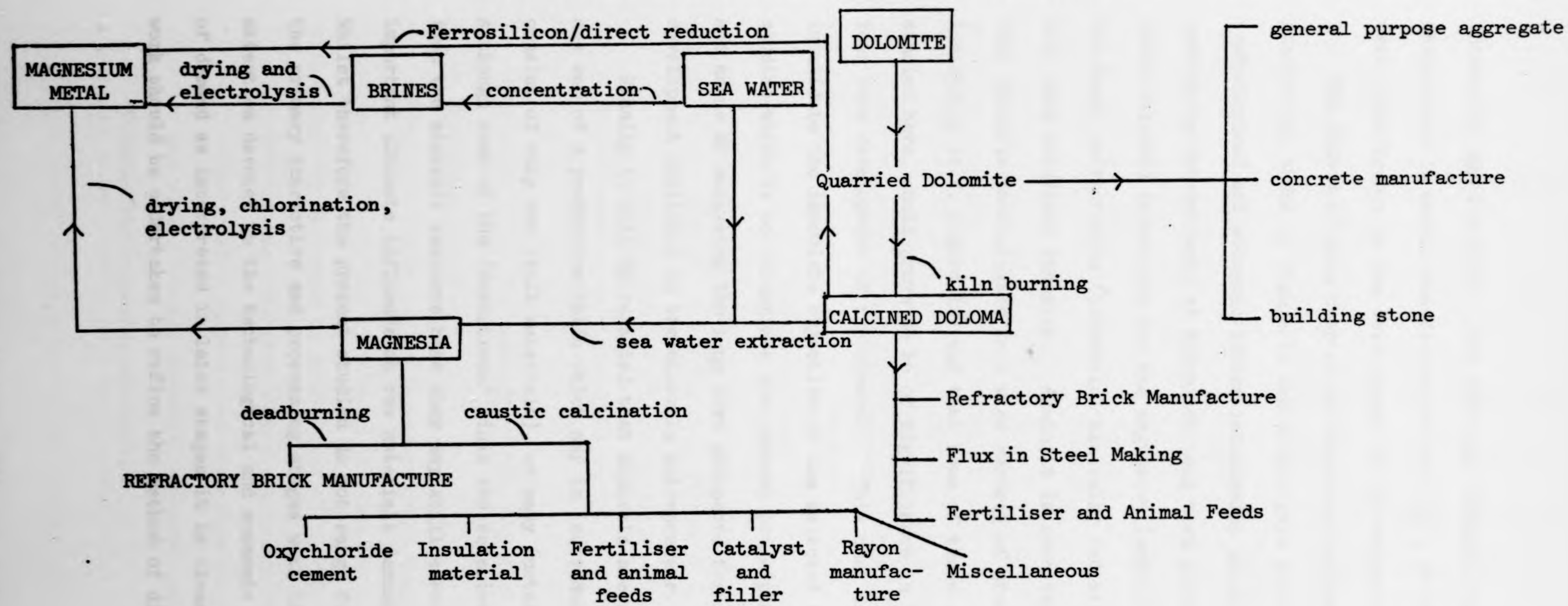


*including: Agriculture, Water purification, filler industry, neutralising agents etc.

Note that proportions are based on tonnages consumed and not value of product.

Source: in part adapted from Cummings, R.H. and Bichan, H.R. (1969), op.cit.

FIGURE 12: EXTRACTIVE ROUTES AND END USES FOR DOLOMITE



industrial applications. And although dolomite does not now participate in metals manufacture in the U.K., it may be of long term significance in the development of the magnesium industry.

The object of this chapter is therefore to disaggregate the statistical trend of figure 10 and investigate the complex technological and economic interrelationships which are the underlying determinants of dolomite's long term potential. The three selected industries are the magnesium (metal) industry the basic refractories (industrial minerals) industry and the U.K. bulk materials industry. Again it is necessary to emphasise that dolomite participates in a wide variety of processing industries (c.f. figure 12) and that some of these end uses, not studied here, could prove to be of significance in the overall long term development of the mineral. This does not however invalidate the immediate objective of the selected industry studies which is to illustrate the general principles, problems and means of assessing the long term prospects for resource development available to the minerals entrepreneur.

Finally it will be recalled that minerals are situated at one end of a production chain which may in individual cases consist of only one (bulk materials), or many (metals) links. Although some of the 'downstream' links are relatively remote from the minerals resource base they may still exercise an important ultimate influence on raw materials demand patterns. Whilst therefore the present studies do not range further than the primary extractive and processing stages with limited attention devoted to the technological and economic determinants of demand as interpreted in later stages it is clear that further work should be undertaken to refine the method of disaggregated analysis employed for such secondary links in the production function.

TABLE 3

WORLD PRODUCTIVE CAPACITY FOR PRIMARY MAGNESIUM METAL PRODUCTION (in metric tons)

Company	Country	Primary Productive Capacity	
Dow Chemical Co.	U.S.A.	120,000	
National Lead	U.S.A.	40,000	(planned)
Titanium Metals Corp	U.S.A.	10,900	
Norsk Hydro A.S.	Norway	50,000	
Dominion Magnesium (Chromasco)	Canada	10,200	
Soc. Italian per il Magnesio	Italy	8,000	
Furukawa Magnesium	Japan	6,000	
Ube Industries	Japan	5,000	
-	U.S.S.R.	45,000	
-	China	1,000	
Pechiney S.A.	France	5,000	
	Estimated total	301,100	

Adopted from: Schmidt, K.H., Die Welt situation bei Magnesium, Metall wirt schaft und Metallmarkt, (1970), March p.285, and updated.

2. CASE STUDY ONE: THE MAGNESIUM METAL INDUSTRY

2:1 Structural analysis

By way of introduction to the magnesium industry[1], the following is a check list of some of the distinctive features of the industry discussed in greater detail in subsequent sections.

(i) Effectively unlimited supply and access to theoretically suitable raw materials including sea water, brines, dolomite, and many other naturally occurring minerals.

(ii) Sophisticated, energy intensive production technology but with the persistence of barriers to the diffusion of technical knowledge.

(iii) Tightly oligopolistic supply patterns with rigid official price structure which may be artificially maintained. Limited forward integration into markets.

(iv) International market area with historical regional emphases and continued significance of individual consumers.

(v) Significantly large governmental stockpile.

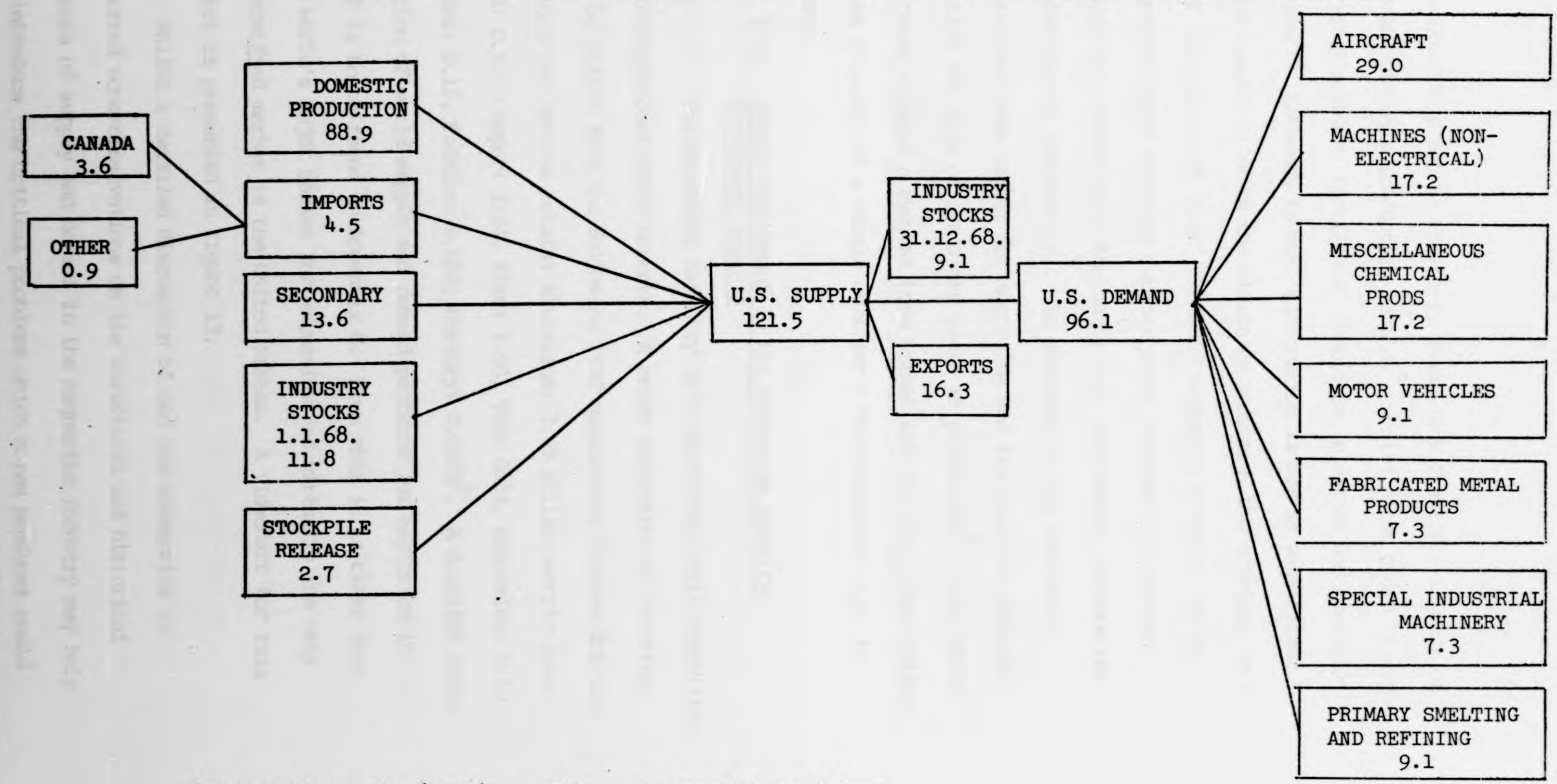
(vi) Insignificant but promising recycling potential.

21:1 Producer structure

World production of primary magnesium metal is limited to a handful of companies (see Table 3) and supply patterns in the western countries are in fact dominated by two companies. In the United States the Dow chemical company is one of the pioneers in magnesium manufacture whilst the other major supplier, Norsk Hydro A.S. is located in Norway. An historically small scale producer National Lead Industries also promises to make significantly increased contributions[2] whilst occasional Soviet participation in western markets should not be underestimated.[3] A comparison of current productive capacity (Table 3) with recent demand estimates[4] suggests that potential supply in the industry tends to run ahead of demand in spite of short term hiatuses. Aside from those producers so far mentioned, all other participants are small, specialist producers either captives of the aluminium industry or producers of titanium metal.

The major producers of magnesium metal control their raw material supplies as well as producing their own electricity.

FIGURE 13: U.S. SUPPLY AND DEMAND RELATIONSHIPS FOR MAGNESIUM METAL (1968), thousand tonnes



Source: Paone, J. (1970), op.cit., adapted with additions

The magnesium plant at Freeport, Texas (Dow Chemical) is part of a large chemicals production complex[5], whilst Norsk Hydro is also a major aluminium, fertiliser, chemicals, plastics and electricity producer.[6] Although forward integration is not as significant in the magnesium as in the aluminium industry, Dow chemical is a major fabricator of 'semi' finished magnesium products and NL industries entry promises further moves forward into markets through its ownership of the major U.S. die casting concern the Doehler-Jarvis Corporation[7]. In contrast to Dow chemicals' diversified home market for magnesium and its domestic monopoly position for much of its sixty years in production[8], Norsk Hydro has never enjoyed a buoyant home market and for many years relied on the strength of a single customer - Volkswagenwerk A.G. in Germany.

21:2 Supply and demand in the magnesium industry: structural aspects

The magnesium industry is a relatively small competitor in international metal markets. A crude indication of its size can be gained from the following 1970 consumption figures for the various non ferrous metals: Aluminium: 3.49 million metric tons, Lead: 0.83, Copper: 1.84, Zinc: 1.05, Tin: 0.54, Magnesium: 0.10 Nickel: 0.15, Cadmium: 0.004, Mercury: 0.0009[9]. A detailed cross section of world supply and demand patterns for magnesium in 1969 is to be found in Appendix C. From this it is clear that the world's major market for magnesium and virtually the only diversified market is the United States. A flowchart for this market is presented in figure 13.

Whilst a detailed discussion of end use categories is deferred some observations on the structural and historical aspects of supply and demand in the magnesium industry may help to introduce the critical problems which a new producer could experience. These problems will be later abstracted under the heading of "barriers to entry" (c.f. Chapter Four, Section 2:1).

The early technology of magnesium production was developed in Europe and especially in Germany such that during the first fifteen years of this century one company, I.G. Farbenindustrie supplied most of the world demand for magnesium metal. During the first world war production was pioneered in the United States where in 1916 H.H. Dow patented the 'bathtub' electrolytic cell. Alternative technologies were employed by a number of companies in the U.S. but only the Dow Chemical Company and the American Magnesium Corporation survived the war years. In 1924 AMC became a wholely owned subsidiary of the Aluminium Company of America:

'During 1927-8 Dow and AMC entered into purchasing and cross licensing agreements whereby both companies could use, royalty-free, the patents that each held covering fabricating and heat treating techniques. AMC ceased production of primary magnesium leaving the Dow plant the only (U.S.) producer of the metal from 1928 until the outbreak of World War II.

In 1931 Aluminium Co. of America and I.G. Farbenindustrie of Germany concluded the Alig agreement whereby they pooled their patents and technical knowledge for producing and fabricating magnesium. Under the terms of this agreement, the Magnesium Development Corporation was organised to hold the patents and issue sublicences. Dow refused to enter into an agreement with MDC. In 1933 Dow's agreement with AMC was amended to provide for equal competitive pricing of fabricated products, and in the hopes of stabilising the magnesium market, Dow then entered into a cross licensing agreement with Alcoa and MDC. Dow agreed not to sell any magnesium in Europe other than to experience. These problems will be later abstracted under the heading of "barriers to entry" (c.f. Chapter Four, Section 2:1).

The early technology of magnesium production was developed in Europe and especially in Germany such that during the first fifteen years of this century one company, I.G. Farbenindustrie supplied most of the world demand for magnesium metal. During the first world war production was pioneered in the United States where in 1916 H.H. Dow patented the 'bathtub' electrolytic cell. Alternative technologies were employed by a number of companies in the U.S. but only the Dow Chemical Company and the American Magnesium Corporation survived the war years. In 1924 AMC became a wholely owned subsidiary of the Aluminium Company of America:

'During 1927-8 Dow and AMC entered into purchasing and cross licensing agreements whereby both companies could use, royalty-free, the patents that each held covering fabricating and heat treating techniques. AMC ceased production of primary magnesium leaving the Dow plant the only (U.S.) producer of the metal from 1928 until the outbreak of World War II.

In 1931 Aluminium Co. of America and I.G. Farbenindustrie of Germany concluded the Alig agreement whereby they pooled their patents and technical knowledge for producing and fabricating magnesium. Under the terms of this agreement, the Magnesium Development Corporation was organised to hold the patents and issue sublicences. Dow refused to enter into an agreement with MDC. In 1933 Dow's agreement with AMC was amended to provide for equal competitive pricing of fabricated products, and in the hopes of stabilising the magnesium market, Dow then entered into a cross licensing agreement with Alcoa and MDC. Dow agreed not to sell any magnesium in Europe other than to

I.G. Farbenindustrie and one customer of long standing in the U.K. By contracts with Alcoa, Dow was limited even in domestic markets.'[10] This emergence of national monopoly has since remained a persistent feature of the magnesium industry and the associated implications of power over price and the spread of technical knowledge are of central importance to the industry's long term development.

In 1941 whilst Dow was scaling up its own production for the second world war effort and assisting others in new plants, some employing alternative technologies, the company was charged with conspiracy through monopoly by the Department of Justice.[11] A plea of nolo contendere was later vigorously defended by the company[12] yet only two years after the end of the war Dow was again the sole US producer and of course I G Farbenindustrie had been disbanded.

During the subsequent period up to the late 1960's the persistence of, on the one hand, surplus capacity and on the other, accumulated stockpiles, added two further potential deterrents to entry. The disappointing growth exhibited by the industry, the only major new contributor being Norsk Hydro to supply the still buoyant German market[13], may account for the lack of technical innovations throughout this period. For Dow and Norsk Hydro then the period was one of consolidation with the US market strongly protected by prohibitive tarrif barriers such that US imports over this period tended to be negligible (c.f. figure 13). More recently a number of developments have occured in the magnesium industry which could alter the historic pattern of development described. In particular, innovations in the production of magnesium from concentrated brines were patented by the National Lead Company in 1968, and the Dow Chemical Company has patented a significant energy saving advance in the composition of electrolytes used in the reduction process. Although National Lead has still to prove the technology of its new venture[13A] at full scale production levels the entry may lead to a fundamental change in the balance of supply and demand in the industry.

Turning from the supply of to the demand for magnesium, although usage of magnesium in pyrotechnics and aircraft during the second world war soared[16] it now appears that the long term effects of this boom were to retard the diffusion of the metal. For under the pre war restrictive agreements magnesium was becoming widely accepted as a general purpose constructional and engineering material, particularly in Germany[17]. Wartime usages were much more restricted and gave rise to a considerable fund of prejudice against the metal which still retards its diffusion. Only within the German market did awareness of magnesium's potential persist eventually giving rise to the Norsk Hydro operation in 1950[18].

The international structure of the magnesium industry can be summarised on two levels. Firstly the two major companies, one with a sheltered and stable domestic market, the other with a consistent source of export demand, and secondly a number of much smaller primary and secondary producers geared primarily to national market characteristics.

2:2 The technological background to the magnesium industry

The relatively high market price of magnesium metal reflects, at least partially, the high costs of extraction and melting. There is no uniquely suitable method of extracting magnesium from its 'ores' and one of the purposes of this section is to indicate the technological scope available which may be appropriately exploited under different economic conditions. Three areas are considered[19]

(i) The basic technical information contributing to the range and choice of extractive techniques available.

(ii) Production technology

(iii) The technical background to the end uses of magnesium.

The discussion commences with an analysis of the relatively high energy component involved in magnesium reduction operations.

22:1 Basic technical information

Free energy data for the formation of various compounds of magnesium can also be used to estimate the amount of energy required to liberate the metal in any theoretical extraction process. Emley (1966) has summarised this information from which it is concluded that the prospects for direct (thermal) reduction at normal pressures and readily practicable temperatures are limited[20]. The point is of considerable significancein relation to comparable processes for copper, lead, zinc and aluminium extraction. Thus magnesium extraction methods using direct thermal processes must depend on relatively cheap reducing agents, high temperatures and reduced pressures to take full advantage of the possibility of displacing an unfavourable reaction equilibrium by continual removal of the magnesium vapour formed.

On the other hand the potential for electrolytic reduction of magnesium oxide appears at first sight encouraging especially in view of the equivalent Hall Héroult process for aluminium[21]. However attempts to derive such an electrolytic process have generally foundered on establishing electrolytes with the necessary properties. Thus magnesium oxide is not appreciably soluble in chloride melts and owing to the chemical reactivity of magnesium it is difficult to find economically attractive chloride free melts which are also inert. The problems have not been completely surmounted and accordingly electrolytic routes to magnesium from magnesium oxide are not presently employed[22]. The next most favourable compound, and the one that is in practice employed most widely is magnesium chloride.

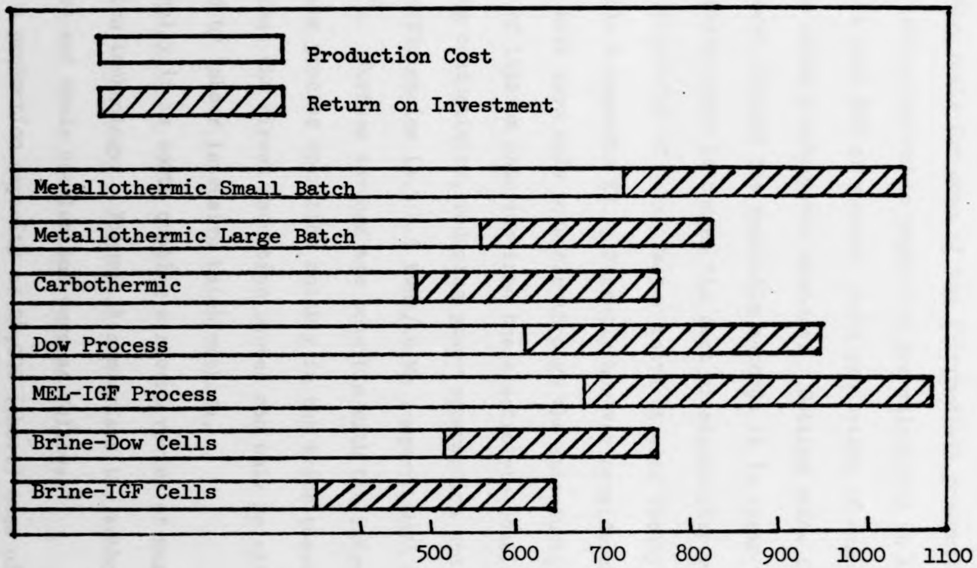
Anhydrous magnesium chloride melts at 713°C. It is also extremely hygroscopic and the conductivity of the melt decreases with increasing water content, and hence the cost of extraction also increases. Additions are therefore desirable to lower the melting point, improve the chemical stability and conductivity, and modify the density of the electrolyte[23]. In practice sodium, potassium and calcium chlorides are used in varying proportions although important recent innovations are subsequently discussed. In summary no matter which route is taken to liberate magnesium from its compounds, the process is invariably energy intensive whilst the electrolysis of magnesium chloride appears the most practicable alternative.

22:2 The technology of magnesium production

Magnesium production technology consists primarily of the preparation of intermediate magnesium rich compounds from naturally occuring ores and the reduction of these compounds to the metal. Within the technical limits described in the previous section there are a very wide variety of alternative methods available the most important of which are compared in Appendix E. For present purposes however four processes include all presently practised techniques: direct reduction of calcined dolomite with ferrosilicon, electrolysis of totally anhydrous magnesium chloride prepared by chlorinating anhydrous magnesium oxide (the I.G. - M.E.L. process), electrolysis of partially anhydrous magnesium chloride (the Dow process), and electrolysis of concentrated brines (National Lead).

To begin with the preparation of intermediate compounds. Although there is no natural occurrence of magnesium metal, magnesium is the eighth most abundant element in the earth's crust being found in over sixty minerals of which only four - dolomite, magnesite, brucite and olivine[24], have been used commercially. Of these only dolomite is now used either in the direct or electrolytic routes to the metal. Sea water and brines are also

FIGURE 14: MAGNESIUM COSTS BY PRODUCTION METHOD (DOLLARS PER TONNE)



Note: For detailed discussion and cost breakdown for individual methods, see Appendix E

Source: Adapted from Elkins, D.A., et. al., (1968), op.cit.

major sources of magnesium. The former contains on average about 0.13% b.w. magnesium and brines may contain relatively greater proportions[25]. Clearly such solar preconcentration is an extremely significant economic incentive for the use of brines as a primary raw material. Where dolomite is the chosen starting material it may have to be chlorinated for subsequent electrolysis whereas brine based processes are net chlorine producers. Production costs for some of the intermediate products involved in the various routes to magnesium are calculated in Appendix E.

Well over 90% of current world production of magnesium is achieved using electrolytic methods. Setting aside the technical differences between the available methods it is clear that no matter which route is chosen the cost of electricity represents a high proportion of total factor costs at over twenty per cent (see Table 4 Appendix E). Recently however considerable cost savings have been made possible through the introduction of small amounts of lithium chloride into the electrolyte considerably improving conductivity, reducing power consumption and increasing energy efficiencies (4.5 - 5 kwhr/lb Mg compared with 8 - 9.5 kwhr/lb Mg)[26]. Further savings are possible with the introduction of continuous process operation notably in the brine based process. In contrast the direct reduction routes can only be effectively operated by labour intensive batch methods.

Finally it is worth quoting a recent review of magnesium production technology. Figure 14 summarises the author's cost estimates and their conclusions were as follows:[27]

"At a production capacity of 24,000 (short) tons of magnesium per year:

(i) With cost reducing improvements, either the metallothermic or carbothermic reduction processes might possibly be operated at a lower costs than electrolytic processes requiring the chlorination of feed materials.

(2) Such an electrolytic plant built and operated at present (1968) costs would have to be improved over the versions evaluated in order to yield a reasonable return on investment at present magnesium prices.

(3) An electrolytic operation reducing magnesium chloride produced from brine and producing chlorine as a by product should be able to make a reasonable return on investment even at a reduced magnesium price."

The present study suggests that existing plant will continue to operate competitively over the short to medium term. In the long term however brine based production will offer the cheapest source of the metal although local market conditions, including secondary supply, could create a renewed role for direct reduction.

22:3 The technical basis for magnesium's end uses

Historically magnesium and its alloys have found widespread application in functions for which the material tended to possess unique properties. As was suggested in Chapter Two, it is probably inadvisable to base future developments solely on existing end use patterns but further diffusion should instead be dependent on the awareness and exploitation of the inherent technical potential of the material.

Of its physical properties magnesium's low density (see Table 4) is perhaps the best known and it is suggested that long term diffusion of the material will mainly depend on a wider exploitation of this property particularly in structural and transportational roles. Magnesium also possesses an outstandingly low thermal neutron absorption cross section which has given it a

TABLE 4

A. MAGNESIUMS MAJOR ADVANTAGE IS ITS LOW WEIGHT

MATERIAL	SPECIFIC GRAVITY	RELATIVE WEIGHT	WEIGHT LB/CU. FT.
MAGNESIUM ALLOYS	1.8	1.0	112
ALUMINIUM ALLOYS	2.8	1.6	175
ZINC	7.1	3.9	443
CAST IRON	7.2	4.0	450
STEEL	7.9	4.4	493
BRASS	8.5	4.7	531
BRONZE	8.8	4.9	550

Adapted from: Design, Magnesium Elektron Limited, p.3

B. SOME RELEVANT PHYSICAL PROPERTIES OF MAGNESIUM

Atomic number	12
Atomic weight	24.32
Youngs modulus	6.4×10^6 p.s.i. (approx)
Density (20^oC)	1.738 g/cm^3
Melting Point	650^oC
Boiling Point	1105^oC
Latent heat of fusion	2.1 ± 0.1 kcal/mole
Heat capacity ($0 - 100^oC$)	0.22 cal/g/^oC
Electrical conductivity (20^oC)	2.24×10^5 mho/cm^3

Adapted from: Emley E.F., op. cit. p.736 - 7

---

limited specialist role in nuclear power generation as a fuel container[28]. Chemically magnesium is a very reactive material with a theoretical solution potential at 25^oC of- 2.38V. This means that in the presence of suitable electrolytes magnesium will dissolve in preference to other metals. From a thermo chemical standpoint reactions in which magnesium is converted into oxide, hydroxide, chloride or fluoride tend to be favoured thermodynamically. This is the basis of many of the metal's industrial applications as well as obvious traditional uses in pyrotechnics. Mechanically magnesium appears at first sight disappointing and it may in practice require expensive changes of equipment to take full advantage of the metal's potential (see Appendix G for an example). Magnesium has a Youngs modulus of about 6.5×10^6 lb / in^2 compared with 10×10^6 lb /in^2 for aluminium and about 30×10^6 lb /in^2 for steel[29]. Parts designed in magnesium have therefore to be stiffer than equivalent steel components. This in general has only a very slight effect on weight because even with thicker sections magnesium products will still be about 70% lighter than steel and 25% lighter than equivalent aluminium parts. It should also be added that recent advances in magnesium alloying technology have improved the mechanical performance range, although the relevant alloys are usually more expensive[30]. A final important characteristic of magnesium and its alloys is their excellent machinability (see Table 5). Magnesium is the easiest of all structural metals to machine. Its ability to withstand higher machining speeds and feeds significantly reduces machining time, increases tool life, reduces labour requirements and decreases down time for tool changing.

2:3 End Use Analysis

Magnesium and its alloys may be machined, moulded or rolled into any of the common forms of basic metal product: slabs, sheets, billets or rods[31]. As previously mentioned some primary producers also manufacture semi fabricated products and most of the modern techniques of, for example, injection moulding are readily applicable to end uses requirements in magnesium. Present day end use categories for magnesium are broadly considered

TABLE 5

A. RELATIVE POWER REQUIRED TO MACHINE METALS

METAL	RELATIVE POWER REQUIRED
Magnesium Alloys	1.0
Aluminium Alloys	1.8
Brass	2.3
Cast Iron)	3.5
Mild Steel)	
Nickel Alloys	10.0

B. COMPARATIVE MACHINABILITY OF METALS (FT/MIN)

METAL	TURNING ROUGH	FINISH	DRILLING (5-10mm drill)	MILLING (100mm miller, 1mm cut)
Steel	130 - 650	200 - 1000	50 - 100	60 - 70
Cr-Nisteel	60 - 300	100 - 400	20 - 65	30 - 45
Cast Iron	100 - 300	200 - 400	40 - 130	45 - 60
Aluminium	250 - 2500	400 - 4000	200 - 1300	650 - 1000
Magnesium	up to 4000	6000 - 8000	500 - 1700	650 - 1700

Source: Design, Magnesium Elektron Ltd, p.1

under applications involving alloying with aluminium, structural applications, and chemical, sacrificial and miscellaneous non-standard uses.

23:1 Alloying with aluminium

Primary magnesium of standard 99.8% purity (known as 998) is widely used by the aluminium industry in the production of magnesium intensive aluminium alloys. Table 5A (Appendix C) indicates that over a third of total U.S. consumption is in this end use area. The attraction of magnesium for such use lies in the increased mechanical strength of the alloys, much improved corrosion resistance, better weldability and 'per part' cost

TABLE 5

A. RELATIVE POWER REQUIRED TO MACHINE METALS

METAL	RELATIVE POWER REQUIRED
Magnesium Alloys	1.0
Aluminium Alloys	1.8
Brass	2.3
Cast Iron)	3.5
Mild Steel)	3.5
Nickel Alloys	10.0

B. COMPARATIVE MACHINABILITY OF METALS (FT/MIN)

METAL	TURNING ROUGH	FINISH	DRILLING (5-10mm drill)	MILLING (100mm miller, 1mm cut)
Steel	130 - 650	200 - 1000	50 - 100	60 - 70
Cr-Nisteel	60 - 300	100 - 400	20 - 65	30 - 45
Cast Iron	100 - 300	200 - 400	40 - 130	45 - 60
Aluminium	250 - 2500	400 - 4000	200 - 1300	650 - 1000
Magnesium	up to 4000	6000 - 8000	500 - 1700	650 - 1700

Source: Design, Magnesium Elektron Ltd, p.1

---

under applications involving alloying with aluminium, structural applications, and chemical, sacrificial and miscellaneous non-standard uses.

23:1 Alloying with aluminium

Primary magnesium of standard 99.8% purity (known as 998) is widely used by the aluminium industry in the production of magnesium intensive aluminium alloys. Table 5A (Appendix C) indicates that over a third of total U.S. consumption is in this end use area. The attraction of magnesium for such use lies in the increased mechanical strength of the alloys, much improved corrosion resistance, better weldability and 'per part' cost savings. Consumption of magnesium by the aluminium companies nevertheless constitutes less than 1% of total aluminium consumption, providing an even smaller proportion of individual product factor costs such that, other things being equal, the aluminium industry's demand for magnesium has been relatively inelastic. Consumption of Mg - Al alloys has however grown faster than the average growth for other aluminium alloys in the last decade. This is largely attributable to the innovation and diffusion of magnesium intensive (8% by weight) alloys for canning purposes - notably in the highly successful 'ring pull' can market.

23:2 Structural Applications

This sector is most conveniently considered as two separate subgroupings: special and general categories. Included in the former are aerospace and military requirements for structural magnesium which have generally exhibited a low price elasticity of demand. The special attractions of magnesium in these roles relates to its low density and high strength to weight ratio. Whilst far from negligible, purchase cost has not in general been a factor of overriding importance. In theory each 100 lbs of aircraft weight saved is worth several thousand pounds per year in additional passenger revenue. Magnesium is used in such diverse parts of an aircraft as the undercarriage, wheels, wings and engines. Helicopters also provide an important market. It is difficult to discern an overall trend in this sector, however, in the absence of detailed information on the relative significance of military to civilian applications. It is suggested that, at least for the U.S. market, much of the magnesium consumed in this sector was in combat aircraft and that because of temperature limitations magnesium may be gradually replaced in supersonic and missile markets by higher temperature materials such as titanium or boron epoxy composites and in more conventional markets by aluminium probably on cost grounds.

In the other subgroup of the structural sector: general engineering applications, magnesium exhibits a relatively higher price elasticity of demand the market being dominated by the cheap general purpose commercial alloy AZ91B[32]. Individual markets include consumer durables, where magnesium participates when lightness with strength is at a premium, industrial machinery and tools, where in addition magnesium's damping abilities and high machining speeds are of value, and surface vehicles. This last area is the most significant and is the only one discussed further[33].

Magnesium was expected to make great inroads into the automobile industry after the second world war. Demand - primarily for AZ91B - has however been relatively stagnant in the face of strong competition from aluminium and plastics. Uses in the U.S. have been mainly in low volume applications such as fuel lamp housings, oil seals, and transmission parts. Elsewhere in the world however magnesium is beginning to find wider acceptance by the automobile industry mainly in the form of pressure die castings. Although a unique case the Volkswagen company is the world's single largest private consumer of magnesium alloys[34]. From 1949 when just over three hundred tons of magnesium went into that year's 'Beetle' production, consumption steadily increased until in 1969 Volkswagen were using more than 100 tons per day. Each car produced uses over 40 lbs of magnesium for the 1200 'Beetle' and about 50 lbs in the 1600 saloon. The reason for such intensive use of magnesium components lies in the unusual design of the 'Beetle'. As the car is powered from the rear a lightweight engine material had to be employed to equalise axle load distributions and improve steering and road holding characteristics. In 1969 Porsche also introduced a magnesium crank case in their 911 sports model using a high temperature (AZ81) alloy.

The main field for die cast magnesium outside such engine and transmission parts has been in the production of wheels. Fiat were the first to use magnesium alloy wheels on a production car although magnesium alloy wheels have been used in racing and rallying for many years. Finally magnesium is suitable for much wider innovation in the walls, floor and frames of commercial vehicles. The use of magnesium in this role would improve vehicle handling, reduce delivery time and petrol consumption.

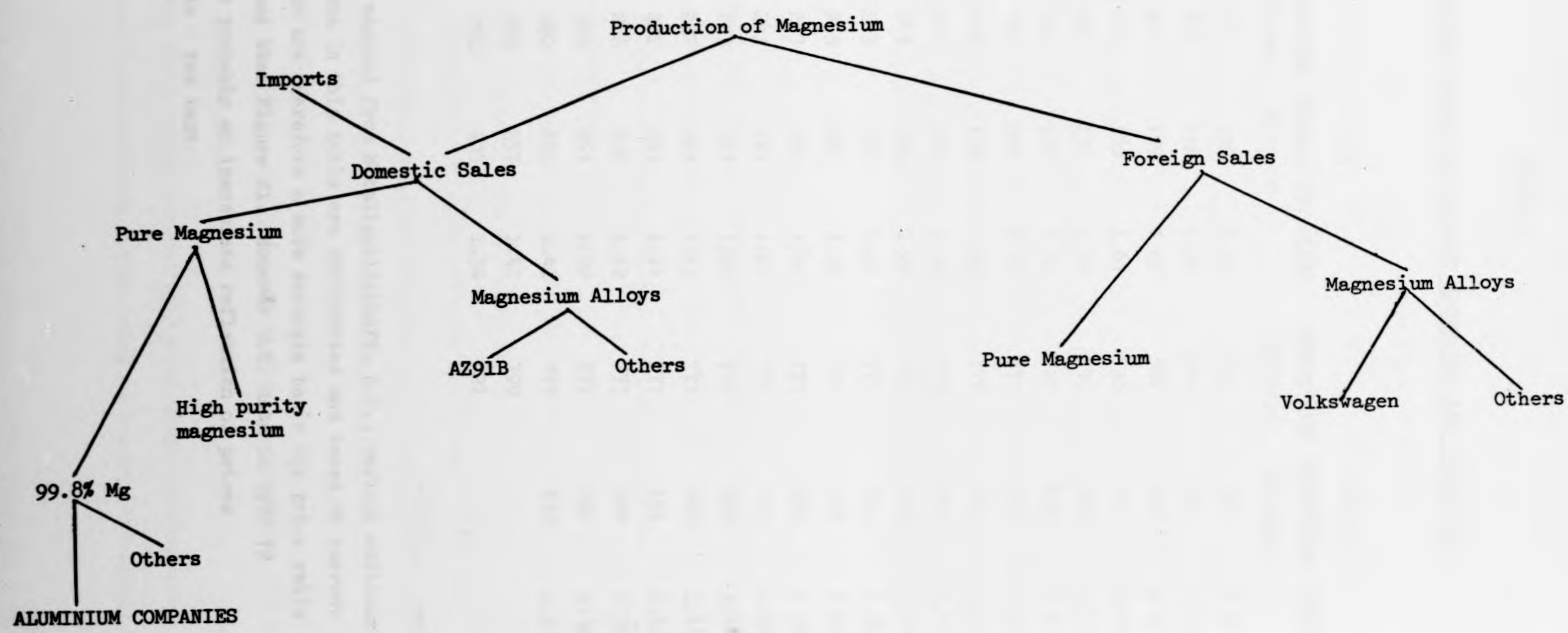
23:3 Chemical, Sacrificial and Miscellaneous End Uses

This sector accounts for approximately a third of current U.S. and a quarter of U.K. magnesium consumption. There are five important sub categories: reduction of other metals, scavenger in iron and steel production, organic chemicals production, rapid oxidation and electrochemical uses. The absolute amounts of magnesium consumed in these applications is individually fairly small, often subject to a low price elasticity of demand, and in certain cases dependent on the derived demand for other metals such as titanium, zircon, and ductile cast iron. Although individual uses are technically interesting their diversity prevents further immediate discussion[35].

2:4 Behavioural Analysis

Examination of market behaviour in the magnesium industry is complicated by the variety of production techniques, the significance of individual suppliers, the segmentation of markets and the power of individual consumers. Nevertheless a

FIGURE 15: FLOWCHART FOR U.S. MAGNESIUM MARKETS



Source: Adapted from Charles River Assoc. (1967), op.cit.

TABLE 6

POSTWAR PRICES OF PRIMARY MAGNESIUM AND ALUMINIUM

	U.K.			U.S.A.		
	Magnesium £/tonne	Aluminium £/tonne	Ratio	Magnesium $/Tonne	Aluminium $/tonne	Ratio
1951	254	126	2.02	540	397	1.36
1952	309	158	1.96	540	406	1.33
1953	320	159	2.01	587	434	1.35
1954	266	159	1.67	595	445	1.34
1955	254	170	1.49	650	483	1.35
1956	254	193	1.32	747	530	1.41
1957	276	200	1.38	777	560	1.39
1958	276	187	1.48	777	547	1.42
1959	243	183	1.33	777	545	1.43
1960	243	189	1.29	777	573	1.36
1961	243	189	1.29	777	561	1.39
1962	243	184	1.32	777	526	1.48
1963	243	184	1.32	777	499	1.56
1964	243	194	1.25	777	523	1.49
1965	243	199	1.22	777	540	1.44
1966	232	199	1.17	777	540	1.44
1967	232	203	1.14	777	551	1.41
1968	266	238	1.12	777	564	1.38
1969	309	253	1.22	777	599	1.30
1970	360	255	1.41	777	633	1.23
1971	363	257	1.41	799		
1972	353	235	1.50	821		

Source: adapted from Metallgesllschaft, A.G., various editions

Note: Data in this table are unconverted and based on current prices and are therefore a more accurate basis for price ratio comparisons than Figure 21. However U.K. data in 1970-72 period is probably an inaccurate reflection of prices obtainable - see text.

conceptual abstraction for international trade in magnesium can be distinguished if a number of simplifying assumptions are initially imposed. Discussion in the present chapter is therefore primarily concerned with pricing policy within the existing industrial structure and discussion of long term growth problems is temporarily postponed. Figure 15 summarises the flow of magnesium to the various sections of the U.S. market. Some preliminary information on production costs has already been referred to (in Appendix E). Prices of primary (998) metal are given in Table 6. The peculiar characteristics of the various market sectors necessitates individual discussion. In each case however several hypotheses of market behaviour are posedand evaluated. Specific hypotheses which seek to explain the divergence between apparent total production costs and market price are:

1. Quantity discounts may be granted to high volume and long term customers reflecting the lower costs of dealing in large quantities and guaranteed production, that is to say the posted price is 'unrepresentative'.
2. Low prices may be charged in markets with more elastic demand characteristics.
3. Differential pricing policies are aimed at stimulating long run demand.
4. Differential pricing policies are designed to reduce entry threats.
5. Differential pricing policies are the result of monopsony.

In the first market sector: sales to aluminium companies proposition 1 is certainly corroborated in recent investigations and appears plausible since aluminium companies are large and regular buyers of standard quality 998 magnesium. But it is believed that not all large customers get such quantity discounts: other factors may also be significant. Since the demand for magnesium to alloy with aluminium is broadly inelastic over historic price ranges and at existing Mg/Al proportions in such alloys, proposition 2 is rejected. But clearly if demand is inelastic then given a tightly oligopolistic supply situation, higher prices should eventually result. Proposition 3 therefore merits attention. If long run demand for magnesium were to be appreciably altered the aluminium industry's magnesium demand curve would have to be shifted. But there is no evidence to suggest that price manoeuvring has encouraged the development of more magnesium intensive alloys and in the interim proposition 3 is therefore rejected. Whilst aluminium companies are apparently fairly unresponsive to moderate price movements in magnesium, in the long term their effect could be an extension of the 'captive' production arrangement presently experienced in the U.K., France, and Norway. Proposition 4 may be of some importance therefore in the large American market. The main barrier to entry is the high capital cost to a newcomer who has to compete with existing producers under the conditions described in Chapter Two. Proposition 4 is provisionally accepted and it is consistent also with proposition 5: that the aluminium companies exert monopsony power - in the form of an entry threat[36].

In the second major market sector: the structural market for magnesium pricing policy appears to differ in the special and general engineering areas. The latter is the major market for commercial magnesium alloys. In the former as has been noted technical properties are most important such that demand is

TABLE 7

PRODUCTION AND CONSUMPTION OF MAGNESIUM ALLOYS, AND ANNUAL AVERAGE PRICE (U.S.)

YEAR	PRODUCTION	CONSUMPTION				AVERAGE PRICE
	Tonnes	Tonnes				$/tonne
		Sand Casting	Die Casting	Permanent Mould	Total	
1960	2087	2324	1386	676	4386	670
1961	3675	2185	1205	586	3976	637
1962	6124	3143	3321	818	7281	465
1963	6896	2976	5063	1270	9309	628
1964	6896	2022	4316	664	7003	661
1965	6986	2685	5080	739	8503	661
1966	8483	3594	4518	573	8686	661

Source: Adapted from CRA (op.cit.), 118.

generally inelastic with respect to price, and in the absence of detailed evidence it appears probable that the producers operate within the official price schedule. The situation is markedly different in the general engineering sector however where demand for magnesium tends to be much more sensitive to price. In addition it has been remarked that pricing policy in relation to AZ91B, the major general purpose alloy has been apparently at variance with policy for other general engineering alloys.

Aside from Volkswagen it seems improbable that proposition 1 is of much significance in the general engineering sector over the long term. Small orders from a fragmented market also reject proposition 5. In favour of hypothesis 3 it has been pointed out[37] that in 1960 Dow chemical specifically reduced the price of AZ91B from 37c to 30c/lb although as Table 7 shows, consumption of magnesium castings actually dropped in the following year. However over the long term price adjustment in competitive areas is obviously a useful means of stimulating demand, even where the highly segmented nature of demand in this sector suggests that such price reduction may not have a universally profitable effect. On this interpretation proposition 2 is partially rejected and proposition 4 is examined as a residual hypothesis. Table 8 appears to confirm that, at least in U.S. export markets, considerable discretion in pricing is practised. Indeed in such relatively competitive areas magnesium is sold at prices frequently below domestic U.S. prices. Such behaviour may be more complex than simple reaction to possible entry threats. Three contributory factors are considered relevant:

(i) U.S. magnesium is occasionally 'dumped' abroad to promote a stable domestic price and demand structure.

TABLE 8

IMPLIED[1] COST OF U.S. EXPORTS, 1955 - 66, BY COUNTRY
(in cents per pound)

	Canada	Mexico	Norway	U.K.	West Germany	Japan	Total[2]
1955	57.5	29.2	42.1	41.5	26.8	30.5	28.8
1956	96.8	30.9	43.2	36.6	39.8	33.8	33.1
1957	55.6	38.1	43.4	43.5	31.9	47.8	46.1
1958	138.0	121.0	0	248.5	35.3	0	54.6
1959	17.9	28.8	0	29.1	25.8	0	27.5
1960[3]	35.1	27.5	28.1	28.1	28.0	77.2	29.8
1961	29.2	27.4	0	28.0	29.2	0	29.5
1962[3]	28.9	27.3	0	28.3	27.9	0	28.4
1963	26.0	27.7	0	28.4	28.0	29.5	28.0
1964	28.0	28.6	28.0	29.0	27.7	28.4	27.7
1965	34.3	32.8	28.0	28.9	27.6	28.8	28.8
1966	36.4	30.4	39.7	32.3	27.8	30.3	29.7

1. Value of each country's imports of magnesium from U.S. divided by quantity of imports

2. Value of total U.S. exports of magnesium divided by quantities of total exports.

3. Unrevised data.

Source: Bureau of Census, U.S. Exports of Domestic Merchandise 1955 - 1965, FT 410

(ii) Unusually high prices reflect technical premiums for certain special purpose alloys.

(iii) 'Once-off' contracts may be negotiated at concessionary price levels.

It should also be noted that at least in the German market proposition 1 is considered relevant.

There is little evidence to suggest that the 'horse trading' atmosphere that surrounds magnesium sales to aluminium companies and to the structural sector exists in other sectors of the market. Individual markets, for example in organic chemical synthesis, commercial pyrotechnics etc. are far too small for effective bargaining powers to be exercised by consumers. There is little likelihood of an entry threat specifically to supply this sector of the market and demand is often inelastic where technical premiums are high and where the cost of magnesium is small in relation to total production costs. Proposition 2 therefore appears to provide an acceptable price determining mechanism in this area.

As a conclusion to this section, therefore, it would appear that market behaviour in the U.S. magnesium industry, the world's only diversified national magnesium market and a possible prototype for future developments elsewhere, is conditioned by two potentially conflicting influences. On the one hand there is a desire to maintain a conservative home market protected if necessary by tariffs, quotas and other informal means of trade restriction[38]. On the other hand there is a growing desire to promote an export market which can only flourish in an atmosphere of free international trade. It is arguable that the territorial trade philosophies adopted by the magnesium producers have adversely affected both development of existing markets and, through dynamic conservatism (see page 38), further diffusion of magnesium in new market areas.

3. CASE STUDY TWO: THE BASIC REFRACTORIES INDUSTRY

This case study is concerned with an industry which processes a group of minerals, including dolomite, for manufacture as basic refractory bricks. The definition of such industrial minerals was examined in Chapter One and this section attempts to isolate the complex interplay of technological and economic factors which effectively determine raw material suitability in a well defined industrial application.

Refractories are simply:

"heat resistant materials that provide the structure or linings for high temperature furnaces and reactors. In addition to being resistant to thermal stress and other physical phenomena induced by heat, refractories are usually required to withstand physical wear and corrosion by chemical agents"[39]. Their importance has been summarised by Kusler and Clarke (1969): "Refractories are as essential to pyrochemical and pyro metallurgical reactions as the materials being processed. Without them no economically practicable way of maintaining high processing temperatures is feasible".[40]

A crude classification of refractories is widely used which is based on their chemical affinities: refractories are either acidic, basic or amphoteric (neutral). Acid refractories such as silica are therefore not generally used in reaction vessels likely to contain basic reaction materials such as high magnesia slags. The common acidic refractory raw materials are silica, fireclay, intermediate and high alumina materials. Basic refractory materials include: dolomite, magnesite, magnesite-chrome, chrome-magnesite and zircon[41]. It is important to note that in particular applications, usually because of the chemistry of the consuming industry's process methods, basic and non basic materials are fundamentally incompatible. As is explored in detail in subsequent sections however, changes in the technology of the consuming industry may create opportunities in new processes for basic refractories to be employed. For example, broadly speaking basic refractories are more 'refractory' than acidic varieties in that most have fusion points in excess of 2000^{o}c as compared with temperatures of up to 1700^{o}c for most acidic refractories. Where a corresponding shift in the chemistry of the process reaction involved also occurs, shifts to higher operating temperatures may dictate the use of basic materials. In this study therefore, passing attention is given to the non basic sectors of the refractories industry for the broad purpose of statistical comparison. The common end product form of processed refractory materials is the refractory brick[42].

3:1 Structural Analysis

By way of introduction, the following features are considered characteristic of the structure of the basic refractories industry in the UK[43]:

(i) The industry is dominated by a tightly oligopolistic supply and monopsonistic demand pattern

(ii) The market for basic refractories is predominantly national, exports constituting an historically small but increasingly significant part of the total

(iii) The basic refractories producers typically manufacture a wide range of all types of refractory although there survive many small, local specialised producers of non basic refractories

(iv) The industry is increasingly, but not traditionally capital intensive

(v) The industry is substantially influenced by the cyclical demand for steel

(vi) Integration from quarry to end product distribution is not uniform

(vii) The industry is unusually sensitive to technological innovation and excellent channels for diffusion exist.

(viii) Diversification is taking place amongst the major producers.

31:1 Producer Structure

The refractories industry is defined in the standard industrial classification under minimum list heading 461/1. In the 1968 census of production 44 enterprises were recorded on this basis. Table 9 is a more recent though not exhaustive summary of U.K. refractories manufacturers. 32 enterprises are listed in this table: those outstanding have either gone of out business or are more probably small specialist producers. Some general statistics on the industry are recorded in Table 10.

There are broadly two types of refractory producer - the large diverse manufacturer and the small, local, specialist. Only the former now produce basic refractories in significant quantities for the following reasons:

(i) The implications of a long term trend towards decreasing total refractories consumption in part due to improved steelmaking practices and in part to the development of superior refractories.

(ii) A demand for better, more reliable refractories which could only be guaranteed through improved manufacturing methods, greater emphasis on research and development, greater capital intensity and so on, which in turn could only be undertaken in larger groupings with access to the greater capital resources necessary.

There are three major and one small, but significant, domestic participants in the U.K. basic refractories industry: G.R. Stein

TABLE 9

U.K. REFRACTORIES MANUFACTURERS

Small Companies: independent specialists		Small Companies : part of larger organisations			Large Companies [1]
Name	Products	Name	Parent	Products	Name
Alconite Refs	M	Adams Pict	Adamsez	F,I	J & J Dyson/Dyson [2]
Astbury Silica	F,S	Bonnybridge Refs	Scotcros	F,HA	GR-Stein/Hepworth Ceramic
Bowens Refs	F	Consett Refs	British Steel	F,HA,B	Steetley
Burn Fireclay	F,HA	Carborundum (UK)	Carborundum (USA)	S	
Craigend Refs	F,HA	DSF Refs	WGI	S,HA,I,M	
		Douglas Firebrick	A.P.Green (USA)	F,HA	
J Hall Refs	F,HA	FF Refs	FF		
J Hewitt	F	Gibbons Refs	Gibbons Dudley	F,HA,I,O,M	
G. Johnson	M	J. Gimson	Norton (USA)	S	
Midland Monolithic	M	A.P. Green (UK)	A.P. Green (USA)	M	
Newbold Refractories	F,HA	Kaiser Electron	Kaiser/Electrorefractaire	M	
Parkinson & Spencer	G	Kingscliffe Insulating	Marshall	I	
Purimachos	M	T. Marshall	Marshall	C	
Refractory Furnace	M	Moler Prods	Marshall	I	
Silbond	M	Morgan Refs	Morgan	M,S	
W. Wild	S,M	Norton Abrasives	Norton (USA)	S	
Williamson Cliff	F,HA,M	Refractory Mouldings	Senior Engineering	P	
		Sneyd Brickworks	G.H. Downing	HA	
		United Fireclay	Gibbons Dudley	F,HA,M	
		T. Wragg	Gibbons Dudley	C	

Key: M = monolithics
HA = high alumina
I = insulating
C = casting pit
S = special
P = precast, refractories
F = firebrick
B = basic
S = silica
O = olivine
G = glass industry, refractories

[1] all produce complete range of refractory products
[2] includes the following subsidiary (refractory) companies: J. Dougall, J. Knowles, Pickford Holland, Price-Pearson

Source: Adapted from Industrial Minerals (1972) October, 31.

TABLE 10

THE REFRACTORY GOODS INDUSTRY: GENERAL STATISTICS

Extracts from Censuses of Production for 1954-1968 Refractory Goods - subdivision of the Bricks, Fireclay and Refractory Goods Industry.[1]

		Unit	1954	1958	1963	1968
Number of Enterprises		No.	88	73	64	44
Number of Establishments		No.	147	149	130	111
Sales of Characteristic Products		£,000	26,218	32,411	37,510	54,211
Index of Specialisation		Percent		95	95	93
Total Purchases		£,000	12,063	16,890	18,697	29,107
Total payments to other organisations		£,000	2,949	3,180	2,793	3,637
Gross output		£,000		35,640	40,436	61,220
Net output		£,000	12,836	15,722	19,035	28,462
Net output per head		£	784	998	1,407	2,039
Total average number employed during year		No.	16,369	15,749	13,525	13,956
capital expenditure on: new building work		£,000	312	626	316	930
Land and existing building	(acq.	"			23	50
	(disp.				64	237
Plant and machinery	(acq.	"	832	1,569	1,540	2,618
	(disp.	"	12	23	62	81
Vehicles	(acq.	"	95	48	52	86
	(disp.	"				

1 No separate information available for Refractory Goods in 1970 Census

(part of the Hepworth Group), the Steetley Company, Pickford Holland (part of the Dyson Group) and the Consett Division of the British Steel Corporation. Some information on the major companies is contained in Table 11. It is important that whereas

TABLE 11

SOME RECENT STATISTICS ON THE MAJOR REFRACTORIES PRODUCERS

	G.R. Stein/ Hepworth[1]	The Steetley Co.[2]	Pickford Holland/ J. & J. Dyson[1]
Turnover Total	71,270	66,488	14,740
Refractories Turnover	20,422	N.A.	12,780
Profit before Taxation Total	9,026	6,014	1,289
Profit attritubale to refracts.	2,052	N.A.	1,363
Earnings per share	4.7p	9.5p	1.8p
Capital Employed	61,160	48,129	5,204
Number of employees	11,800	4,980	2,519
Exports	7,486	6,568	2,626

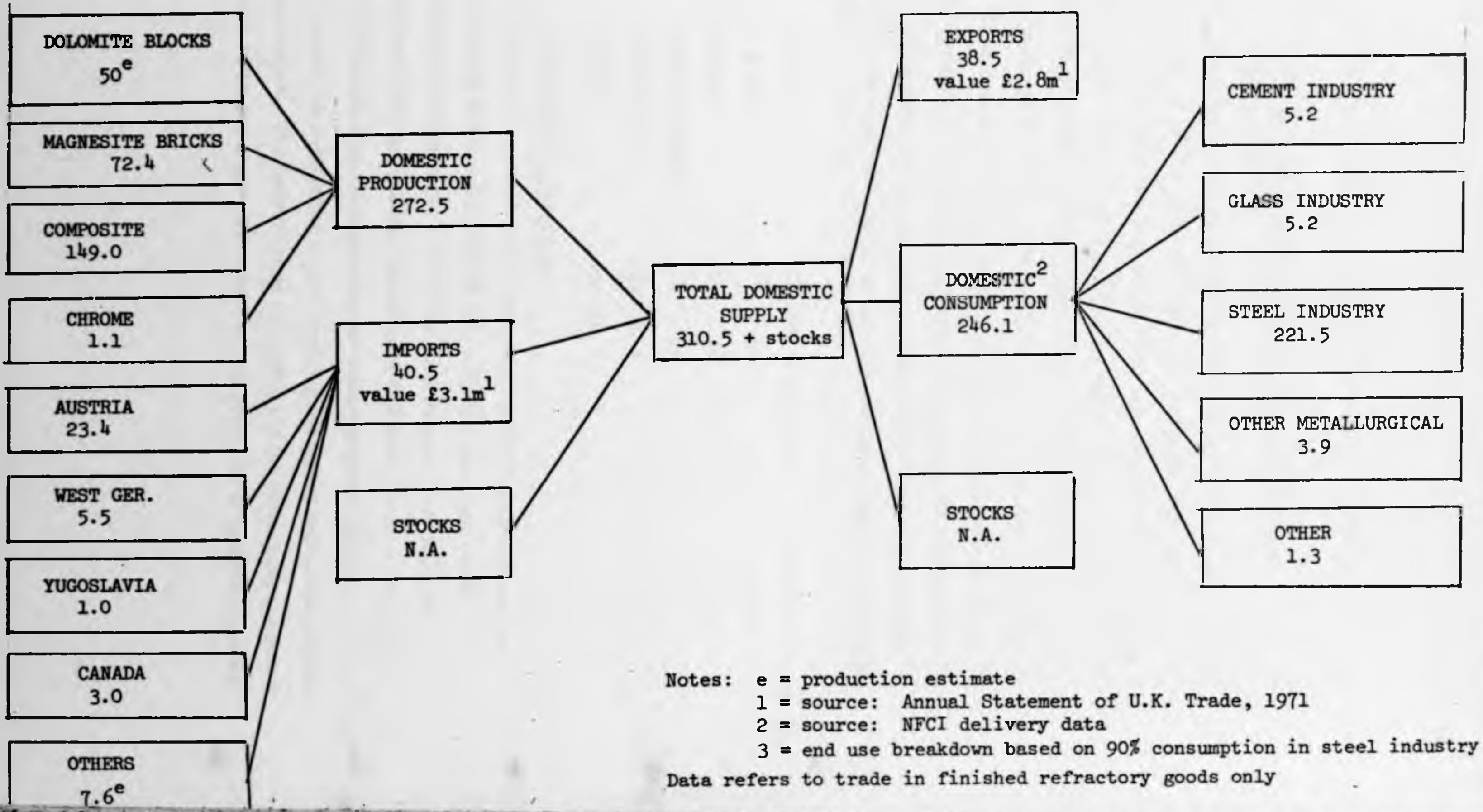
[1] to year ending 31st March 1972

[2] to year ending 31st December 1971. Figures are in £'000 unless otherwise indicated.

Source: company reports, various.

G. R. Stein are the largest U.K. basic brick makers, they either import most of their basic raw materials or buy from the Steetley company. This latter has a monopoly of current U.K. sources of high grade dolomite and sea water magnesia, as well as a part interest in a high quality Sardinian sea water plant. It is believed that Pickford-Holland have also traditionally bought in their raw materials. The Consett Brick Company became part of the British Steel Corporation with the nationalisation of the steel industry in 1968. In terms of absolute output the company's basic refractory contribution is insignificant but in terms of

FIGURE 16: FLOWSHEET OF SUPPLY AND DEMAND IN THE U.K. BASIC REFRACTORIES INDUSTRY, 1971, THOUSAND TONNES



Notes: e = production estimate
1 = source: Annual Statement of U.K. Trade, 1971
2 = source: NFCI delivery data
3 = end use breakdown based on 90% consumption in steel industry

Data refers to trade in finished refractory goods only influencing market behaviour the company occupies an important position.

31:2 Supply and demand in the basic refractories industry: structural aspects

A flow sheet illustrating the supply and demand pattern for finished basic refractories in 1971 is given in figure 16. Although there is a significant raw materials import trade in magnesite (calcined and dead burnt) and chrome very little dolomite of refractory grade is imported[44]. Imports of finished refractory bricks however contribute 13% of overall total consumption. There is no published information available on the function of stocking and destocking activities in the overall supply and demand pattern although as is discussed subsequently such activities must be important in the light of the cyclical demand pattern for steel products. Approximate market shares for the major domestic companies are:[45]

Company	All basic products (%)	dolomite products (%)
G R Stein	35	40
Steetley	30	40
Pickford Holland	25	-
Consett Brick	approx. 5	20
Imports	approx. 5	-

3:2 Technological Background

Refractories are materials which tend traditionally to be consumed in large volumes and which command only a modest price per tonne. Recently major consumers such as the steel industry have indicated a willingness to pay for quality improvement and there is now a long term trend in evidence towards more expensive products with superior performance characteristics in turn implying decreased total consumption of refractories. The technological background to the refractories industry is therefore increasingly concerned with the provision of optimum levels of end product performance under varying economic and technical manufacturing and service conditions. This interplay of technical and economic factors is of considerable importance in the estimation of long term raw materials requirements.

At the present time only five raw materials[46] are technically and economically suitable for basic refractory manufacture. These are dolomite, magnesite, sea water magnesia, chrome and tar. Dolomite and magnesite are both quarried and then dead burnt in rotary kilns at temperatures in excess of 1600°C to drive off as much carbon dioxide as possible. The kiln product may be crushed and ground and in the case of magnesite subject to various upgrading processes such as magnetic separation or froth flotation, to produce a suitable raw material for brick manufacture. Sea water magnesia is produced by reacting the highly insoluble magnesium salts present in sea water with lime, or doloma, to yield magnesium hydroxide which is then calcined in rotary kilns. About 1.5 tonnes of dolomite are required to produce 1 tonne of sea water magnesia compared with 2 tonnes of natural magnesite to yield one tonne of magnesia. Chromite may be quarried,frequently from awkwardly distributed ores in metamorphic serpentinite type rocks. Contamination of raw material with silica is virtually unavoidable and ore dressing techniques are usually employed. Major sources of chrome are the Transvaal and the Philipinnes.[48] The increasing use of tar bonded and impregnated basic refractories has elevated the significance of tar as a refractory constituent to the extent that a great deal of interest has recently been shown in achieving tar compositions which conform to specification. In general the tar is a by product of the destructive distillation of coal.[49]

The most common form of refractory end product is the refractory brick. Bricks are manufactured from ground and sized raw materials by placing them in a suitable mould, 'forming' them by subjecting them to high pressures and firing them in a kiln. The overall aim is to produce, as economically as possible, a brick with wearing properties ideally consistent with the properties of its granular constituents. To prevent ingress of the agents of wear to the brick such as steelmaking slags in service, it has been found desirable to accommodate for the imperfections of the brick in terms of pores, microfractures and the like, either by bonding or impregnating the bricks with tar. In particular impregnation can dramatically improve refractory performance. There is however a technical economic optimum for each product beyond which further improvements in performance through lower porosity and higher density can only be achieved at incrementally greater costs of impregnation and processing. The tendency towards higher firing temperatures in line with higher temperature service requirements is subject to similar technological economic considerations[50] although the innovation of the semi continuous tunnel kiln has greatly facilitated the achievement of superior refractories. Hydraulic presses have also increased in power with greater throughputs. Substantial improvements in quality control have resulted.[51]

Accurate current information on refractory prices, raw material costs, and value added are understandably difficult to obtain, and such information as is available is at best only an order of magnitude indication. Dolomite suitable for brick making purposes is believed to be sold, already dead burnt and ground at £16/tonne delivered.[52] Sea water magnesia of brick making quality sells at approximately £27-30/tonne although concessionary prices are obtainable in large volume contracts. The price of imported natural dead burnt magnesite is very variable, being dependent upon country of origin, quality, and quantity demanded. Prices of the order of £55-85/tonne delivered to U.K. destinations appear reasonable in the absence of detailed information. Table 12 details some recent price information for

TABLE 12

PRICE COMPARISONS:[1] U.S.A. AND U.K. BASIC OXYGEN FURNACE REFRACTORIES

	U.S.A.		U.K.		
TYPE	$ short ton	Ratios	£/l.t.	$ short ton	Ratios
Tar-bonded dolomite	115	1.00	24.5	52	1.00
Tempered dolomite	124	1.08	-	-	-
Toughened dolomite	-	-	34.5	74	1.41
Tar bonded magnesite (80-85%)	1.47	1.28	-	-	-
Tempered magnesite	156	1.36	-	-	-
Tar bonded periclase (90 + %)	178	1.55	70	150	2.86
Tempered periclase	187	1.63	-	-	-
Tar-impregnated dolomite	180	1.56	44	94	1.80
Tar-impregnated periclase	250	2.10	94	201	3.84

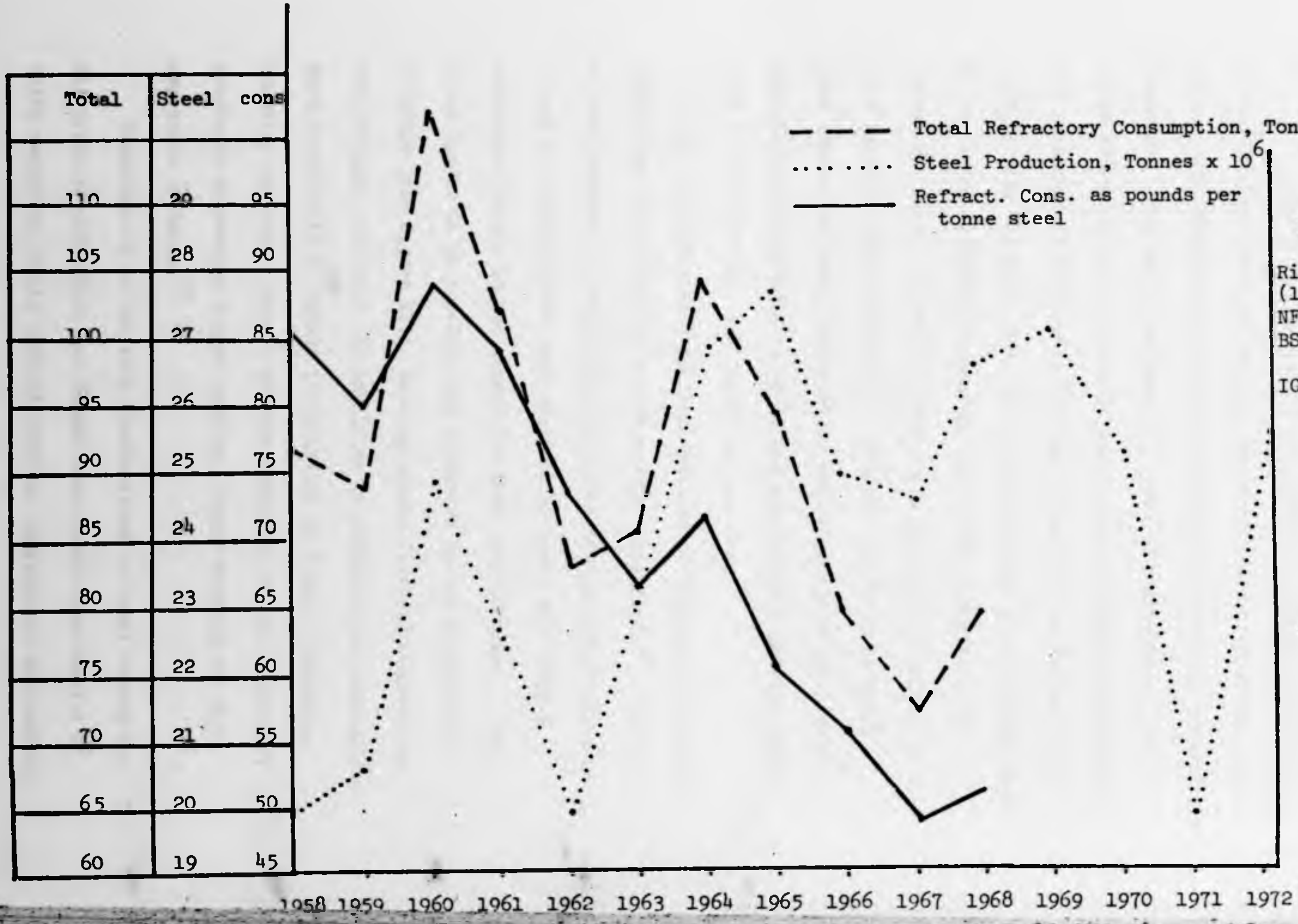
[1] 1968 prices: now considerably out of date but ratios probably still fairly accurate.

Source: Forchheimer O.L. and Charlton E. op. cit., 92

finished refractory products by category. It should be noted that in addition to bricks a wide variety of formed refractory shapes are manufactured, as well as castable refractory linings, refractory mortars and cements.

Finally the technical background to the end uses of refractory products is reviewed in Appendix F.

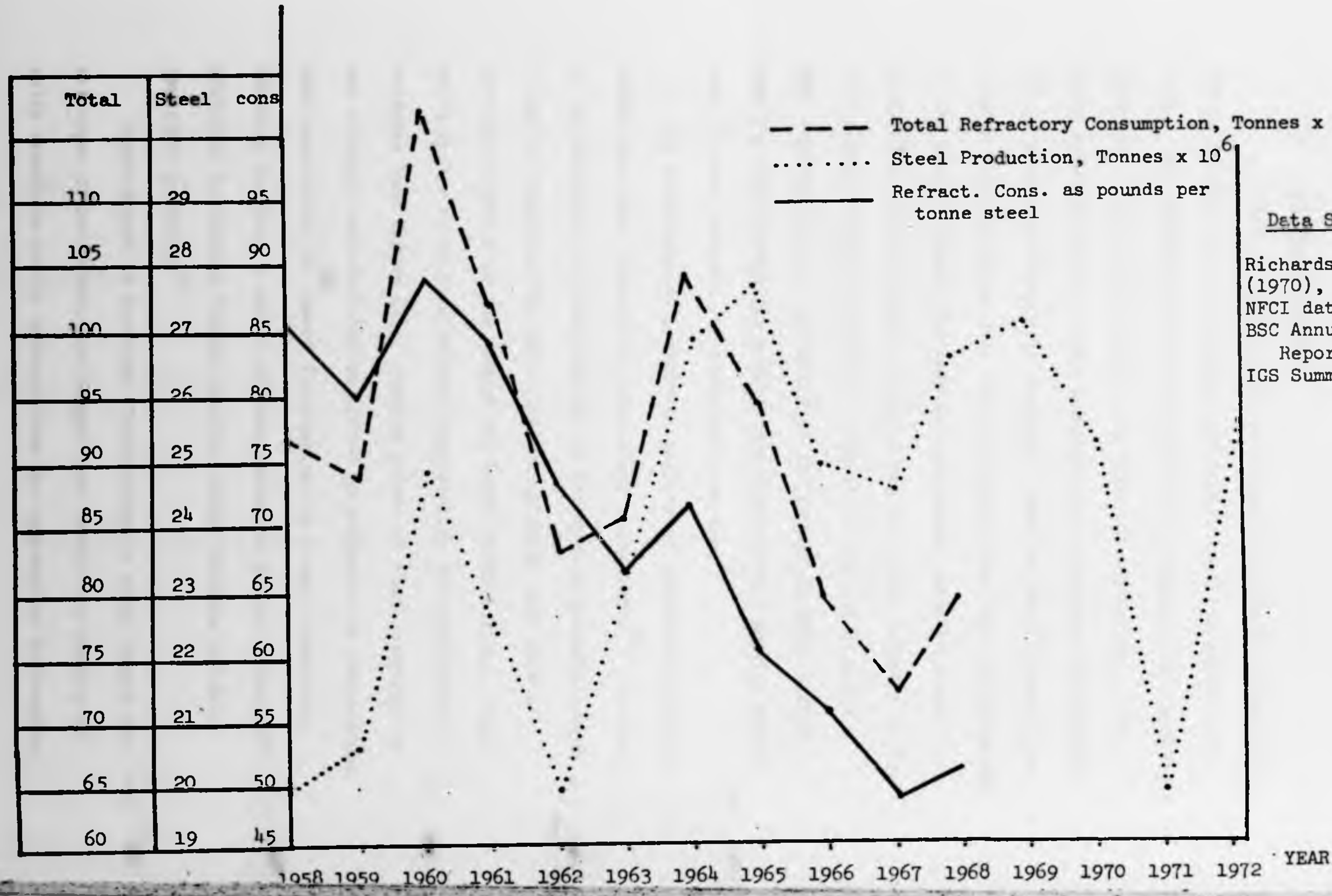
FIGURE 17: U.K. STEEL PRODUCTION, REFRACTORIES CONSUMPTION IN STEEL (TOTAL AND POUNDS PER TONNE STEEL PRODUCT)



Data Sources:

Richardson, H.M. (1970), op.cit.
NFCI data,
BSC Annual Reports,
IGS Summary

FIGURE 17: U.K. STEEL PRODUCTION, REFRACTORIES CONSUMPTION IN STEEL (TOTAL AND POUNDS PER TONNE STEEL PRODUCT)



Data Sources:

Richardson, H.M. (1970), op.cit.
NFCI data,
BSC Annual Reports,
IGS Summary

3:3 End Use Analysis[53]

Table 13 details the percentage of annual refractories production delivered to various industries over the period 1958-1969. The dominance of the iron and steel industry is immediately apparent. The table includes all types of refractory. For basic refractories the steel industry alone consumes approximately 85% of annual production on average. Most of the following discussion will therefore deal with the market for basic refractories in the steel industry for whereas many other industries are occasional buyers of basic refractories the steel industry is the only regular large consumer.[54] Finally it should be noted that exports of basic refractories are proportionately higher than for the industry as a whole and constitute a growing market both for end products and technical know-how.[55]

The recurrence of a cyclical pattern of industrial activity within the steel industry is now widely recognised.[56] In view of the dominance of this industry on refractory demand patterns it may be expected that such cyclical activity will have a pronounced effect on the demand for basic refractories. This would appear to be conclusively supported by the statistical evidence (see figure 17): turning points in steel consumption are strongly reflected and amplified in refractories consumption. Such sensitivity to demand fluctuations in a major consuming industry has been a source of some incentive to the refractory producers to develop higher quality, longer wearing and more expensive products.[57]

Superimposed on the wide fluctuations in total demand for all types of refractory are longer term trends the details of which cannot be easily deduced from the aggregative information

TABLE 13

PERCENTAGE OF ANNUAL REFRACTORIES PRODUCTION DELIVERED TO VARIOUS INDUSTRIES (1958 - 1969)

INDUSTRY	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Iron and Steel	64.5	67.5	71.5	69.1	68.4	70.1	72.6	71.6)	70.8	69.6	72.9	75.7
Other Metallurgical	1.6	1.6	1.7	1.5	1.6	1.4	1.5	1.6)				
Carbonising	8.6	6.3	6.5	6.3	4.8	4.4	2.9	1.9	2.5	2.6	1.4	1.2
Glass	0.9	1.2	0.9	1.4	1.0	1.2	1.1	1.0	1.5	1.4	1.6	1.8
Electric Power and Railways	2.3	1.7	1.3	1.4	1.4	1.6	1.0	1.1	No data	No data	No data	No data
Cement	No data	No data	No data	No data	No data	No data	No data	No data	0.9	1.2	1.2	1.4
Others	13.8	14.7	12.1	12.8	14.8	13.6	13.9	15.0	16.2	15.0	13.4	10.6
Export	8.3	6.8	5.9	7.4	7.8	7.7	6.8	7.7	8.1	10.1	9.5	9.2

Source: Richardson, H.M. (1970) op. cit.

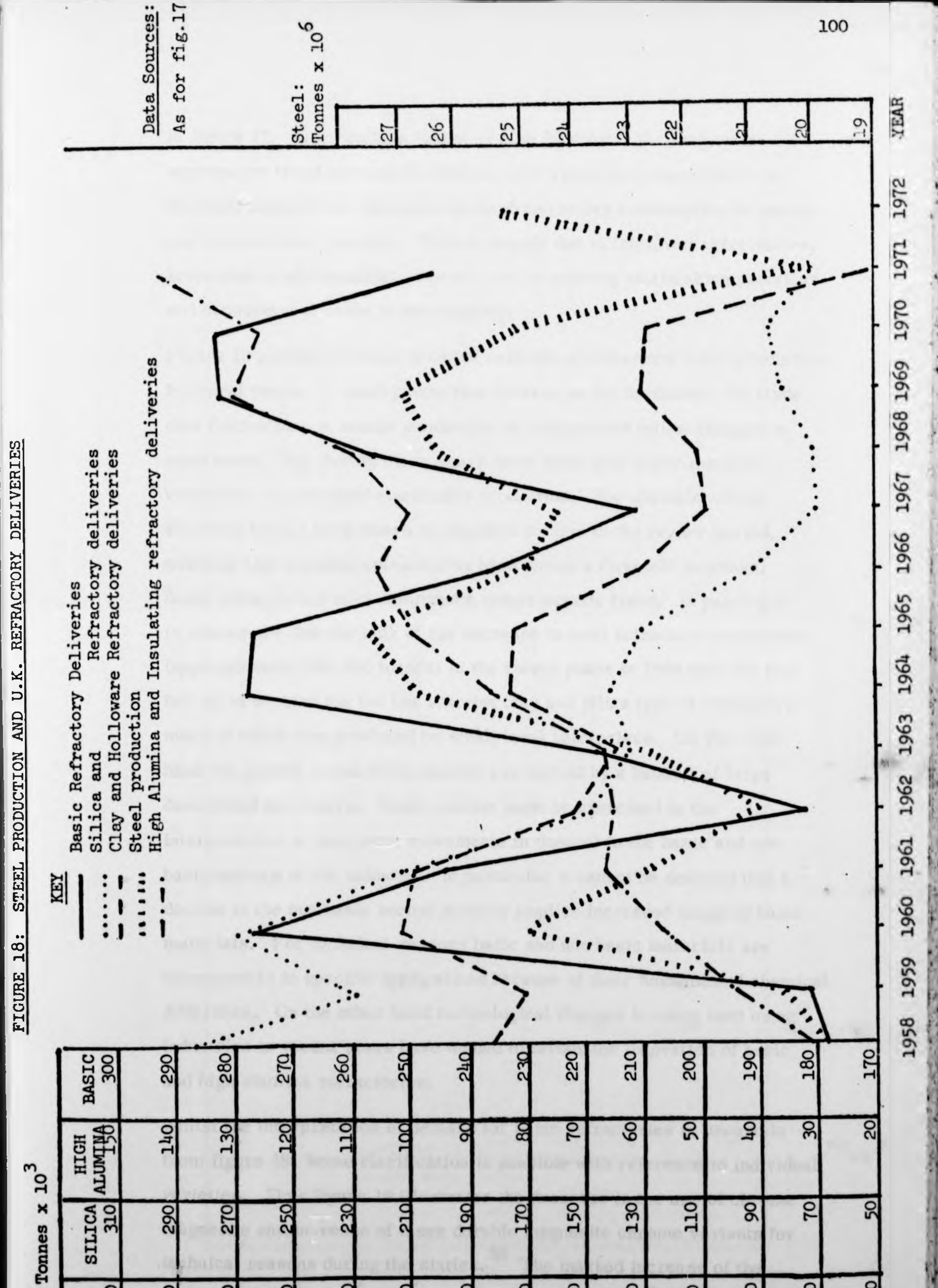


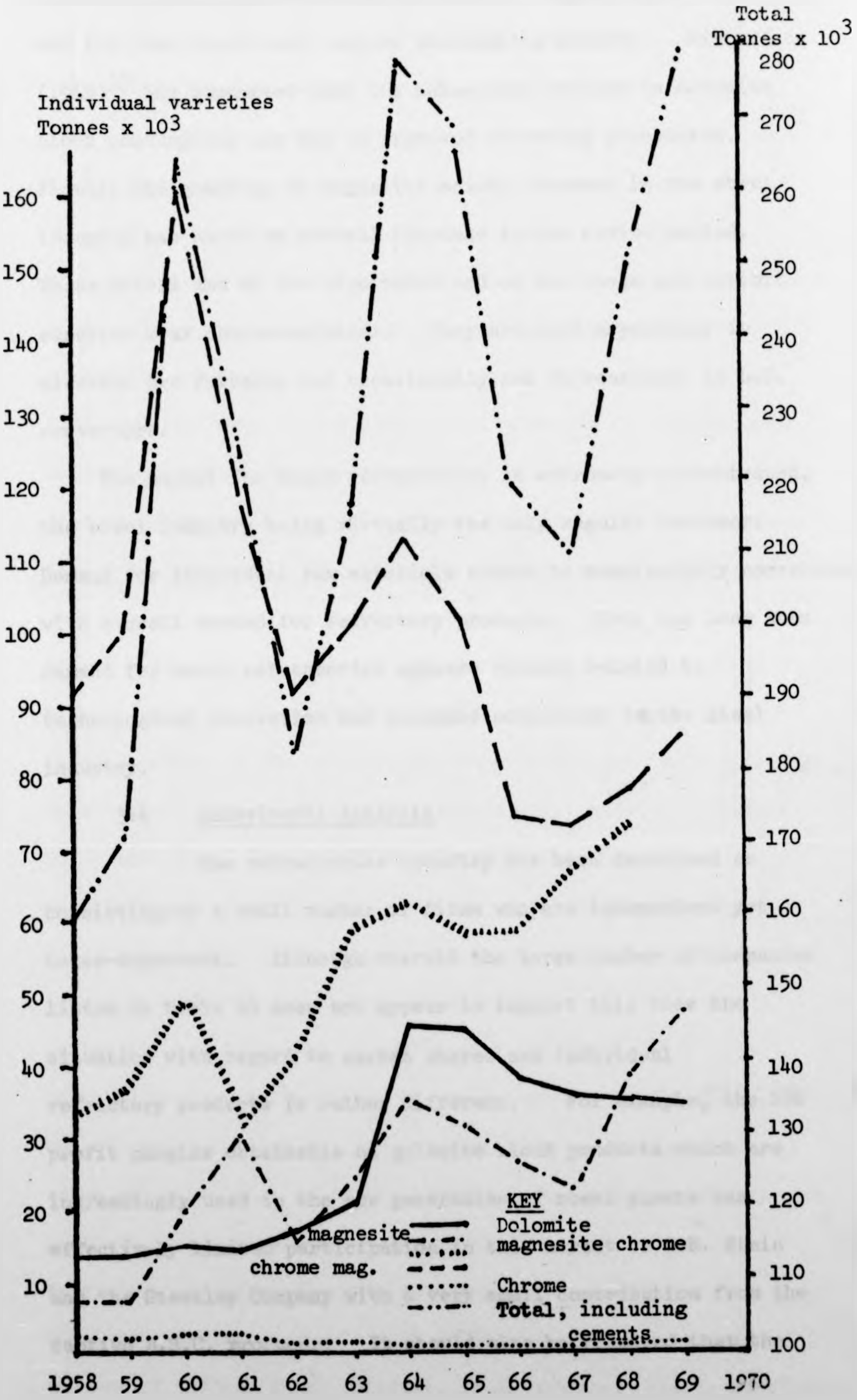
FIGURE 18: STEEL PRODUCTION AND REFRACTORIES DELIVERIES

in figure 17. Nevertheless figure 17 also illustrates the long term aggregative trend towards decreasing total refractory consumption in the steel industry as expressed by total refractory consumption in pounds per tonne of steel product. This is largely due to improved refractories, innovation in steelmaking, improvement in existing steelmaking practices and economics of scale in steelmaking.

Figure 18 provides a more detailed analysis of refractory brick production in recent years. If steel production is taken as the barometer for trade then fluctuations in annual production of refractories follow changes in steel trade. But during these years there have been superimposed variations in individual commodity production. For example silica/siliceous bricks have shown an absolute decline in the review period, whereas high alumina refractories have shown a threefold increase. Basic refractories have exhibited a rather erratic trend. In passing it is noteworthy that the bulk of the decrease in total refractory production (approximately 300,000 tonnes) in the eleven years to 1969 was due to a fall off in demand for the low alumina clay and silica type of refractory much of which was produced by small local enterprises. On the other hand the growth areas of the market are served by a handful of large diversified producers. Great caution must be exercised in the interpretation of long term movements in demand in the basic and non basic sectors of the industry. In particular it cannot be deduced that a decline in the non basic sector directly implies increased usage of basic materials. For technical reasons basic and non basic materials are incompatible in specific applications because of their fundamental chemical difference. On the other hand technological changes in many heat using industries in recent years have tended to favour the innovation of basic and high alumina refractories.

Whilst the interpretation of demand for basic refractories is uncertain from figure 18, some clarification is possible with reference to individual varieties. Thus figure 19 illustrates the decrease in the use of chrome magnesite and increase of more durable magnesite chrome variants for technical reasons during the sixties.[58] The marked increase of the tonnage of dolomite

FIGURE 19: TONNAGES OF BASIC BRICKS CONSUMED BY THE STEEL INDUSTRY



Data Source: As for Fig. 17

bricks consumed in 1964 coincided with the rapid diffusion of the L.D. and other basic oxygen steelmaking methods. Richardson (1968)[59] has suggested that the subsequent decline in dolomite block consumption was due to improved operating procedures. Finally the quantity of magnesite bricks consumed in the steel industry has shown an overall increase in the review period. These bricks are at the high price end of the range and exhibit superior wear characteristics. They are used especially in electric arc furnaces but occasionally and increasingly in L.D. convertors.

The market for basic refractories is extremely concentrated, the steel industry being virtually the only regular consumer. Demand for individual raw materials cannot be meaningfully correlated with overall demand for refractory products. Over the long term demand for basic refractories appears closely related to technological innovation and economic conditions in the steel industry.

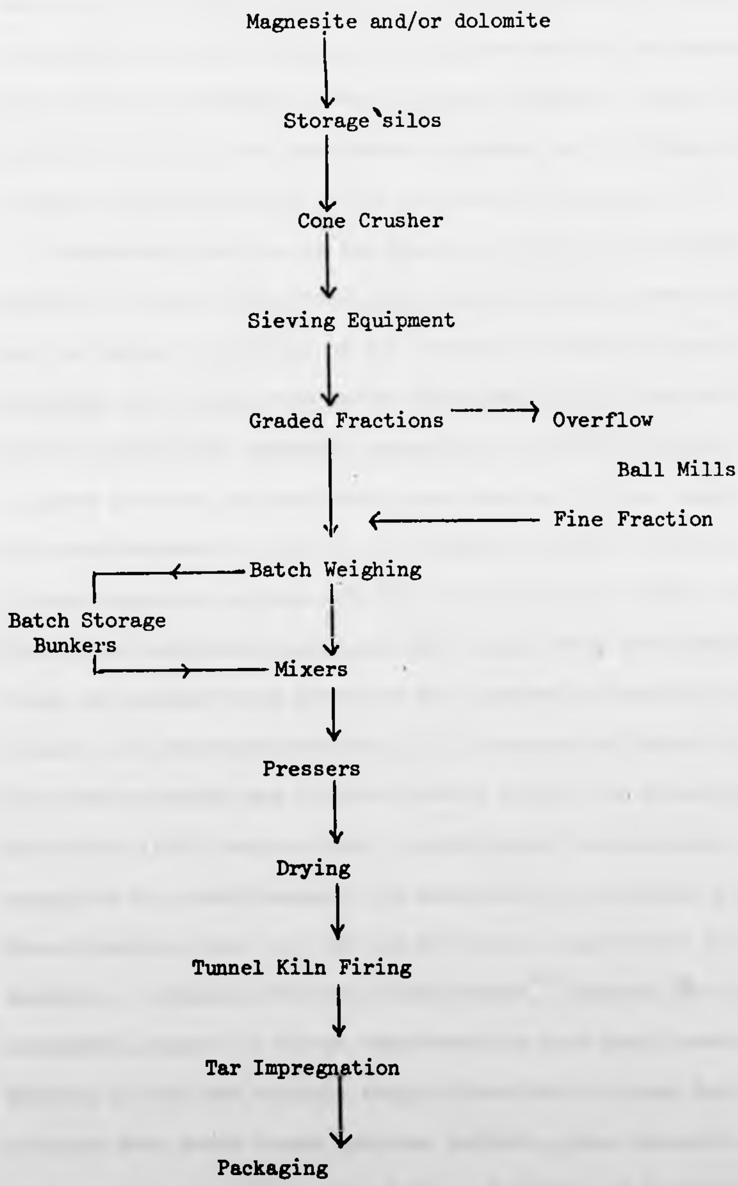
3:4 Behavioural Analysis

The refractories industry has been described as consisting of a small number of firms who are independent yet inter-dependent. Although overall the large number of companies listed in Table 10 does not appear to support this view the situation with regard to market shares and individual refractory products is rather different. For example, the low profit margins obtainable on dolomite block products which are increasingly used in the new generation of steel plants has effectively limited participation in this market to G.R. Stein and the Steetley Company with a very small contribution from the captive B.S.C. producer. It should also be recalled that the

Steetley Company have a monopoly of current sources of high grade refractory dolomite in the U.K. whereas G.R. Stein have no dolomite quarrying interests. The low profit margins in this area are at least partially attributable to the bargaining power which the largest single buyer, the British Steel Corporation, can exert on producers.[60] Additional, wider, pressure on producers could also eventually result from the possibility of the Corporation actually scaling up its own internal sources of refractory production.

Over the past fifteen years as steelmaking techniques have advanced to permit faster rates of production with vastly greater degrees of capital intensity, vessel availability[61] has become a decisive criterion. When demand is buoyant there is clearly considerable incentive to achieve maximum throughput, and in any case a high level of capacity utilisation is frequently assumed at the outset in the assessment of financial viability. At certain points in the steel cycle refractories cost will therefore be secondary to consideration of refractory quality. There is therefore strong incentive for refractories producers to continually develop new, or generally improved products and recent years have seen a considerable increase in research and development funding by the major producers in all areas of refractory manufacture. The British Steel Corporation also operates its own refractories research centre which is both capable of evaluating new products and internally generating technical advances. In the long term the aims of such research might be interpreted as contrary to the interests of the refractory producers since if the 'perfect' refractory were developed consumption would fall dramatically. But in the absence of such an ideal material, steel producers are increasingly

FIGURE 20: FLOWSHEET FOR PRODUCTION OF TAR IMPREGNATED FIRED MAGNESITE AND/OR DOLOMITE BRICKS



Source: Lythe, J.W., Oxygen Steelmaking Refractories, Refractories Journal, (1966), 487.

prepared to pay for improved quality and research and development can therefore offset decreased total consumption by extending the range of products suitable for applications under different technical and economic conditions. The development of such a theoretical innovation model, with implications for raw materials development is attempted in the following chapter. Some concluding remarks to this section are however necessary on the behavioural aspects of pricing policy in the refractories industry.

The strong position of the Steetley Company, in raw material supply and in brick and block production of dolomite refractories and its balancing monopoly of U.K. domestic sea water magnesia resources has already been noted as has the historic competition between natural and synthetic magnesia. The price range of finished products is considerable and deserves further analysis. Sea water magnesia is sold to brick makers for about £30/tonne. Finished magnesite bricks sell for about £50/tonne (1970) whilst high grade impregnated periclase (MgO) blocks fetch over £90/tonne. Since the manufacturing processes are apparently identical for dolomite and magnesite products (c.f. flowsheet on figure 20) and since raw materials and finished product prices for dolomite are £9 and £44 (1970) respectively it would appear inexplicably expensive to convert magnesia raw materials into finished products. Transformation costs were £35 and £64/tonne respectively for dolomite and magnesia. Evidence from the United States,[62] although not strictly comparable, suggests a closer transformation cost relationship. Bearing in mind the monopoly supply situations it seems fair to conclude that where demand patterns indicate, some manoeuvre of the present price differential between dolomite and magnesite products is theoretically possible. As has already been discussed there has been a substantial increase in demand for dolomite refractories over the past ten years associated with the basic oxygen L.D. process. Many of the now obsolete open hearth plants continue in operation and provide a significant component of the demand for magnesite, magnesite-chrome and chrome-magnesite basic products. As these open hearth plants shut down there may be a decrease in demand for such refractories even though the electric arc furnace uses similar varieties. In the face of such a long term shift in demand it may be that the price differentials between dolomite and magnesite products will gradually disappear.

4. CASE STUDY THREE: THE BULK MATERIALS INDUSTRY

Bulk materials are naturally occurring mineral aggregates which are in plentiful, if local geological supply such that local demand does not limit availability. Bulk materials are therefore defined in terms of the function they fulfil: the simple provision of structural volume. Where local conditions do not favour the technological and economic criteria associated with this function then the mineral deposit in question cannot be considered as a bulk material resource.

Because of their plentiful supply and easy access to the means for their production, which need not entail technological sophistication or substantial investment, bulk materials tend to command only a very modest price when compared with the industrial minerals or metals. And because of their relatively low marketable value bulk materials tend only to be transported relatively short distances from the point of extraction. The costs of distribution are, in fact, a very significant component in the total cost of bulk material production. Because of the low product price traditionally obtainable for bulk materials the industry has tended to operate on a cost plus basis such that very small resources have been devoted to innovation. More recently the integration that has taken place in the industry yielding economies of scale, together with a more realistic pricing policy has led to a change in the traditional aim of the industry from simply providing structural volume to the provision of materials at a defined technical and economic optimum. Here the division between bulk material and industrial mineral is especially hard to define but for the purposes of this study the traditional distinction is maintained.

4:1 Structural Analysis[63]

Table 14 reflects the dual character of bulk material

TABLE 14

A. ANALYSIS OF ESTABLISHMENT BY SIZE, 1970

Size Group	Enterprises	Establish-ments	Total Employ-ment	£'000 Gross Output	£ Net Output per head
1 - 10	242	277	1852)	38,534	4,199
11-24	126	184	3380)		
25-49	75	133	4558	40,767	4,424
50-99	40	64	4402	34,794	4,100
100 & over	24	43	6751	45,463	3,451
Total	473	701	20943	159,557	3,987

B. NUMBER OF ESTABLISHMENTS AND ENTERPRISES

	1963	1968	1970
Enterprises	521	452	473
Establishment	745	759	701

Source: adapted from Census of Production, various years

supply in the U.K. There appears to be an inconclusive trend towards fewer enterprises and establishments. Thus in 1970 the 24 largest firms out of a total of 473 accounted for a quarter of the industry's total output in value terms. The fluctuating numbers of enterprises and establishments also reflects the large number of small, local, firms possibly operating on an intermittent basis, and the numbers of pits and quarries opened by the larger firms for the purposes of a specific construction project only.[64]

Activity in the bulk materials industry is closely correlated with the general economic climate albeit on a regional rather than national level. Although not the only reason for a trend towards integration in the industry a strategic objective of minimising such regional imbalance through market power exercised on a national scale, has played a significant part in recent developments.

There are two major reasons why aggregate producers might seek vertical intregation. Firstly they might want to protect their outlets by offering a full range of products and services. Secondly they might wish to share in profits related to the further processing of stone. As a result many companies are now increasingly committed to a wide range of activities - extraction, processing, coating and laying (tarmac), production of ready mixed concrete, civil engineering, transport and merchanting. For a large established company this kind of diversification may add to its strength and usefully spread overheads but it may also weaken a smaller company whose strength has been specialisation. Ready mix concrete is a notable example of forward integration and most of the largest companies involved in aggregate supply such as Amey, Amalgamated Roadstone, Hoveringham and the Steetley Company, have now set up large scale ready mix facilities. Backward integration is also a recent feature of the supply structure for bulk materials. In particular a number of companies in other sectors of the construction industry integrated backwards into raw material supply as have a number of ready mix concrete producers.

The concentration of bulk material supply patterns into fewer but larger enterprises has accelerated in recent years. There have been moves towards rationalisation with many small unprofitable sites being closed and production concentrated at a small number of highly mechanised quarries which may individually produce over one million tonnes of saleable aggregate per year. There have also been a number of recent major entrants to the industry: most notably the large mining house Consolidated Goldfields which within the space of a few months in 1967-8 established itself as a leading aggregate producer with the acquisition of Amalgamated Roadstone, Greenwood St. Ives and several smaller companies.

4:2 Technological Background

Any solid mineral could be used as a bulk material although the common raw materials are sand and gravel, limestone (including dolomite), igneous and metamorphic rocks, sandstone, shale, slate, chalk and clay. The extractive technology includes initial blasting in quarries or dredging in pits, crushing and drying where applicable, grading and sizing, and storing for subsequent distribution. Low marketable value seriously limits the scope for product improvement as already discussed. However labour saving innovations have raised average production rates from an approximate average 50 tonnes/hour in 1950 to over 200 tonnes/hour in recent years confirming the value of mechanisation in the industry. A modern crushed rock quarry can now produce over one million tonnes of saleable material per annum with a labour force of only twenty to thirty men. Innovations such as high capacity loaders, hydraulic excavators, impact breaker crushing plants and more effective explosives techniques have all contributed to the overall rise in productivity.

4:3 End Use Analysis

Table 15 illustrates the 1970 supply and demand

TABLE 15

SOURCES AND USES OF AGGREGATES, 1970 ESTIMATES (MILLION TONNES)

Total Market	Sand and Gravel	Crushed Rocks	
Sand and Gravel 110	Sand and Gravel 110	Limestone 80	Supply
Crushed Rocks 130		Igneous Rocks 40	Supply
		Sandstone 10	Supply
Total Market 240	Sand and Gravel 110	Crushed Rocks 130	Supply
Concrete 130	Concrete 90	Concrete 40	Demand
Roadstone 90	Roadstone 10	Roadstone 70	Demand
Others 20	Others 10	Others 20	Demand

Note: Supply data from Somerset C.C. report (1971) op. cit. 264, (based on 1969 proportions). Demand proportions based on estimates in Peters R.H. (1971) op. cit., 60.

situation in the aggregates market. Although the building and dimension stone sectors are not included in this summary it is believed that discussion of the market for aggregates is a satisfactory if not entirely comprehensive proxy for the bulk materials market.

The marketing of bulk materials is essentially distribution at minimum cost. The location of processing plant is usually tied to location of aggregate deposits to avoid transporting heavy waste material. The average location of markets in the regional to local context is then generally established such that the overall marketing problem is arranging distribution of required quantities at minimum cost. The major markets for aggregates are the building industry and road construction: in both cases total demand may be fairly described as inelastic to the extent that even major reductions in price by a quarrying company could do little to affect demand for a particular project. Similarly the cost of sand and gravel has little effect on the demand for concrete in general construction work. However the individual operator may alter his share of a given market by price manipulation although profit margins are rarely sufficient to lend weight to major price wars.

Nearly one third of total annual output of aggregates is used in road construction and repair, where a significantly higher proportion of crushed rock and slags than sand and gravel is used. Technical parameters for this application include abradability, porosity, permeability and for top surface wearing areas in addition colour is important. Generally speaking market sectors are governed very much by local, traditional, prejudice and innovation by technical substitution is a slow process. In this context dolomite is generally regarded as a 'marginal' aggregate, that is to say one that is normally considered suitable for construction work only where other 'higher quality' materials are not economically available locally. Work on the estimation of sectoral consumption of road aggregates has been undertaken by the Road Research Laboratory.[65]. They concluded that roughly one (long) ton of aggregate was consumed for each £18.5 (1966) spent on constructing major roads. Just less than half the annual total demand for roadstone was consumed in either new construction or major improvements and just over half on minor maintenance. Interpreting these figures in terms of specific end uses the RRL survey showed that 40% of production was consumed as bituminous materials or surface dressing, 20% in concrete roads and lean concrete road bases with the remaining 30 - 40% being used as unbound aggregate in sub-bases, road bases and ancilliary work.

As concrete becomes more widely used in constructional work increasing attention is being paid to cleanliness, particle size, texture and grading of aggregates. There is, in effect, a trade-off between improved workability and cement saving achievable with larger aggregate sizes and ease of handling and finishing with the smaller sizes of aggregate. New methods of production have segmented the market with the introduction of for example high grade artificial lightweight aggregates capable of close quality control during manufacture. Indeed concrete may eventually develop into a much more versatile material.[66] The escalating prices of timber and plastics for example and developments in fibre/cement composite materials could render the latter an economically attractive substitute. Such materials can be injection moulded into products which could substitute in traditionally metalliferous or plastics end uses.

4:4 Behavioural Analysis

As Table 16 indicates fixed costs constitute a significant proportion of quarry expenditure including elements of the cost of raw materials (20%), fuel (5%), transport (33%), wages and salaries (19%) and overheads. There has been a traditional tendency in the bulk materials industry to compute prices on a 'cost-plus' basis and in particular to underestimate the cost of holding land for quarrying purposes especially in

TABLE 16

ESTIMATED COST STRUCTURE OF THE QUARRYING INDUSTRY, 1969

	1969	1963 Comparison
Sales	100	100
Costs		
Raw Materials	20.2	18.8
Including		
Explosives		0.8
Tar/Bitumen		1.8
Maintenance Mats.		5.8
Other		7.4
Fuel	4.8	4.7
Transport	33.4	27.7
Wages and Salaries	11.8	22.6
Overheads	5.9	6.1
Gross Surplus	16.9	20.1

Source: Census of Production, 1963, and Peters R.H. op. cit. p.80

urbanised areas. The gross surplus in the cost model of Table 16 approximates to the industry's average gross trading profit before depreciation provision which therefore further underestimates the significance of fixed costs such as plant, vehicle and land replacement.

With increasing capital intensity in the quarrying industry particularly since initial trends towards much larger industrial groupings began approximately twenty years ago, there have arisen strong incentives to achieve an acceptable rate of return on capital investment which would render the various companies competitive as investment attractions. In parallel with this trend has been the significant achievement of economies of quarrying scale up to a present optimum in excess of one million tonnes of saleable material per annum from an individual site.

A recent approximate indication of market shares is given in Table 17 which shows that the six leading producers of aggregates

TABLE 17

ESTIMATED MARKET SHARES, 1970

	Output (in millions of tons)	% of total	Sector of Industry
Tarmac	20	11	Crushed rock, slag
Amalgamated Roadstone	15	8	Crushed, rock, sand & gravel
R.M.C.	12	6	Sand and gravel
Hoveringham	10	5	Sand and gravel
Tilcon	10	5	Crushed rock
Amey	9	5	Sand and gravel
Blue Circle Aggregates	6	3	Sand and gravel
Steetley	6	3	Crushed Rock, sand & gravel
E.C.C. Quarries	5	3	Crushed rock
Redland	5	3	Sand and Gravel
British Dredging	3	2	Marine Aggregates
Man-Abell	2½	1	Crushed rock

Source: Peters R.H. (1971) op. cit., 61

are (1970) responsible for about 40% of the total U.K. output of aggregates. It might be concluded that signs of incipient market failure could be detected possibly where artificial pricing policies were known to apply. In general however aggregate prices have remained at a low level and return on capital invested in the industry is still with few exceptions, relatively modest for three major reasons:

(i) Weak, cyclical demand encourages temporary, informal, price cutting to gain orders and maintain individual sales volume.

(ii) There is a degree of buying power exerted on the aggregate producers despite vertical integration, for example in the ready mix concrete market where six producers control at least 75% of the market.

(iii) The underlying structure of the aggregates industry is not conducive to price stability since the small, local, producer with low overhead costs can frequently undercut the large nationally organised supplier on specific contracts in his area.

The overall conclusion then is that market behaviour in the aggregates industry has been historically conditioned by the low level of prices obtainable.

5. INTERIM CONCLUSIONS

This chapter has analysed three minerals consuming industries which may have dolomite as a raw material in common. Later chapters deal with the problems and prospects for growth in these industries and the interpretation of these features as opportunities for minerals development. For the present however it is clear that the conditions governing dolomite's role as a bulk material are very different from other industrial applications and that the application of the investment and diffusion models examined in Chapter Two will require appropriate changes in emphasis from one industry to another. In the next chapter therefore some simple long term growth forecasts are prepared and the sensitivity of such forecasts to various critically important technical and economic variables are discussed.

CHAPTER FOUR

LONG TERM GROWTH PROBLEMS AND PROSPECTS

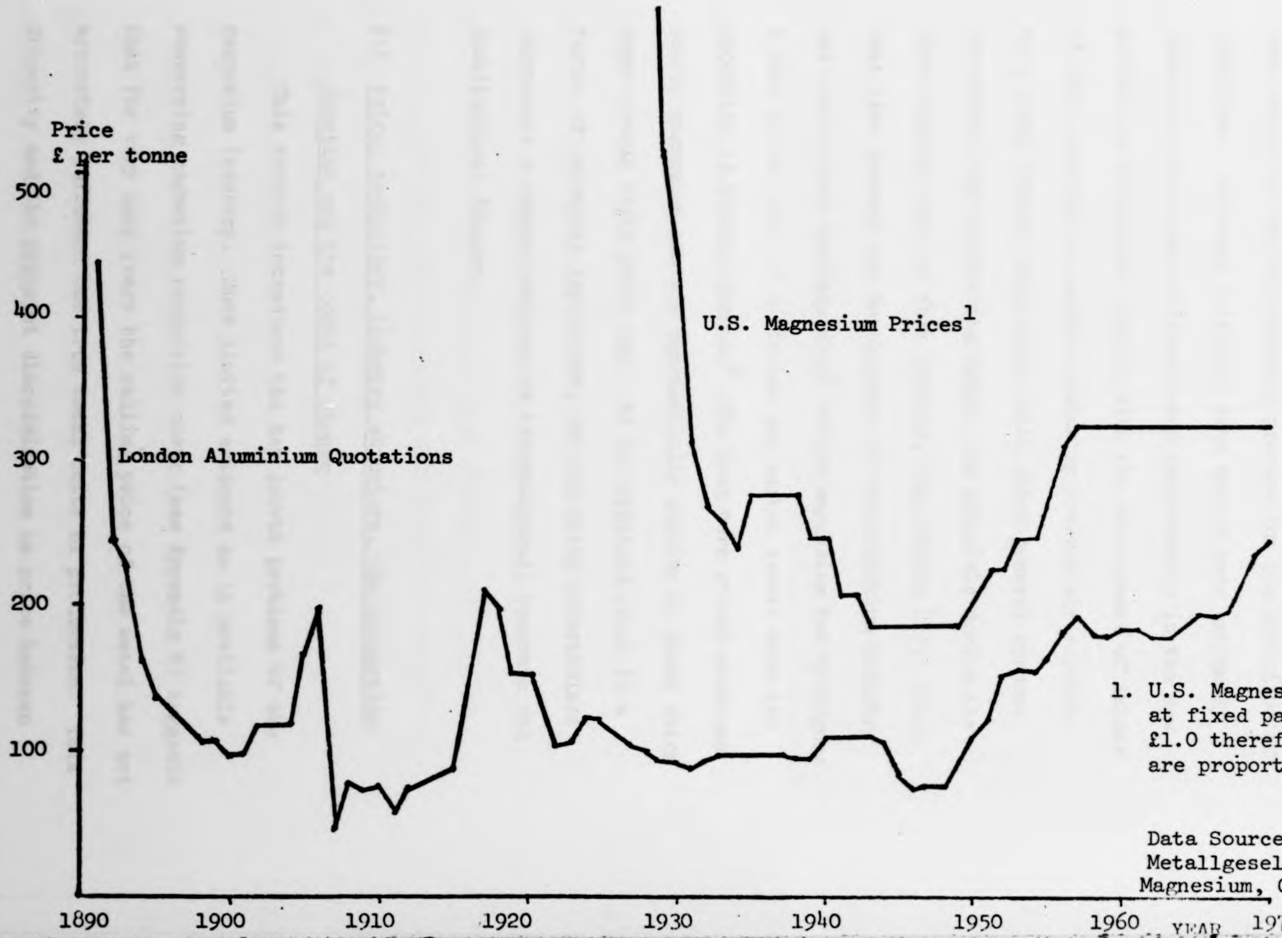
1. INTRODUCTION AND OBJECTIVES

Chapter Three presented broad analyses of three qualitatively distinct minerals consuming industries which may have a mineral raw material, dolomite, in common. The conditions governing minerals participation in such primary processing industries varied considerably. In this chapter several key long term growth problems are abstracted from the case study material for further analysis. Where appropriate reference is made to aspects of production and diffusion theory as introduced in Chapter Two. This chapter also attempts some simple forecasts of long term demand for the products of two of the case study industries which serve as a background to the opportunity planning studies proposed in Chapters Five and Six. Finally reference is made to the technological and economic factors which may influence the achievement of these demand projections.

Each of the industries studied in Chapter Three was found to represent a unique combination of structural, technological, economic and behavioural factors such that any corroboration of theory proposed in this chapter must be regarded as provisional. Much further work needs to be carried out both on other minerals and in other minerals consuming industries.

In this chapter two of the study industries, the magnesium and basic refractories industries, are re-examined. The third case study, the bulk materials industry is reconsidered in a specific regional development context in Chapter Six.

FIGURE 21: COMPARATIVE PRICES OF MAGNESIUM AND ALUMINIUM



1. U.S. Magnesium prices converted at fixed parity rate, \$2.4 = £1.0 therefore historic prices are proportionately overstated.

Data Source: Aluminium, Metallgesellschaft
Magnesium, Comstock, H.B. (1968), op.cit.

118

2. CASE STUDY ONE: GROWTH PROBLEMS AND PROSPECTS IN THE MAGNESIUM INDUSTRY

The technology for the production of magnesium evolved in the same period as the Hall-Heroult process for the reduction of aluminium. Although initially both metals were extremely expensive subsequent diffusion and improvements in the new production techniques coupled with the development of larger if still specialist markets gradually lowered their price to a level broadly competitive with other general purpose structural and engineering metals and materials during the first thirty years of this century, (see Figure 21). Since that time however the development of the aluminium industry has accelerated spectacularly[1] whilst magnesium has undergone a much slower rate of diffusion and market growth with the exception of wartime demand.[2] The long term growth problems facing magnesium now are substantially similar to those which began nearly fifty years ago. As is explained price is a factor of universal importance; but one which nevertheless represents a complex balance of technological, economic and institutional factors.

2:1 Price, technology, industry structure, the production function and the costs of change

This section introduces the key growth problems of the magnesium industry. Such limited evidence as is available concerning magnesium production costs (see Appendix E) suggests that for very many years the selling price of the metal has not accurately reflected the true total costs of production. This disparity and the apparent discrimination in price between various sectors of the international market,[3] were concluded in Chapter Three to have resulted from the monopolistic structure of the industry. The major producers have been historically responsible for many innovations which have resulted in lower production costs which were not generally passed on to consumers in the ideal manner described in Chapter Two.[4] In terms of the simple production function model outlined therefore monopoly at the national level has resulted in higher prices than would be reasonably expected were perfect competition to prevail. Beyond this assertion however it is difficult to establish whether the corollary hypothesis, that expansions in output are less than in the perfectly competitive case, is applicable. For demand has gradually concentrated in areas where price has not been a factor of overriding importance[5] with the result that the monopolist producer has not experienced the necessary incentive to pass on innovation dependent cost reductions. And yet the market has grown at a steady rate since magnesium is at a technical premium in such applications as military pyrotechnics and aircraft. All that can be asserted with confidence therefore is that prices have been managed at levels which are sufficiently high to earn an acceptable long term rate of return for established producers and yet sufficiently low in key market sectors through price discrimination to discourage entry.

As was suggested in the previous chapter pricing policy is not the only instrument available to the established producers which may form an effective barrier to potential entrants. In the following paragraphs therefore these other 'barriers to entry' are reviewed.

In the first place it is clear that despite the theoretically free access to the technical knowledge necessary for magnesium production there are serious practical problems involved which may be described as the learning costs of innovation. For whereas in the aluminium industry technology in the form of plant and essential know-how can be purchased 'off the shelf' this is not currently possible in the magnesium industry. And in the case of the more recent technical advances these are still the subject of patent agreements.[7] The potential entrant has therefore to consider whether his learning costs associated with an earlier technology with possibly more expensive operating costs but incurring no royalty fees are an attractive alternative to paying royalty fees for the operating cost improvements involved in 'buying in' the most recent round of technical advances.[8] The importance of this problem which may result in a permanently displaced cost schedule for the potential entrant should not be underestimated and it is known that at least one major manufacturing concern has quite recently withdrawn its entry plans largely on these grounds.[9]

A second potential barrier to entry introduced in the previous chapter concerned the historical pattern of excess capacity in the magnesium industry. In the past this was explicable largely as the result of redundant wartime capacity. More recently as was explained in Chapter Three the changing character of warfare has considerably reduced magnesium's strategic importance. It is therefore expected that, as conventional markets expand, particularly in the aluminium and engineering industries the balance of supply and demand will tend to more closely reflect wider economic trends. Some support for this hypothesis is the cancellation of major development projects by Dow and Norsk Hydro early in the 1970s[9A]. This was done in the belief that the combination of reduced levels of military activity in Vietnam and of the potential extra output of other new ventures would result in a surplus. However, by 1974 bouyancy in the commercial market sectors (particularly alloying with aluminium) resulted in a shortage of the metal.[9B]

A third possible barrier to entry concerned the effects of the existence of a large U.S. stockpile. To the established producers occasional stockpile releases have been viewed as contributing to long term price stability. But to the potential entrant it would appear that historically the level at which these prices were stabilised was insufficiently high to adequately defray the costs of entry. Recently the U.S. Government has announced its long term plans to remove magnesium from the list of strategic materials and to considerably reduce or even abolish the stockpile which stood at approximately 125,000 tonnes in 1969, representing over half total world consumption in that year.[9C]

A fourth potential barrier to entry concerns the restrictions to international trade in magnesium. Despite the Kennedy round tarrif reductions, in June 1972 the duty on magnesium imported into the U.S. remained as high as 20% ad valorem. Bearing in mind that the U.S. market for magnesium is the only really diversified market for the metal it is clear that the non U.S. based entrant may have to look to alternative areas for market developments. To a certain extent for example this has occurred in Italy with the relatively small SIIM-Ravelli plant producing mainly for the Italian motor industry. Elsewhere in the world aside from the two major producers as was explained in Chapter Three the pattern has been largely one of captive production either for the aluminium or titanium industries (e.g. U.K., France, Japan).[9D]

Potential barriers to markets, notably through vertical integration, do not appear as highly developed in the magnesium as in other metals' industries. The industry appears to have preferred the provision of technical advice to independent fabricators of secondary products. Admittedly the primary and secondary fabrication of magnesium requires engineering expertise, but in techniques which are commonly employed throughout the metals and plastics industry: hot rolling, sand and gravity moulding, injection diecasting, welding, and so on. Clearly an entrant with absolutely no background in such techniques may, as with the patent licensing question discussed above, view the acquisition of such skills as an element in the overall costs of change in addition to purchase of any specialised equipment necessary to take advantage of magnesium's favourable fabricating characteristics (c.f. Appendix G.). As regards the end markets themselves there is little direct published evidence to suggest that access is limited. In practice it will be recalled that the recent entry of the National Lead Company was at least partially influenced by their ownership of one of the largest die casting companies in the U.S., the Jarvis corporation. On balance therefore as is pursued further in the following chapter, a view of planning for entry to the magnesium industry which fails to adequately encompass potential market areas even in the specialist sectors is likely to be seriously deficient.

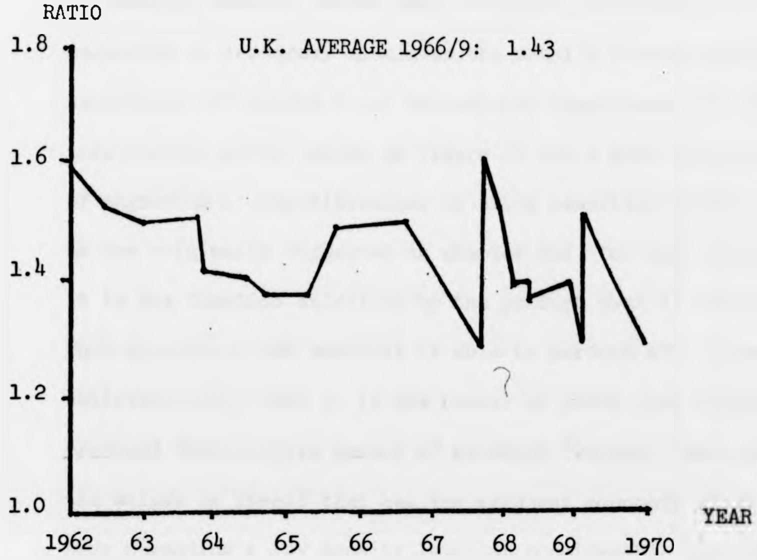
A sixth barrier to entry concerns any economies of scale which may be enjoyed by established producers but which cannot be achieved by new entrants possibly because of the small size of the total market. The economics of the alternative production processes are considered in Appendix E, from which it would appear that several of the techniques investigated are broadly competitive at the 25,000 t.p.a. capacity level (see Figure 14). In practice, however, it is recognised that more particularly for the electrolytic routes which involve comparatively heavy capital commitment[9f] the realistic minimum scale of entry would have to be of the order of 30-50,000 t.p.a., which it will be recalled represents nearly one quarter of current world consumption. At the other extreme the various 'captive' producers operate alternative direct reduction techniques at capacity levels less than 20,000 t.p.a. Clearly therefore the scale of any proposed operation would have to be carefully tailored to perceived market characteristics; the size of any individual magnesium market is not sufficiently large to result in the development of economies of scale in distribution as an effective barrier.

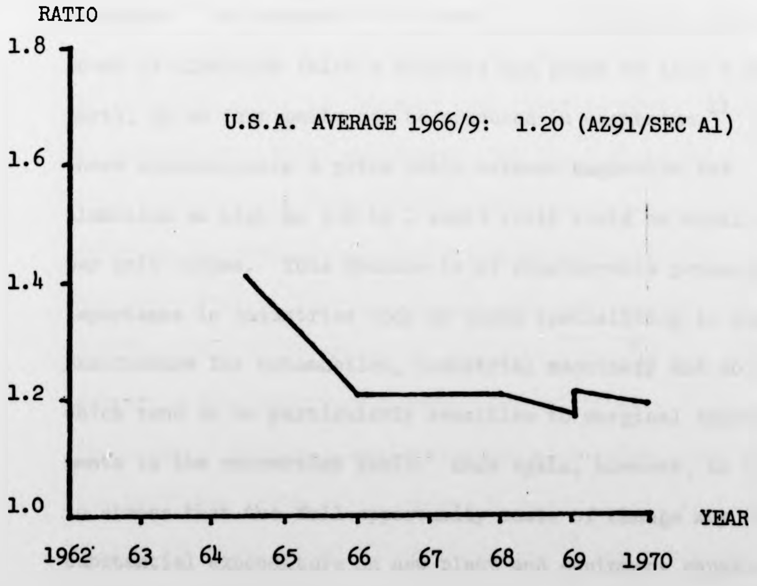
A final barrier to entry considered here relates to the general issue of research and development costs. The possible problems with patents and the acquisition of "know-how" for a new entrant have already been introduced. In addition it will be recalled that magnesium products participate in areas of sophisticated technology including the military and aerospace sectors such that continuing R & D expenditure to service R & D market development may deter potential entrants. This issue is especially complex, not least because of the total absence of published information on R & D expenditure in the industry. Some recent developments may however be significant. As is pursued in more detail in the following section the historic importance of magnesium's military and aerospace applications undoubtedly stimulated the development of many high performance alloys. It is believed that a considerable element of this expenditure was directly funded by the U.S. government. With the recent and prospective decline in magnesium military importance it may be significant that Dow Chemicals "in-house" research and development program has been substantially curtailed with a new independent non profit-making research body set up and funded by the U.S. industry as a whole and under the auspices of the Battelle research organisation: "Research programs will be conducted on a contract basis for industrial companies, groups of companies and for producers and users of magnesium".[9F] It would obviously be naive to assume that this development will totally remove all the research and development barriers to primary magnesium production and some outstanding areas of research need are identified in the following section, but the Institute's establishment does appear to offer the eventual prospect of wider diffusion of magnesium technology. The preceding paragraphs have examined in some detail the problems confronting a totally new entrant to the magnesium industry. Such problems are considerably more complex than implied in the opportunity costs of change model for replacement and net new investment proposed in Chapter Two. Certainly where there is an established pattern of improvement isolated "innovations" including superior quality raw materials, production cost lowering technical advances or emerging market opportunities can be assessed according to whether the innovation results in lower total costs including the costs of change. But for the totally new entrant recommendations based solely on isolated nominal advantages are unlikely to provide compelling justification for change. For the magnesium industry a wide range of innovations from raw materials to end markets were in fact necessary before National Lead, a major new producer, considered entry seriously. And the familiar development time lags or gestation period delays suggest that even greater changes will be incurred before a representative market share is established and a positive cash flow is achieved.

In summary a preliminary conclusion is that the monopoly variant of the Salter model of the replacement/net investment criterion does not satisfactorily incorporate the effects of the various practical barriers to entry observed in the magnesium industry. And in addition the relation between price and demand is not adquately explained in the simple model. For, historically, the long term effect of high prices was to limit demand to "special" categories for which magnesium possesses outstanding or unique properties. And the long term effect of such restrictions in the scope of demand has been to reduce the incentive to pass on cost reducing technological innovation in an effort to expand demand. Producers have apparently preferred to maintain "sheltered" markets and conservative pricing policies, confident that effective barriers to entry would continue to preserve the status quo.

Before analysing the barriers to the diffusion of magnesium as a material one further general aspect of the price problem should be mentioned. On a price per tonne basis magnesium has

FIGURE 22: UNIT WEIGHT PRICE RATIO, PRIMARY MAGNESIUM/ SECONDARY ALUMINIUM





Source: Adapted from Cambell, G. (1971), Metals & Materials, May, 173.

for many years, compared unfavourably with its potential substitutes notably aluminium, zinc and plastics.[10] Figure 22 for example details recent unit of weight price ratios of magnesium to secondary aluminium,the metal's closest general substitute. If weight is of determining importance then the unfavourable price ratios in Figure 22 are a good indication of magnesium's competitiveness in price sensitive markets. But, as was originally suggested in Chapter One, for many applications it is the function fulfilled by the product that is criticial. Thus provided a new material is able to perform this function satisfactorily, then it is the number of parts that can be produced from a given amount of material (weight), and not the weight in itself that has the greatest economic significance. Here magnesium's low density lends it considerable competitive advantage. For whereas 2 2/3 parts can be produced from one pound of aluminium (with a standard one pound of zinc = one part), up to four parts can be produced in magnesium.[11] In these circumstances a price ratio between magnesium and aluminium as high as 1.6 to 1 would still yield an equal cost per unit volume. This feature is of considerable potential importance in industries such as those specialising in component manufacture for automobiles, industrial machinery and so on which tend to be particularly sensitive to marginal improvements in the conversion ratio. Once again, however, it is vital to stress that the full opportunity costs of change may involve substantial expenditure on new plant and equipment capable of using magnesium to best advantage (see Appendix G for a fuller discussion).

2:2 Barriers to the diffusion of magnesium

Clearly the most important single barrier to the diffusion of magnesium, in the sense proposed in Chapter Two, is its relatively high price. But other no less important barriers to diffusion exist: barriers which are not easily expressed in terms of relative costs and benefits of magnesium. These are considered here under the industry's technology and markets, and the psychological barrier against magnesium.

Chapter Three and Appendix E indicate the lack of exploration and exploitation of alternative methods of magnesium production. Currently the aluminium industry is under mounting pressure to reconsider or devise alternative production technologies in view of politically generated raw material price rises.[12] Whilst a comparable break in traditional raw material supply has yet to occur in the magnesium industry the industry lacks the confidence to extend the potential scope of existing technology to cover specific raw material or market anomalies. The trend for example in other basic process industries towards ever larger plants achieving substantial apparent economies of scale, yet experiencing high fixed cost components, may benefit from qualification before wholesale application to the magnesium industry's long term development. For whilst direct reduction routes are at present considered outmoded by virtue of their high operating costs and technical problems, their scale of optimum operation (< 25,000 tonnes/annum)[13] may ultimately revive the method for use in areas remote from the sea and sources of brine, with large diversifying markets close to hand and a source of suitably high grade dolomitic raw materials.

On the other hand the development of such large turnover markets as gave rise to the mini mill concept in the steel industry is as yet very far from being realised in markets for magnesium products.[14] For the present the advantage undoubtedly lies with the brine based process (Appendix E) which will be subject to further improvement and scale economies. And it will continue to be complemented by the traditional sea water electrolytic routes from the major established companies. The prospects for direct reduction will probably depend on developments in retorting techniques [15] and of less labour intensive methods of reduction.

There is also a well established need to develop more, commercially competitive, magnesium alloys.[16] Magnesium's traditional participation in areas of sophisticated technology, notably the aerospace industry, led to the development of many technically outstanding but expensive alloys which have subsequently been slow to diffuse. The industry has been criticised for the general lack of commercial market direction in its research and development programme. For example two traditional problems in magnesium technology concern melting losses and protective finishes. The former problem has only recently been overcome by using an atmosphere of sulphur hexafluoride under which to conduct primary melting.[17] This relatively simple remedy for primary melt losses of up to 10% also reduces labour costs and removes the need for expensive flux. Concerning protective finishes it is a common experience that parts and equipment designed to simply replace steel, aluminium or plastics with magnesium can experience premature corrosion, although recent advances in protective finishing processes have reduced the problem. Fisher (1970)[18] has shown that premature corrosion is more often due to poor design rather than inherent material defects.

On the other hand the development of such large turnover markets as gave rise to the mini mill concept in the steel industry is as yet very far from being realised in markets for magnesium products.[14] For the present the advantage undoubtedly lies with the brine based process (Appendix E) which will be subject to further improvement and scale economies. And it will continue to be complemented by the traditional sea water electrolytic routes from the major established companies. The prospects for direct reduction will probably depend on developments in retorting techniques [15] and of less labour intensive methods of reduction.

There is also a well established need to develop more, commercially competitive, magnesium alloys.[16] Magnesium's traditional participation in areas of sophisticated technology, notably the aerospace industry, led to the development of many technically outstanding but expensive alloys which have subsequently been slow to diffuse. The industry has been criticised for the general lack of commercial market direction in its research and development programme. For example two traditional problems in magnesium technology concern melting losses and protective finishes. The former problem has only recently been overcome by using an atmosphere of sulphur hexafluoride under which to conduct primary melting.[17] This relatively simple remedy for primary melt losses of up to 10% also reduces labour costs and removes the need for expensive flux. Concerning protective finishes it is a common experience that parts and equipment designed to simply replace steel, aluminium or plastics with magnesium can experience premature corrosion, although recent advences in protective finishing processes have reduced the problem. Fisher (1970)[18] has shown that premature corrosion is more often due to poor design rather than inherent material defects.

Turning to the barriers to diffusion in end product markets it is clear that the magnesium industry has carried out a policy of piecemeal innovation in specialist product roles. Frequently the diffusion of magnesium into non-specialist product and market roles has resulted from external innovation. Thus it was the aluminium, and not the magnesium industry which pioneered the 5082 magnesium intensive alloys from which 'aluminium' cans are made. The aluminium industry has since become the largest single market for magnesium. Other examples of external initiative include the Volkswagen company's sponsoring of innovations in magnesium die casting technology and novel engineering applications, the U.S. Army's support for the neglected magnesium-sea water battery, and innovations by the chemical industry notably in scavenging roles and organic chemical synthesis. The reasons for the industry's apparent lack of initiative in promoting magnesium probably relate again to its monopolistic structure focussing attention on lowering production costs whilst pursuing a conservative role in markets and partly to an unwillingness to integrate forward into such markets. The result is that apparently unforseeable combinations of circumstances have yielded specific opportunities for actual or potential consumers, with the producers assuming a passive role in the provision of technical advice rather than active commitment to new product development.

The final barrier to the diffusion of magnesium (and the most difficult to adequately interpret) includes the psychological prejudice against the metal. Magnesium has certainly suffered from the popular misconception that on the one hand it is inflammable and on the other that it is easily corroded.[19]

Despite similar underlying problems with other common structural and engineering materials (for example steel and iron rust, plastics melt, wood burns etc.) these misconceptions have undoubtedly retarded the diffusion of magnesium. The widespread use of magnesium in pyrotechnics during wartime and the early corrosion problems experienced in poorly designed magnesium bodied aircraft gave this prejudice much impetus during the Second World War at a time when otherwise the metal was diffusing slowly into many non-specialist roles. Magnesium is also popularly confused with aluminium and a policy of consumer education is clearly necessary to establish the important differences and complementary relationships between the two materials, much in the manner of the relation between iron and steel. Relaxation of such intangible psychological barriers to the diffusion of magnesium is a very long term growth problem for the industry which may only be resolved when the metal appears prominently in a range of non-specialist, non-traditional applications.

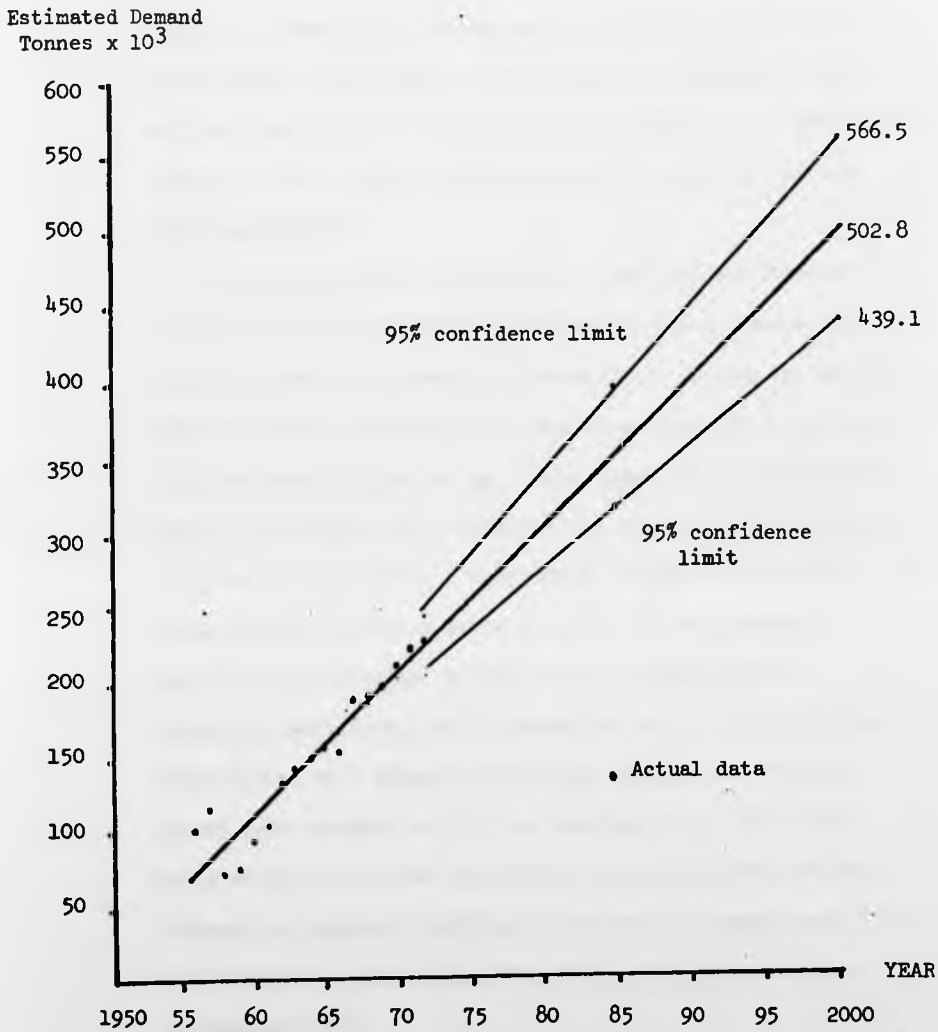
In terms of the model proposed in the final section of Chapter Two magnesium appears to have passed through the first and second and is possibly entering the third stage in the diffusion process for new materials. Broadly speaking the Schon model appears to fit the observed development of the magnesium industry. Thus the innovation of magnesium is not essentially the communication of a well defined package of concepts, products, ideas and so on as implied in the Rogers model. The innovation and diffusion process are one and the same: the diffusion of magnesium being subject to continual re-emphasis, redefinition and change in sponsorship as new contributory advances are exploited or as environmental circumstances change. Secondly the diffusion of magnesium has typically 'elicited positively antagonistic reaction ... defined as dynamic conservatism'. But such conservatism has paradoxically come from within the industry, from those who are concerned to protect the relatively comfortable status quo. Thirdly the diffusion of magnesium does not look like the fanning out of an innovation from a single source. Opportunities for further diffusion tend to occur as the result of a conjunction of previously unrelated factors: diffusion may be dependent on a network of contributory advances. At present magnesium appears to be diffusing in a limited range of non-specific applications. Further progress would undoubtedly be made if production cost reducing technical advance were passed on in the form of lower prices. Finally, magnesium continues to experience a common problem in replacement substitution: simple replication of design leading to an unsatisfactory exploitation of the inherent technical potential of the substitute.

2:3 Long term prospects for magnesium: basic forecasts and disaggregated analysis

This section provides a conventional demand extrapolation for magnesium and a qualifying sensitivity analysis based on trends in individual end use categories.

Demand for magnesium has been particularly subject to wartime influences. During such periods (c.f. Appendix C, Table 1), abrupt shifts in demand of the order of several hundred per cent were experienced. Aside from these war years, the very

FIGURE 23: EXTRAPOLATION OF WORLD MAGNESIUM CONSUMPTION TO 2000



Equation: Y = 9.79X-476.0 where Y = estimated demand, thousand tonnes and X = year

Regression coefficient correlation: $R^2 = 0.905$

Confidence limits (0.95) on coefficients A = 476.0 (-363.5 → -588.6), B = 9.8 (8.0 → 11.5) small size of most non-U.S. markets and the distorting influence of individual consumer contracts suggest that correlation of magnesium demand with macroeconomic variables at a national level cannot be undertaken with any great confidence. This section does however include passing reference to an econometric analysis of U.S. demand for magnesium conducted by Charles River Associates.[20]

As an introduction to the individual end use forecasts a statistical extrapolation of aggregate global demand may provide a basis for subsequent comparison. During the period 1961-1971 world consumption of magnesium rose fairly steadily by an average 6.3% per annum. This figure is somewhat lower than the 8% growth in consumption "in recent years" recorded by other investigators. Consumption figures on a global basis are not available prior to 1961. In the absence of such data, and bearing in mind the distorting wartime influences mentioned, world production data for 1955-1972 was extrapolated as a simple time series regression. Various curves were computed to fit the data:the aim at this stage being solely to achieve the closest possible correspondence between the computed regression line and the actual data. The following three curves were found to have high coefficients of correlation (R^2):

Curve	Coefficient of Correlation
$Ym = 9.8X-476.0$	0.905
$Ym = 1.8e^{0.1X}$	0.844
$Ym = 2.1X^{4.3}$	0.840

where Ym = demand for magnesium in thousand tonnes and X = year where X = 0 at year 1900.[21]

On the simple, quantitive basis of its high relative coefficient of correlation the first equation was employed and its estimates of future magnesium demand are to be found in Figure 23. The curve suggests that continuation of present trends in aggregate consumption could give rise to a world demand of 355 thousand tonnes by 1985 and over 500 thousand tonnes by 2000.

Such straightline extrapolation of course yields no information about possible changes in demand patterns or the likelihood of departures from the forecast trend. This is the role of disaggregated analysis of trends in individual end use categories. A special study of such end use sensitivities has recently been undertaken by the U.S. Bureau of Mines,[22] although their analysis is based on examination of U.S. markets such that any extrapolation to the global level will be open to qualification. The three major market sectors are: alloying with aluminium, structural applications, and chemical and sacrificial uses. The results of the analysis are summarised in Table 18.

(i) The demand for magnesium in the aluminium industry

Chapter Three identified the aluminium industry as the world's largest single consumer of magnesium metal. As the demand for magnesium constitutes a relatively small proportion of the aluminium industry's total production costs it was suggested that demand for magnesium in this area was relatively price inelastic. In constructing an econometric model of the demand for magnesium in the U.S. aluminium industry, Charles River Associates[23] assumed that the supply of magnesium in the relevant price range was perfectly elastic thereby suggesting a simple delineation of the demand curve through price and avoiding the familiar identification problem.[24]

Table 18

SUMMARY OF SENSITIVITY ANALYSIS: DEMAND FOR MAGNESIUM IN U.S. MARKETS, 2000 A.D.

(Thousand tonnes)

END USE CATEGORY	Forecast Base	Low	High
Aluminium Alloying	70	65	80
Structural Markets:			
Aircraft and Missiles	170	100	300
Motor Vehicles	35	30	60
Industrial Machinery	80	60	100
Fabricated metal products	30	20	45
SUB TOTAL	315	210	505
Non-structural Markets:			
Miscellaneous chemical products	35	20	45
Cathodic protection	30	15	30
Reducing Agent	35	25	70
SUB TOTAL	100	60	145
GRAND TOTAL	485	335	730

Sources: All except Aluminium Alloying, Paone, J (1970), op.cit.

Table 18

SUMMARY OF SENSITIVITY ANALYSIS: DEMAND FOR MAGNESIUM IN U.S. MARKETS, 2000 A.D.

(Thousand tonnes)

END USE CATEGORY	Forecast Base	Low	High
Aluminium Alloying	70	65	80
Structural Markets;			
Aircraft and Missiles	170	100	300
Motor Vehicles	35	30	60
Industrial Machinery	80	60	100
Fabricated metal products	30	20	45
SUB TOTAL	315	210	505
Non-structural Markets;			
Miscellaneous chemical products	35	20	45
Cathodic protection	30	15	30
Reducing Agent	35	25	70
SUB TOTAL	100	60	145
GRAND TOTAL	485	335	730

Sources: All except Aluminium Alloying, Paone, J (1970), op.cit.

The following equation was eventually chosen on the basis of its high correlation coefficient:

$$Qt = -1.388 + 94.83\ Wt - 559.2\ PM_{t-1} + 1181.7\ PA_{t-1}$$

Where Qt = total consumption of magnesium in aluminium alloys at time t, in short tons

Wt = total production of wrought aluminium alloys, in short tons

PM_{t-1} = price of 998 magnesium at time t-1, years

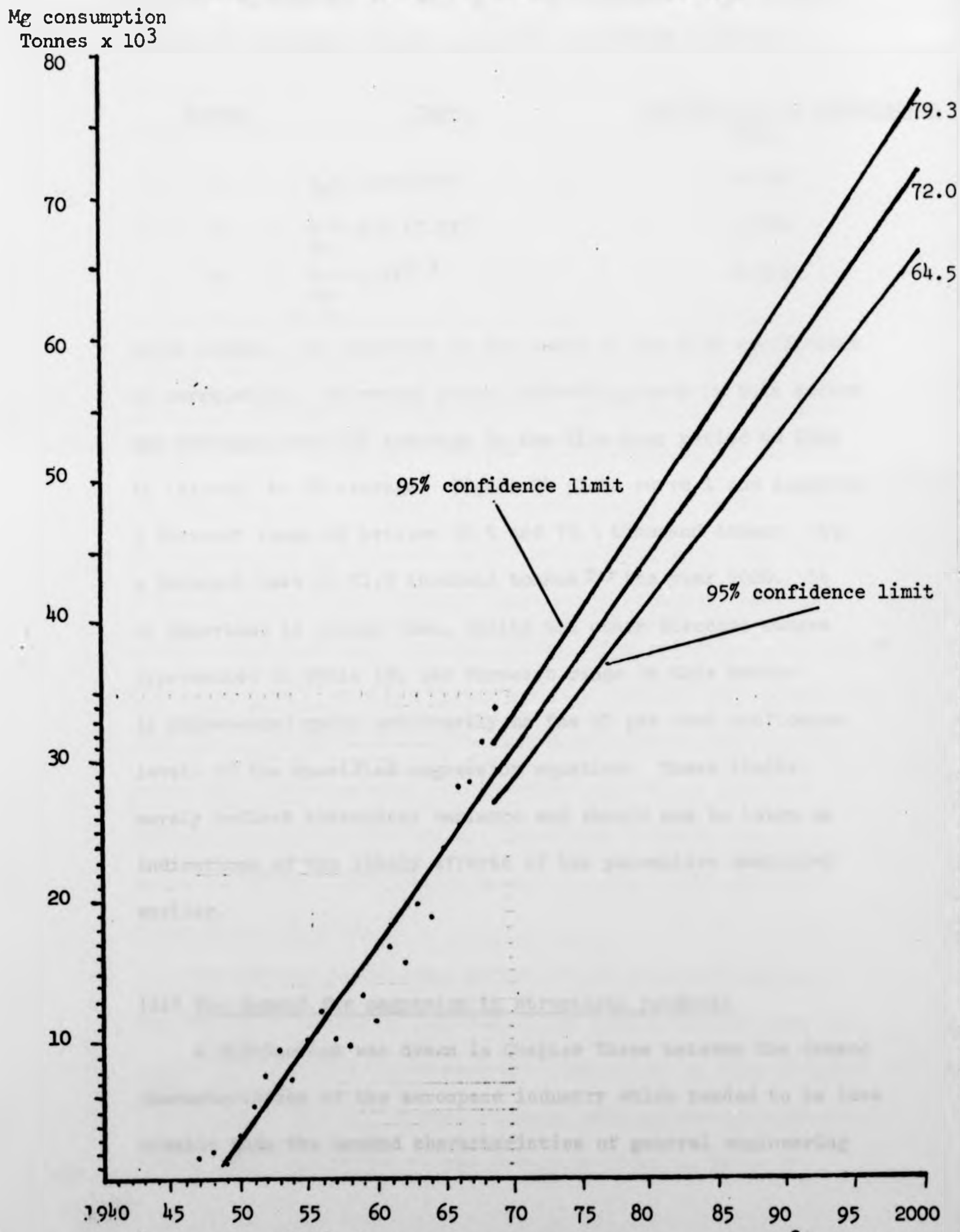
PA_{t-1} = price of aluminium at time t-1, years

This equation gives quantitative expression to the views (a) that demand for magnesium in the aluminium industry is linked with demand for, in particular, 'aluminium' cans manufactured from wrought aluminium alloy and (b) that demand for aluminium alloys is a delayed response to the price of aluminium products. However it is not clear from the analysis whether official price information was used or as seems probable informal information on actual prices charged to the aluminium producers. In view of the great difficulty of forecasting metal prices it is also clear that the equation is mainly of short to medium term forecasting significance. Over the long term demand is also unlikely to remain inelastic. For example factors which could influence further development in this sector include movements in the price of other packaging materials including plastics paper and glass, as well as the possibility of increased recycling of used cans and other implications of a growing concern for environmental quality.

Although the Charles River econometric equation is not therefore readily adaptable to yield a long term forecast of

FIGURE 24: U.S. MAGNESIUM FOR ALUMINIUM, ALLOYING, EXTRAPOLATION TO 2000

Data Source US Bureau of Mines, Minerals Yearbooks Annual



Equation: $Y = 1.38X-65.8$ where Y = consumption in tonnes x 10^3, X = Year

Regression coefficient of correlation, $R^2 = 0.928$

Confidence limits (0.95) on coefficients: A = 65.8(-55.6→75.9), B = 1.38 (1.20→1.55) magnesium demand in this sector some estimate of likely demand under present trends is required. Figure 24 represents a simple alternative time series correlation based on the data in Table 6, Appendix C. The following equations were specified, (where Y = magnesium usage in the U.S. aluminium industry):

Number	Curve	Coefficient of Correlation (R^2)
1	$Y_{ma} = 1.4X - 65.8$	0.928
2	$Y_{ma} = 0.9\ (7.1X)^{e}$	0.894
3	$Y_{ma} = 1.5X^{7.3}$	0.912

Curve number 1 was selected on the basis of its high coefficient of correlation. In recent years, (1950-70), growth in this sector has averaged over 13% although in the five year period to 1969 it 'slowed' to 9% average. Figure 24 plots curve 1 and suggests a forecast range of between 64.5 and 79.3 thousand tonnes, with a forecast base at 71.9 thousand tonnes for the year 2000. It is important to stress that, unlike the other forecast ranges represented in Table 18, the forecast range in this sector is represented quite arbitrarily as the 95 per cent confidence levels of the specified regression equation. These limits merely reflect historical variance and should not be taken as indications of the likely effects of the parameters mentioned earlier.

(ii) The demand for magnesium in structural products

A distinction was drawn in Chapter Three between the demand characteristics of the aerospace industry which tended to be less elastic than the demand characteristics of general engineering consumers. The econometric demand analysis referred to in the previous section appears to corroborate this distinction although demand elasticities[25] for general engineering uses including surface vehicles (-.431) and machinery and tools (-.631) were not as high as for consumer durables (-1.032). This may well be a consequence of the specification of the preferred equations but it does agree with qualititative expectations since magnesium is regarded as a luxury weight saving item in consumer goods.

Reverting to the special category, to obtain a forecast of potential demand in aircraft and missiles by 2000, the U.S. Bureau of Mines combined demand in 1968 with projected growth in aircraft passenger miles.[25] As a result U.S. magnesium demand in this sector was forecast to range between a low of 100 thousand and a high of 300 thousand tonnes in 2000. Factors which were seen as influencing the achievement of a high level forecast included an increased awareness of the potential of magnesium-lithium high strength alloys, improved price competitiveness, and a more critical appreciation of payload characteristics. Conversely technological shifts to superior materials such as boron epoxy composites or high strength steels, or improved competitiveness of titanium and other high strength non-magnesium alloys could result in the low end of the forecast range being achieved.

The general engineering sector of the structural market for magnesium is widely regarded as the most promising area for future growth. Bearing in mind the limitations of long term GNP correlations, the U.S. Bureau of Mines used an average 4.0% GNP growth rate[26] to arrive at the forecasts given in Table 18.

Factors which were expected to influence the achievement of a high forecast level other than generally improved price competitiveness included: the wider appreciation of the favourable payload characteristics of magnesium in motor vehicles especially where energy conservation is desirable; increased affluence accelerating the demand for luxury weight saving consumer durables; and increased awareness of the high horsepower to weight ratio achievable with magnesium particularly in hand held machinery. Conversely decreased technical or price competitiveness compared with substitutes such as aluminium, zinc, or plastics could reduce magnesium's potential to the low end of the forecast range.

(iii) The demand for magnesium in non-structural uses

Demand for magnesium in non-structural applications excluding alloying with aluminium has remained fairly steady since the Second World War (see Figure 3, Appendix C). The two major sub-categories included in this end use area include applications as a reducing agent for titanium and other metals, and as a cathodic protection material, the so called sacrificial end use. A miscellaneous category includes a growing variety of small volume applications ranging from scavengers in the production of ductile cast iron, to Grignards reagents in the chemical industry.[27] Faced with such a diversity of applications the Bureau of Mines correlated sacrificial and chemical uses with anticipated population growth (1.6% per annum), and reductant uses with anticipated GNP growth of 4.0% per annum (Table 18). Demand in the chemical industry would be favourably influenced by magnesium's wider diffusion in the synthesis of organic chemicals. The possibility of further hiatuses in demand in this area due to wartime manufacture of pyrotechnics should also be mentioned. The forecast base for cathodic protection is also the forecast high as no major innovations in this field which would increase demand for magnesium were anticipated. On the other hand improved corrosion protection of structural materials through surface finishes or improved design could result in a forecast low. Growth of magnesium as a reducing agent is related to the production of titanium, beryllium, uranium, zirconium and hafnium. Continued growth in demand for these materials could yield a high level forecast of 70,000 tonnes but conversely innovation of sodium or calcium as reducing agents or development of electrolytic reduction processes could influence the achievement of a low level forecast of 25,000 tonnes in 2000.

2:4 Conclusions

Table 18 sets out the various estimates of demand for magnesium in individual sectors for the year 2000 in the U.S. market: The U.S. market currently accounts for approximately 40% of total world consumption. On this basis the resultant figure for aggregate world demand for magnesium in 2000, at 1.21 million tonnes contrasts sharply with the aggregative extrapolation arrived at in Figure 23. Whether the U.S. market will continue to account for approximately 40% of the total world consumption in the year 2000 will depend partly on the extent to which magnesium diffuses into non-specialist, non-traditional applications in world markets as a consequence of the resolution of the key growth problems identified in this case study. In any case such forecasts are no more than

Table 19

A summary of exploratory growth strategies for magnesium development

A) Strategies that may specifically improve price competitiveness

(i) Technological innovation to lower production costs

(ii) Technological innovation to lower melting costs and improve corrosion resistance

(iii) Increased competition from new producers

(iv) Reduced restrictions to international trade

B) Strategies that may have a more general effect in increasing magnesium's acceptability

(i) Development of improved commercially competitive alloys

(ii) Promotion of non-traditional end uses particularly in 'volume' applications

(iii) Forward integration into markets particularly in general engineering sector

(iv) Education of designers and consumers, piecemeal development plausible order of magnitude estimates based on practical end use extrapolations.

Therefore they must be seen not as a definitive statement of the industry's long term development pattern but as recommendations to the planner, entrepreneur, and resource developer to explore individually promising sectors now with a view to capitalising on suitable opportunities as and when they occur in the forecast period.

Finally to return briefly to the implications for mineral development. The present study suggests that the problem of mineral resource development for the magnesium metal industry is only marginally related to the character and disposition of the relevant mineral deposits. Certainly the study suggests that dolomite's role in the industry is currently overshadowed by production methods using alternative raw material feedstocks. But the long term growth problems and prospects of the industry are related much more closely to the industry's structure, the pricing policies of its major participants, and their conservative market development strategies. Table 19 lists a number of exploratory growth strategies for magnesium development which have emerged in this case study. These strategies are considered again in the light of the opportunity planning method proposed in Chapter Five.

3. CASE STUDY TWO: GROWTH PROBLEMS AND PROSPECTS IN THE BASIC REFRACTORIES INDUSTRY

Many of the problems in the long term development of the magnesium industry are understood as those of a new material which is slowly diffusing into the very wide range of end uses that are characteristically served by other metals. In contrast the refractories industry serves a well established industrial function with a fairly narrowly definable range of both products and applications. The function of refractories remains as "the provision of heat resistant linings for vessels in which pyrometallurgical processes are carried out".[29] Therefore the key long term growth problem for the refractories industry is not the promotion of the diffusion of refractories as such, but rather to gain insight into the technological economic conditions under which improved refractory products can be innovated and to interpret possible changes in the operating conditions of consuming industries and pattern of demand for their products which would dictate a change in the type of refractory product required. This section attempts a preliminary analysis of these problems. The demand characteristics for refractories in the steel industry, the largest consumer of basic refractories, are used to illustrate the general principles involved although they are probably also applicable to other industries provided the operating constraints and their effects on refractory materials can be clearly identified.

3:1 Growth problems in the refractories industry: a model of refractory innovation

The demand for refractories in general and basic refractories in particular is strongly and unambiguously correlated with the demand for steel. Several econometric analyses of long term demand for the latter have been attempted[30] encountering varying degrees of success either in terms of numerical accuracy or as an aid to development planning. There being little the refractories producer can do to influence overall demand for steel products, the refractories industry assumes as a major planning objective the anticipation of turning points in the cyclical demand pattern for steel. The forecasting of suitable periods in which to promote innovations or improvements in product performance or the interpretation of changes in steel technology are direct consequences of this dependence of the refractories industry on the steel industry.

The salient long term changes in refractory consumption patterns as identified in Chapter Three were: a persistent decrease in all types of refractory product consumed, a shift towards more durable high alumina and basic refractories, and a revival of the use of dolomite as a major refractory raw material. The underlying reasons for these changes were found to be respectively improvements in refractory product performance and steelmaking practices; increased throughput from existing and new steelplants which led to higher operating temperatures in which only the more durable high alumina and basic refractories could perform satisfactorily, and the introduction of the basic oxygen process which at the outset exacted less than half the refractories consumption of the outmoded open hearth process.[31]

With increasing capital intensity and concentration of output in the steel industry the criterion of vessel availability has assumed a critical importance. Table 20 compares the relevant operating statistics of the three most important modern steel technologies. The significant comparison for present purposes is the operating to downtime ratio which for

TABLE 20

SALIENT STATISTICS OF MODERN STEEL PRACTICE IN RELATION TO REFRACTORIES

Furnace	Electric Arc	Open Hearth	Basic Oxygen System
Capacity (tonnes)	100	350	250
Output rate (tonnes/hr)	28	28	250
Refractories Consumption			
kg/tonne steel product	8.5(18.7)[3]	11(24.3)	3(6.6)
kg/operating hour	238(524.8)	308(689)	750(1659.8)
Campaign Life (days)	20	210	16 2/3[1]
Downtime (days)	1	21[2]	5
Operating/Downtime ratio	20	10	3 1/3

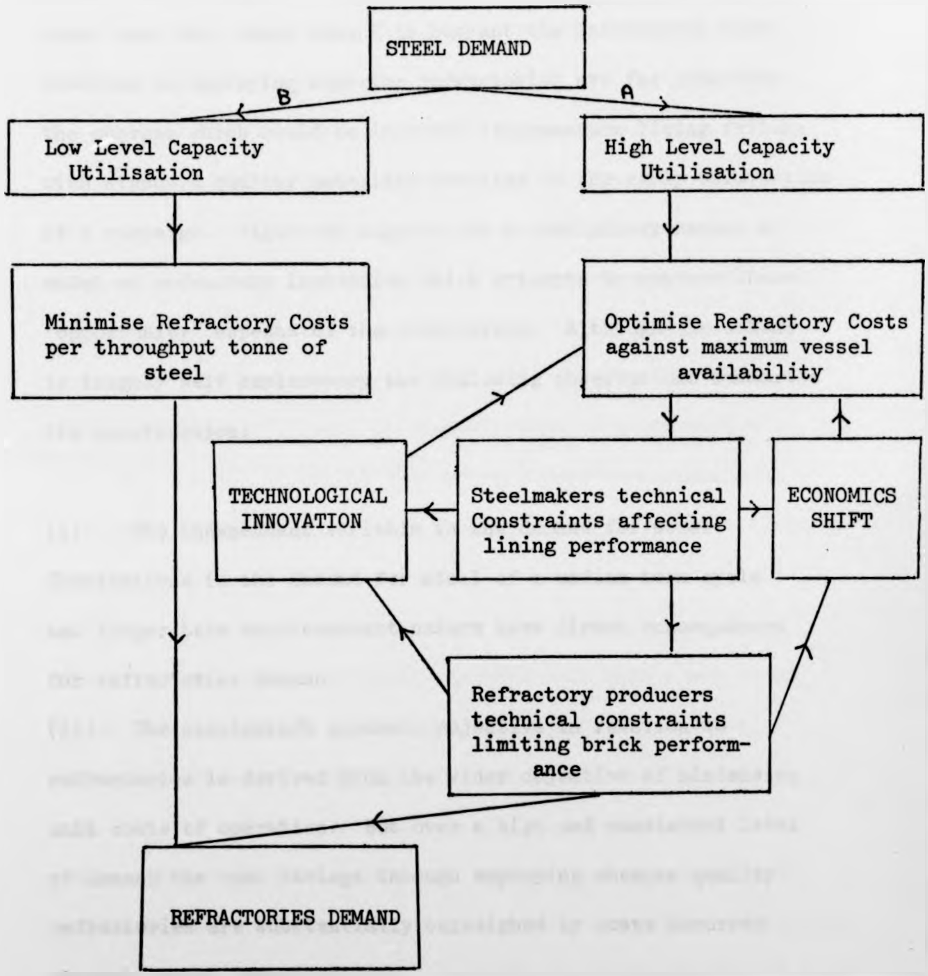
[1] Assumes campaign life of 400 heats

[2] includes mid-campaign repairs

[3] equivalent pounds per tonne figures

Source: C Hardy (1972), BOS refractories - A question of continuity, op.cit.

FIGURE 25: A MODEL FOR STEELPLANT REFRACTORY SELECTION



the basic oxygen system is only one third that of the open hearth. In a plant embodying high fixed charges there is therefore considerable incentive to improve this ratio. As the main purpose of downtime is to reline the vessel it is clear that when steel demand is buoyant the incremental costs involved in employing superior refractories are far less than the charges which could be incurred if premature lining failure with standard quality materials resulted in the early termination of a campaign. Figure 25 suggests in a preliminary manner a model of refractory innovation which attempts to capture these 'opportunity' aspects of the steel cycle. Although the scheme is largely self explanatory the following observations summarise its construction:

(i) The independent variable is the demand for steel. Fluctuations in the demand for steel of a medium term cycle and longer term non-recurrent nature have direct consequences for refractories demand.

(ii) The steelmaker's economic objective in relation to refractories is derived from the wider objective of minimising unit costs of operation. But over a high and consistent level of demand the cost savings through employing cheaper quality refractories are substantially outweighed by costs incurred through vessel unavailability.

(iii) In times of high level capacity utilisation therefore route A is followed. Maximum vessel availability should be optimised against refractory cost. Ideally the technical constraints on refractory performance which detract from maximum levels of vessel availability are identified, they are related to the properties of the bricks and ultimately back to raw material sources and manufacturing techniques.[32]

(iv) The refractories producer in committing himself to the objective of maximising vessel availability is nevertheless subject to the constraints of his own technical capabilities and economic objectives. Thus to the extent that knowledge exists as to how products can be improved, and that steel demand renders such high quality materials economically attractive, producers will be encouraged by the possibility of increased profits to innovate higher quality refractories.

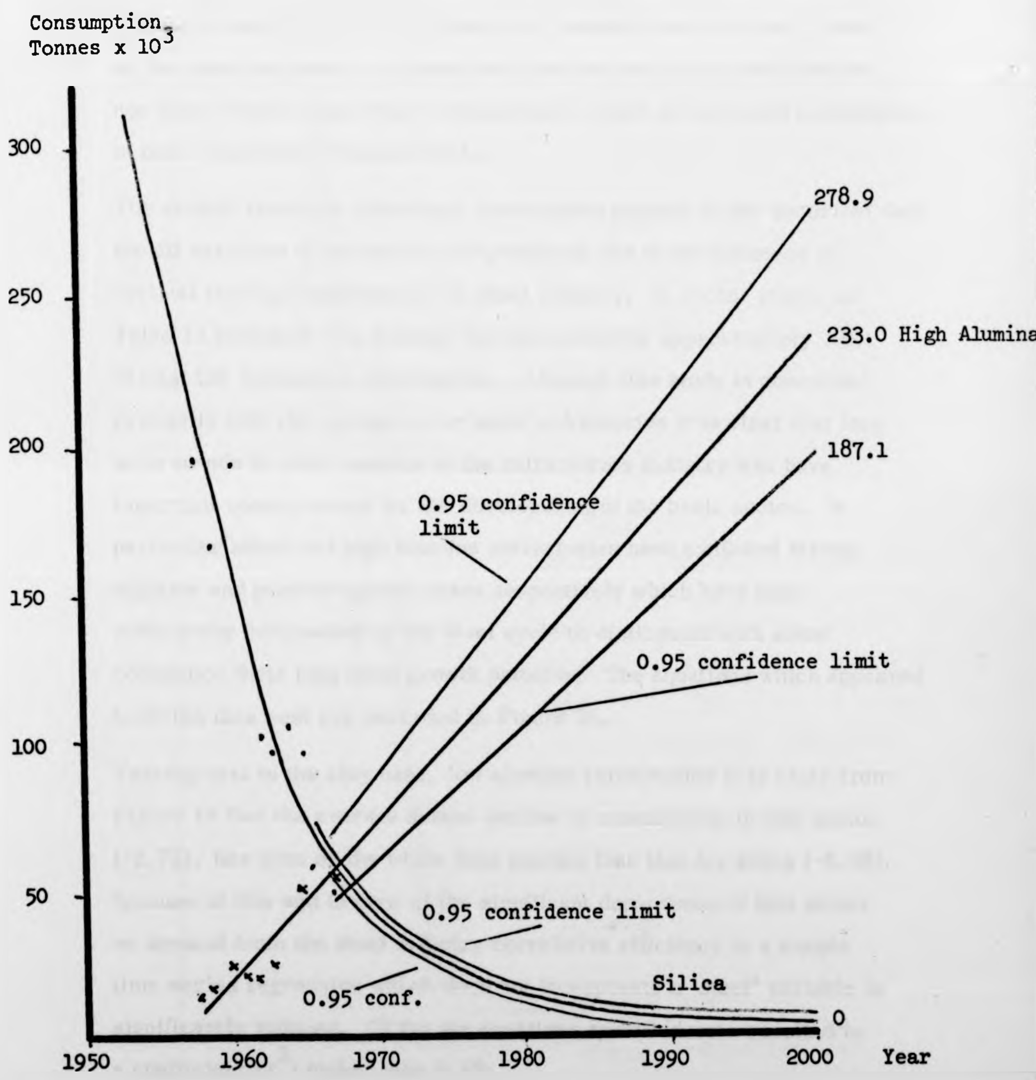
(v) Alternatively in a situation of depressed steel demand there may not be the pressure to maintain high throughput levels and vessel availability may not be critical. Route B in Figure 25 therefore leads to the selection of refractories with the balance of emphasis on price rather than quality. Eventually however there are technical constraints which limit the scope for cost minimisation.

Routes A and B in the model are abstractions from a continuum of demand patterns in which a dynamic relationship exists between refractory purchase costs, refractory quality, vessel availability and the stock of potential innovations resulting from advances in either steel or refractories technology. In practice innovation and diffusion are piecemeal and discontinuous processes. Thus a potential innovation may be developing at the margin with its performance and functional characteristics widely communicated amongst potential consumers. A period of several years may however elapse before a crisis or sudden change in the operating circumstances of the consuming industry provides the opportunity for actual innovation. A typical example concerns the substitution of magnesite chrome for chrome magnesite bricks in the all basic open hearth furnace. The premature wear tendencies of the latter were widely recognised and the phenomenon was thoroughly investigated. For many years however no concensus emerged as to the fundamental causes of such lining failure. It eventually required a major series of tests sponsored jointly by the producers and major consumers [33] before a clear recommendation leading to the widespread innovation of magnesite rich composite bricks resulted. Similarly the suggestion that basic refractory performance could be improved by employing markedly higher firing temperatures to give a 'direct-bonded' product[34] required the more precise control and higher temperatures achievable with the tunnel kiln process which was not widely diffused in the industry at that time. The general pattern of innovation emerging would therefore appear to be one of major discontinuity followed by a series of minor improvements. For example Richardson (1970)[35] has indicated that the decline in dolomite refractory consumption in the steel industry in 1965-9 was a direct consequence of improved operating procedures following the major innovation of the basic oxygen process in 1964.

Because of the historically fragmented nature of the refractory and steel industries the diffusion of refractory innovations in the latter was frequently dependent on personal relationships and tradition, with trade organisations providing a useful additional technical forum. With the amalgamation of the steel industry and its eventual nationalisation however the industry moved more towards the establishment of generally applicable standards of refractory performance consistent with current innovations in steel technology. Subsequently only the largest refractory producers found that they could attract sufficient capital to accelerate their research and development programme to the required level and offer the widening range of products and services necessary, whilst at the same time surviving prolonged periods of depressed trading conditions. The current situation for the three major producers could therefore be described as one of oligopolistic rivalry. The attention that would be brought to bear on the pricing policies of the major producers would probably be more searching were there only a single producer, and such a single producer would still be susceptible to the adverse effects of the steel cycle. On balance therefore no single producer wishes to achieve a total monopoly yet each is anxious to capitalise on new opportunities for innovation when they arise. The steel industry for its part is now able to exercise considerable pressure on producers through centralised buying[36] and, in a different sense, through the testing of refractories and the internal generation of technical advances on its own refractories research laboratory.

Having briefly introduced the conditions under which innovation of new or improved refractory products may be undertaken the next section provides a brief analysis of long term trends in refractories consumption, whilst the final section of this study deals with the possible influence of various factors on the identified growth patterns.

FIGURE 26: CONSUMPTION AND FORECASTS FOR SILICA AND HIGH ALUMINA REFRACTORIES IN THE STEEL INDUSTRY



Equations:

Silica: $Y_{sil} = 1.04e^{-0.15X}$, High Alumina: $Y_{hal} = 5.39X-306.3$

Coefficients of Correlation:

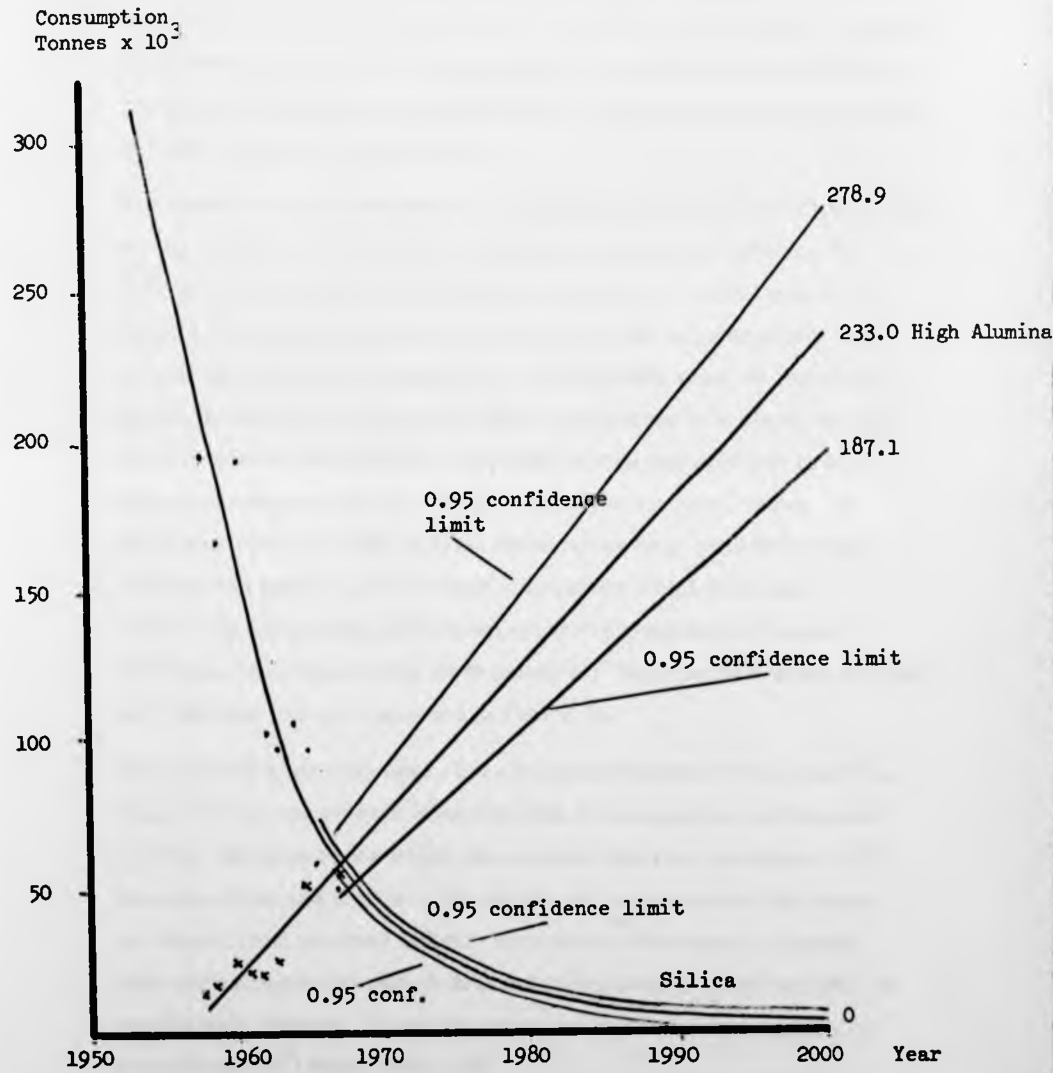
Silica 0.923, High Alumina 0.916

Confidence Limits of Coefficients (0.95)

Silica: A = 1.04 (7.92 → 137491), B = -0.15 (-0.12 → -0.18)

High Alumina: A = -306.3 (-228.3 → -384.2), B = 5.39 (4.16 → 6.63)

FIGURE 26: CONSUMPTION AND FORECASTS FOR SILICA AND HIGH ALUMINA REFRACTORIES IN THE STEEL INDUSTRY



Equations:

Silica: $Y_{sil} = 1.04e^{-0.15X}$, High Alumina: $Y_{hal} = 5.39X-306.3$

Coefficients of Correlation:

Silica 0.923, High Alumina 0.916

Confidence Limits of Coefficients (0.95)

Silica: A = 1.04 (7.92 → 137491), B = −0.15 (−0.12 → −0.18)

High Alumina: A = −306.3 (−228.3 → −384.2), B = 5.39 (4.16 → 6.63)

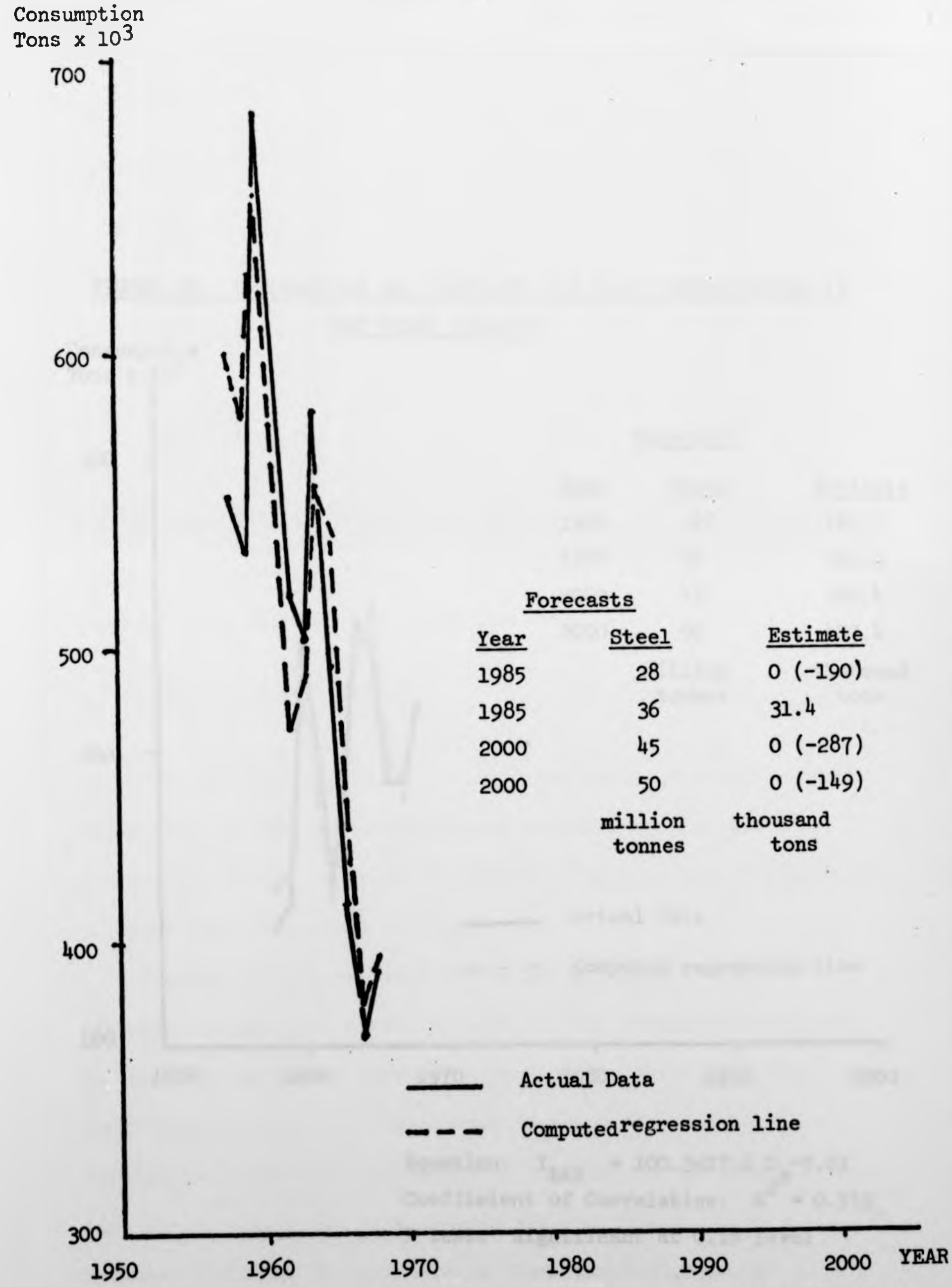
3:2 Exploratory Forecasts of Refractory Demand

Trend analyses for the basic and non basic sectors of the refractories industry are discussed in this section since the present structure of the industry, its future development, and opportunities for new sources of production are likely to be influenced by trends in both sectors. However as has been stressed in previous sections the conclusion that a decline in non basic consumption would automatically result in increased consumption of basic materials is unjustifiable.

The erratic trends in refractory consumption present in the historical data for all varieties of refractory are primarily due to the influence of cyclical trading conditions in the steel industry. In recent years, as Table 13 indicated this industry has accounted for approximately 70% of total UK refractory consumption. Although this study is concerned primarily with the prospects for basic refractories it is clear that long term trends in other sectors of the refractories industry will have important consequences for the development of the basic sector. In particular silica and high alumina refractories have exhibited strong negative and positive growth rates respectively which have been sufficiently independent of the steel cycle to distinguish with some confidence their long term growth patterns. The equations which appeared to fit the data best are recorded in Figure 26.

Turning next to the clay base, low alumina refractories it is clear from Figure 18 that the average annual decline in consumption in this sector (-2.7%), has been on the whole less marked than that for silica (-8.0%). Because of this and in view of the significant dependence of this sector on demand from the steel industry correlative efficiency in a simple time series regression which does not incorporate a 'steel' variable is significantly reduced. Of the six equations specified none resulted in a coefficient (R^2) higher than 0.65:

FIGURE 27: CONSUMPTION AND FORECASTS FOR FIRECLAY REFRACTORIES IN THE STEEL INDUSTRY

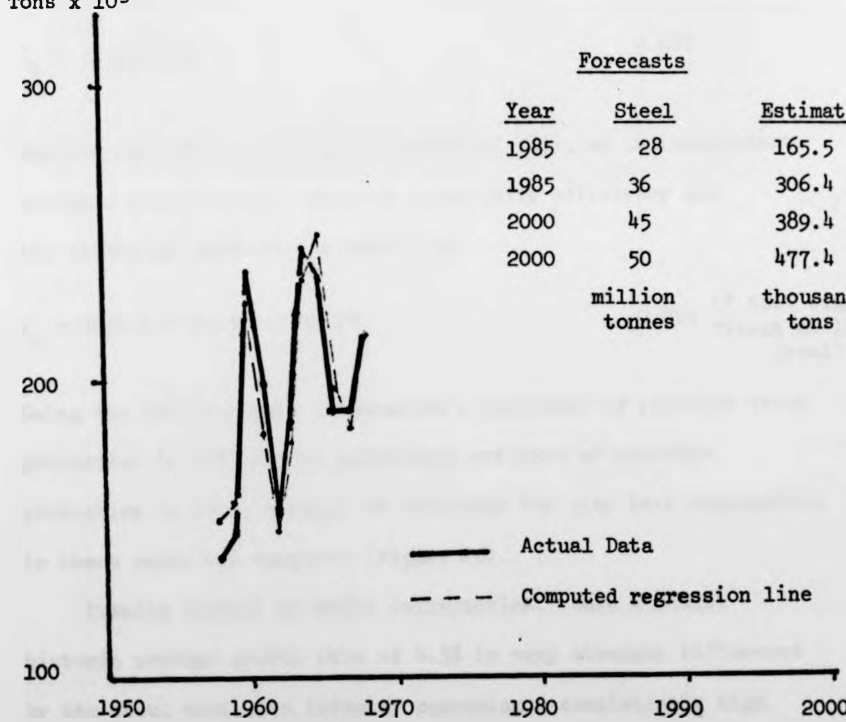


Equation: $Y_{CLY} = 2254.9+27.78X-37.9X$

Coefficient of Correlation: $R^2 = 0.845$

F test: significant at 1% level

FIGURE 28: CONSUMPTION AND FORECASTS FOR BASIC REFRACTORIES IN THE STEEL INDUSTRY



Forecasts

Year	Steel	Estimate
1985	28	165.5
1985	36	306.4
2000	45	389.4
2000	50	477.4
	million tonnes	thousand tons

Equation: $Y_{BAS} = 100.3+17.6\, S_x - 5.0X$
Coefficient of Correlation: $R^2 = 0.919$
F test: significant at 0.1% level

Clay (Low Alumina)

Curve	Coefficient
$Y_c = 1920.2-22.3X$	0.597
$Y_c = 9101e^{-4.6X}$	0.630
$Y_c = 68775946X^{-2.9}$	0.617
$Y_c = \frac{86195}{X} - 858$	0.570
$Y_c = \frac{1}{9.62-4.1X}$	0.650
$Y_c = \frac{X}{7.9X-0.37}$	0.620

However the addition of steel production (Sx), as an independent variable significantly improved correlative efficiency and the following equation was specified.

$Y_c = 2254.9 + 27.7Sx - 37.9X$ 0.845 (F test significant at 1% level)

Using the British Steel Corporation's estimates of possible steel production in 1985 and an additional estimate of possible production in 2000, a range of forecasts for clay base consumption in these years was computed (Figure 27).

Turning finally to basic refractories. Here a modest historic average growth rate of 4.5% is very strongly influenced by the steel cycle, the industry consuming a consistently high proportion of total U.K. deliveries (average 85%). Very low correlative efficiency was therefore recorded in the simple time series regression with indexes ranging from 0.174 to a maximum of 0.262. The addition of steel production as an independent variable resulted in very much higher correlative

TABLE 21

GROWTH RATES IN REFRACTORY CONSUMPTION IN STEEL INDUSTRY AND SUMMARY OF FORECASTS TO 2000

	CLAY		SILICA		HIGH ALUMINA		BASIC	
YEAR	Growth rate %	Steel as % of Total	Growth rate %	Steel as % of Total	Growth rate %	Steel as % of Total	Growth rate %	Steel as % of Total
1959		59.8		72.3		67.2		84.3
1960	18.2	64.6	17.7	71.8	29.1	76.0	51.9	86.8
1961	-7.2	63.1	-21.0	69.1	20.0	65.0	-11.8	83.0
1962	-13.4	61.4	-30.5	68.8	-2.0	61.8	-25.2	86.0
1963	-4.0	62.2	-8.1	72.0	1.2	71.3	19.9	86.6
1964	11.6	64.1	4.6	74.8	31.0	97.3	27.4	89.3
1965	-0.5	54.8	-8.9	74.3	15.9	97.3	-1.1	86.4
1966	-12.2	52.2	-27.9	68.9	5.5	109.5	-10.3	83.9
1967	-7.2	50.1	-27.3	72.5	-4.4	106.7	-10.8	86.9
1968	0.8	52.7	0.4	68.5	9.3	114.1	20.5	84.4
1969	6.3		16.9		18.0		6.5	
1970	-0.8		6.3		-2.8		-0.3	
1971	23.7		-18.2		13.3		-12.6	
AVERAGE	-2.7	58.5	-8.0	71.3	11.2	86.6	4.5	85.2

FORECASTS	CLAY tons x 10^3		SILICA tons x 10^3			HIGH ALUMINA tons x 10^3			BASIC tons x 10^3	
YEAR	HIGH	LOW	MED	LOW	HIGH	MED	LOW	HIGH	HIGH	LOW
1985	31.4	0	4.0	2.0	8.2	152.1	124.7	179.6	306.4	165.5
2000	0	0	0.4	0.1	1.5	233.0	187.1	278.9	477.4	389.4

Notes:

1. Data for growth rates from Richardson H M (1970), op. cit.
2. Data for total refractory consumption based on NFCI figures for U.K. deliveries from U.K. Manufacturers, source, Industrial Minerals (1972), October.
3. Unrevised data was used for forecast runs in long tons x 10^3
4. Steel as % of total refers to consumption of type of refractory in manufacture of steel as percentage of total U.K. deliveries of that type.

efficiency, the computed regression equation being highly significant (F test significant at the 0.1% level). The equation was specified as follows:

BASIC

Curve	Coefficient
$Y_{bas} = 100.3 + 17.6S_x - 5.0X$	0.919 (F test significant at 0.1% level)

Again using the independently estimated forecasts of possible steel demand a possible range of basic refractory consumption in the steel industry for 1985 and 2000 was calculated. The equation and these forecasts are plotted in Figure 28.

Statistical analysis of the available data for consumption of refractories in the steel industry suggests a significant long term change in the industry which largely accords with qualitative expectations. This is that demand will be increasingly concentrated in the high alumina and basic sectors of the industry. According to the extrapolations total demand for refractories in the steel industry in 1985 could stand at 35% of the 1960 consumption figure of 1167 thousand tonnes and by the end of the century demand would at approximately 55% of the 1960 level be devoted entirely to basic and high alumina products.

Although qualitative expectation may confirm the general trend of the statistical extrapolations judgment should be exercised in both extrapolating the results for the steel industry to other consuming sectors of the refractories industry and in confirming the unqualified decline of low alumina, and silica varieties. Improved products, shifts to methods with lower processing temperatures, emphasis on purchase cost: these are all factors which could certainly halt the decline of clay and silica refractory products.

As regards the basic refractory forecasts it should be emphasised that these are tentative, order of magnitude estimates which are strongly dependent on the erratic fortunes of the steel industry which others have experienced great difficulty in forecasting even over much shorter periods. The dangers of extrapolation are demonstrated in an alternative forecast of the demand for basic refractories. Beginning with the British Steel Corporation 1985 forecast for production at between 28 and 35 million tonnes, the disposition of their plant will then be such that approximately 80% of production will be from the new generation of basic oxygen steel convertors and 20% from electric arc furnaces. Hardy (1972) has presented data on current average refractories consumption by steelmaking method (Table 20).[37] Even assuming that no further improvements in refractory consumption are achieved total basic refractory consumption in the steel sector would be between 115 and 144 thousand tonnes.[38] Taking 129 thousand tonnes as an average estimate this calculation suggests that demand for basic refractories could be 40% less than demand in 1968, whereas the regression equation suggests, by coincidence, that demand could be up to 40% more. Clearly therefore the extrapolative forecasts could be subject to considerable error for without doubt further refractory saving innovations may be anticipated in both producing and consuming industries. The following section examines a number of critical factors which may influence such departures from the extrapolated trends and concludes with a review of the role of dolomite as a refractory.

3:3 Factors influencing the prospects for growth in refractories demand

The following six factors are believed to include the most important determinants of refractories demand and possible shifts in that demand over the long term future: the steel cycle and possible long term relaxations in the steel intensity of the economy, possible shifts to lower processing temperatures, the general course of innovation in steel technology, possible innovation of alternative methods of containing high temperature reactions and the general scope for innovation in the refractories industry. These factors are briefly considered individually.

The periodic but irregular marked fluctuations in steel consumption have been described as the steel cycle. As was discussed, the implications of the cycle for refractories producers are most important in short to medium term production planning. In boom periods domestic producers may be unable to keep pace with demand, but where the first indications of a depression are signalled the steel industry may cancel orders with little or no advance notice leaving producers in the difficult position of having to honour raw materials contracts which can result in severe cash flow problems. As was observed the longer term effect is to encourage market concentration as refractory producers attempt to gain more effective bargaining powers with both the steel industry and raw material suppliers, and to achieve greater security during slump periods either through spreading costly overhead burdens including research and development or to achieve greater independence through diversification.

The important influence of steel demand on refractory supply patterns is however subject to minor qualification. For in recent years it would appear that the steel intensity of the national economy has relaxed slightly. As Rowley (1972)[30] has suggested the conventional view that the price elasticity of demand for steel is low ignores increasing income elasticities amongst consumers. These may be much higher in relation to steel versus non steel substitute materials in such products as automobiles and other durable consumer goods. Further, steel demand must be increasingly considered in a European and international context where price changes on the domestic front will be balanced by foreign producers anxious to retain a competitive position in the U.K. market. Over the long term however the immense opportunity costs involved in any major relaxation in steel intensity appear such as to justify the industry's continuing if slowly declining influence on long term refractory demand patterns.

Although the steel industry enjoys a relatively low energy conversion factor for the production of metal from iron ore[39] it is clear that concern over long term energy shortages, accelerating prices and the costs of developing new sources of energy will all lead to an effort to reduce energy losses in the steel making process. Over the medium term this could result in a shift to the high quality basic and alumina refractories since any attempt to retain 'waste' process heat actually within the steel convertor, the simplest conservation measure, would lead to higher thermal gradients across the refractory lining. Alternatively the waste heat could be 'recycled'. But there are considerable difficulties in achieving satisfactory regeneration. It will be recalled that one of the major problems with the now obsolete open hearth process was its high refractory costs in part consequent on the maintenance of expensive refractory lined heat regeneration chambers. At present fundamental shifts to low processing temperatures in the steel industry appear remote and impractical.[40] One of the major disadvantages of low processing temperatures would almost certainly be decreased throughput tonnages.

Barring therefore fundamental shifts to low processing temperature the pattern of technical advance in the steel industry over the next quarter century is widely seen as one of improvement and modification of the basic oxygen L.D. process. An increasing component of general quality steel output will come from the electric arc furnace with, where local conditions permit,increasing contributions from the mini mill concept and possibly direct reduction alternatives. The LD convertor exacts less than half the consumption of refractories per tonne of product than any other hot metal process. Indeed half the cost savings of the LD process could be attributed to decreased refractory costs. Whilst therefore alternative processes are being continually examined it is widely held that there are still considerable economies to be achieved with the LD process, and that the major problems will be increasingly those of rationalising ancilliary plant to accommodate for the massive output rates achievable. Improvements in the LD process may well take the form of an oxygen bottom blowing plant called the Q-BOP, which provides more efficient, quieter and quicker steel conversion. This refinement, remarkably similar in concept to the basic Bessemer process introduced 120 years ago, should have an even lower refractories consumption than the existing LD method.[41] Lastly it should be noted that even with existing techniques improvements in operating practice also tend to reduce refractories consumption: the so called learning curve effect.

The final group of factors believed to influence refractory consumption patterns concerns innovations in the refractories industry itself. It includes both the prospects for fundamental substitutes for traditional refractories and also innovations in manufacturing techniques. On the first issue the functional connotations of the term refractory suggest that any 'substitute' would be defined as a refractory. However the common refractory materials are now well established such that the development of an alternative method of containing high temperature reactions would in practice be conceived as competitive substitution. For example water is not commonly thought of as a refractory. Yet it is occasionally suggested that the increased volume of steel that could be made in a vessel with a 'non refractory' water cooled lining could render the method economically attractive. In the absence of detailed information however it is believed that energy losses through conduction would probably be prohibitive.

The general trend of innovation in the refractories industry in recent years has been towards purer raw materials, closer control and partial automation of the manufacturing process, and higher pressing and firing temperatures. Purity of raw materials and strength of the manufactured brick at service

TABLE 22

The effect of various factors on the demand for refractories

FACTOR	EFFECT
MOVEMENTS IN STEEL DEMAND,	have definite effects on the demand for all refractories
RELAXATION IN STEEL INTENSITY	general effect might be to lower total refractories consumption since non-steel processes tend to favour high quality refractories
SHIFTS TO TECHNIQUES WITH LOWER PROCESS TEMPERATURES	could lead to decreased consumption of high quality basic and high alumina varieties where alternative process chemistry is involved
INNOVATIONS IN THE STEEL INDUSTRY	since the L. D. is such a low consumer of refractories there would have to be substantial alternative benefits in any new process to justify a higher refractories cost. The general projection would therefore be for decreased refractories consumption
ALTERNATIVE METHODS OF CONTAINING HIGH TEMPERATURE REACTIONS	Decrease in consumption of all types of refractory
INNOVATION IN THE REFRACTORIES INDUSTRY	"
GENERAL IMPROVEMENTS IN OPERATING PROCEDURES (LEARNING CURVE)	"

temperature ranges are increasingly regarded as good indicators of likely service performance (see Appendix F). Although the classification of refractory products still reflects their mineral origin (silica, dolomite, clay), recent trends in refractory manufacture particularly in Japan suggest that mineralogical comparisons will eventually cease to be appropriate as composite materials are produced to a technological economic optimum for specific applications. This transition is perhaps foreshadowed in the newer LD convertors where the trend is towards using different quality refractories in areas of the convertors experiencing abnormal wear characteristics rather than just simply thickening the refractory lining.

3:4 Conclusions

The previous section introduced various factors, summarised in Table 22, which could affect the achievement of the straight line extrapolative forecasts for refractories in Section 3:2. Almost without exception the effect of these factors would be either a decrease in the consumption of all types of refractories or an increase in the use of higher quality basic and alumina products with an accelerated decline in clay and silica varieties.

As with the previous case study the primary conclusion for the study of the basic refractories industry is that the complex interactions of factors which effectively determine the demand for mineral raw materials goes far beyond questions of geological availability or mineralogical purity. Nevertheless the refractories industry is found to be 'closer' to its raw material base than the magnesium industry. The consumer is concerned that the final product should in some measure reflect the properties, physical, chemical and mechanical, of its raw material constituents whilst magnesium product consumers focus at best on the properties of the metal. It is also possible to interpret the service characteristics of a refractory product in terms of brick performance and raw material specifications whereas with magnesium implications for raw material development are a more complex function of the chosen production technology. However even in the refractories industry the technology of production, structure of the industry and market behaviour all intervene to segment the market, some areas of which can only be apparently supplied by very large manufacturers supporting costly over-heads such as research and development, and other residual complementary areas in which the many small specialist producers survive. These aspects of the refractories industry and their implications for planning for minerals development are examined in greater detail in the following chapter.

Finally to return briefly to the future role of dolomite as a refractory raw material. The mineral is currently widely regarded as the major lining material for the basic oxygen L.D. steel convertor. Despite decreased consumption in the period 1965-9 due to improved operating procedures it would appear that, in so far as the long term future of the LD is secure, so is the future for dolomite as a refractory. But it must also be recalled that the supply of high grade refractory dolomite and synthetic magnesia are the subject of monopoly in this country. Therefore a concentration in demand for dolomite refractories may suggest a restructuring of the present somewhat artificial price relationships between the two materials which are generally close substitutes. This could lead to a long term trend either to composite dolomite/magnesia materials as suggested in the previous section or, since magnesia is ultimately more refractory than dolomite, to wholesale substitution. At prsent the former possibility appears the most likely outcome.

4. INTERIM CONCLUSIONS

This chapter has attempted to provide various types of forecast of demand for the products of two of the minerals consuming industries studied. Emphasis has been placed upon the definition of the underlying determinants of demand and the likely effect of changes in such factors over the forecast period. It remains to interpret these, on the one hand, quantitative trend extrapolations and, on the other, primarily qualitative factor analyses in terms of their implications for mineral resource development. This is a major objective of the following chapter.

CHAPTER FIVE

PLANNING FOR LONG TERM MINERAL RESOURCE DEVELOPMENT

1. INTRODUCTION AND OBJECTIVES

Previous chapters have examined the practical and theoretical aspects of the participation of minerals resources in primary processing industries. A major objective of the present chapter is to further the analytical discussion of growth problems and prospects begun in Chapter Four by proposing a positive method of planning for long term minerals development. The method, called opportunity planning, is applied to the two industries discussed in Chapter Four to generate opportunities which may imply long term resource development and which should be the subject of further detailed investigation. By systematically considering the various growth strategies proposed in relation to the minerals industries concerned it is hoped to avoid neglecting unconventional opportunities which may otherwise be overlooked.

The chapter is divided into three sections. Firstly the theory and definition of planning are briefly discussed. Next a model of opportunities relevant to planning for minerals development is proposed and its construction explained in detail. And thirdly the model is applied systematically to the studies of the magnesium and basic refractories industries to arrive at a summary of key opportunities in each. The model is also applied to the third case study, the bulk materials industry, in the following chapter six in a specific regional development context.

2. THE DEFINITION AND SCOPE OF PLANNING

There are many definitions of planning which may be the result not so much of the novelty of formal institutionalised planning as the fairly haphazard manner in which it is often carried out. Some recent formulations for example include the following:

"-Planning is a goal directed decision making process"

"-Planning is the formalisation of the factors involved in determining goals and the establishment of the decision processes to achieve these goals"

"-Planning is a process whose function is to reduce entropy and increase organisation within the environment"[1]

From these and other examples planning appears to involve the development and structuring of alternative means for the achievement of an objective or the means for deciding between alternative objectives. Planning is therefore fundamentally distinguished from 'operational' decision making by virtue of its abstraction from specific situations. The planner seeks to improve the facilities for decision available to the receiver of the plan. The importance of this distinction stems from the impossibility of omniscience by the planner, the possible conflict of values and norms between planner and decision maker,[2] and the intervention of unforseeable events which may require a reordering of priorities in the specific situation eventually confronting the decision maker.

Having established a working definition of planning the problem of the scope or extent of planning in mineral resource development arises. As a matter of practice planning is well established institutionally as corporate planning, planning for urban renewal and development, regional and national development plans, and even global planning models. The need for planning is commonly unquestioned:

> "'Planning' owes its popularity to the fact that everybody desires, of course, that we should handle our common problems as rationally as possible, and that in so doing we should use as much foresight as we can command"[3]

Industrial development in general and mineral resource development in particular require sustained co-operation over long time periods such that at first sight it does appear acceptable, as Hayek suggests, to encourage a closer community of ideas and objectives. As earlier chapters have indicated however the amount of 'foresight' available over long term periods is invariably deficient whilst the complexity of individual situations often leads to ambiguous predictions or conflicting recommendations. Therefore:

> "The question is whether for this purpose it is better that the (planner) should confine himself in general to creating conditions under which the knowledge and initiative of individuals is given the best scope so that they can plan successfully, or whether a rational utilisation of our resources requires central direction and organisation of all our activities according to some consciously constructed blueprint"[4]

There are two extremes of opinion on this issue relevant to development problems. The first class of opinion is typified by 'laissez-faire' attitudes, such as those of the classical economists who place ultimate reliance on the impersonal mechanism of the forces of supply and demand as overall arbiter as to what shall be produced, at what price, and for whom.[5] The alternative 'collectivist' approach suggests that the planner, a priori, must choose between alternative objectives. The first approach seeks to provide a suitable framework within which development may take place. The second must reach far into the realm of specific organisation and direction: it must map out the chosen route to development and seek to regulate the resources at its disposal accordingly. The following features of mineral resource development suggest that application of this second approach is inappropriate:

(i) Industrial organisations are complex social systems which are often able to achieve a given objective by a number of different possibly compensating means. This is the so called principle of equifinality encountered in open (dynamic) systems theory.[6] Rigid planning tends to reduce such organisational flexibility.

(ii) Planning for minerals development often involves inheriting established problems. Directed planning tends to minimise the importance of this inheritance and frequently assumes an essentially passive environment within which necessary changes can be introduced.

(iii) Goals, objectives and purposes are finally dependent on intangible norms and values. Directed 'collectivist' planning, must a priori discriminate between alternative objectives, impose norms and values, and attempt to anticipate 'operational' decision making.

Care should be exercised however before a centralised, collectivist, planning approach is totally abandoned. For the entrepreneur in minerals development the long term uncertainties and the inevitable loss of flexibility to respond to favourable 'chance' opportunities implied in the collectivist approach do suggest a compromise. For the large corporation however which may only be concerned with major opportunities for market development in new or established areas clear cut planning directives may usefully embody the long term objectives of corporate policy and strategy. And again, in terms of public policy, an attitude of constant readiness to scrap the obsolete and innovate with the narrow aim of short term profitability is not easily reconciled with the overall welfare function of public institutions. It is therefore necessary to stress that in the following discussion the object is to develop the full range of strategies for minerals development that the entrepreneur should assess and that certain strategies may be effectively redundant where the profit function is tempered by the constraints of social welfare, long term security, or simple maintenance of the status quo.

Having said this it is clear from the industry studies that the entrepreneur cannot adopt an uncompromising 'laissez-faire' attitude either. Oligopolistic supply situations were found to be the rule, costs of entry were found to be significant barriers, considerable control over price could occasionally be exercised and so on. Considerable uncertainties also attended forecasts of future demand patterns. It is therefore unrealistic to assume that the implications of perfect competition will prevail in a plan for long term minerals development. Nevertheless the case studies suggested many opportunities for improvement and innovation such that whilst the exact timing of their initiation remains uncertain they can still be regarded as opportunities worthy of further detailed investigation. The structuring of these various opportunities is here called opportunity planning. Opportunity planning seeks to provide a simple practical alternative to the grand strategic approach of collectivist planning without invoking naive assumptions as to the totally impersonal operations of a perfectly competitive market system.

3. OPPORTUNITY PLANNING FOR MINERAL RESOURCE DEVELOPMENT

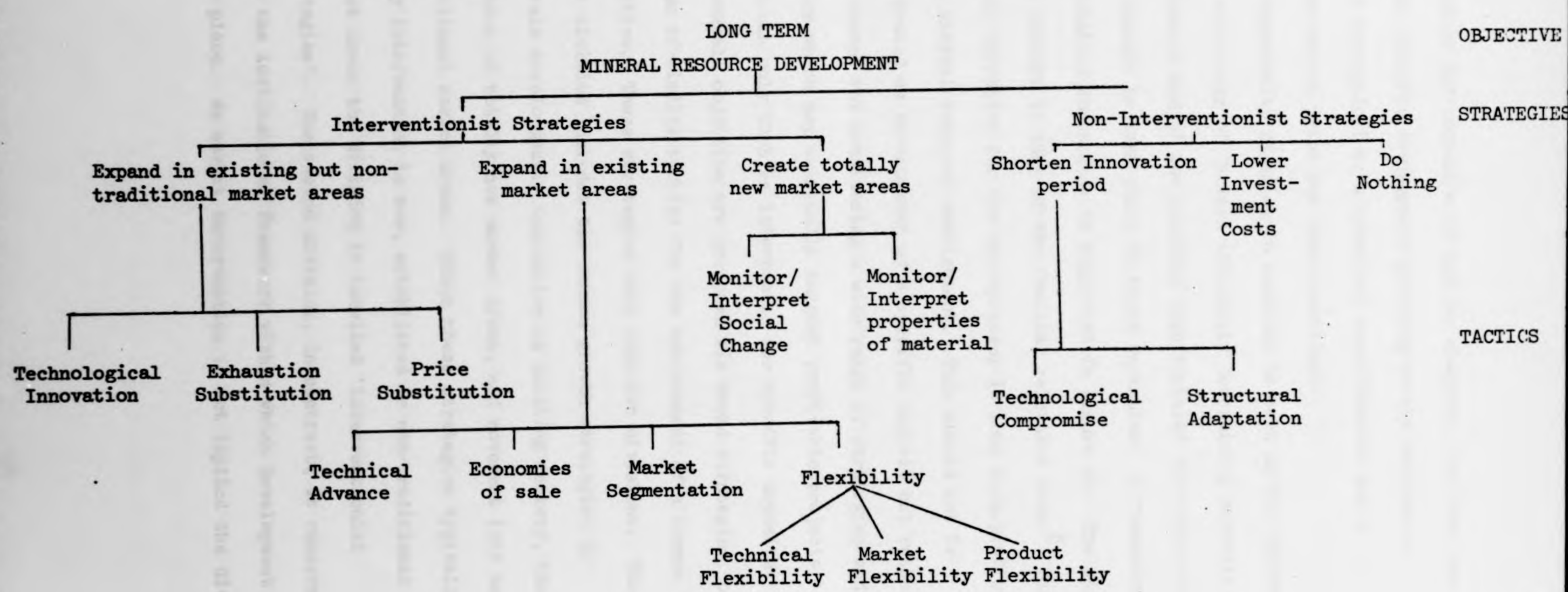
3:1 Introduction

Mineral resources derive their meaning and significance from social needs which technology enables them to fulfil. As one writer has suggested:

> "Natural resources have economic reality and significance only relative to the character and trend of technological change. They are as changeable as the technology which defines and surrounds them."[7]

Whilst this view may be extreme for such 'basic' resources as air and water, change whether the result of technological innovation, market shifts or social hiatus, is the essence of opportunity in the long term development of minerals resources. Such opportunities are not adequately reflected in extrapolations of current production methods or market configurations. Indeed from the study of the complex relations between minerals,

FIGURE 29: PLANNING FOR MINERAL RESOURCE DEVELOPMENT: A NETWORK APPROACH



technology and economics in earlier chapters, the view that mineral resource development planning merely requires a demand extrapolation, a technical specification and a current market price has been questioned.

Opportunity planning in contrast is seen as the assessment of a wide range of factors ultimately determining minerals development and of the possible opportunities which may arise were changes to take place in these variables. A framework for detailed comparison is suggested in Figure 29. The underlying concept is that of the familiar relevance tree.[8] The overall objective for the entrepreneur is long term, profitable, mineral resource development. This should not be interpreted as development of a specific deposit but rather as a reason for considering a wide range of strategies and tactics which may eventually suggest profitable projects which can only then be interpreted for specific deposits. Under the overall objective are proposed six broad strategies, or groups of similar tactics for the achievement of a common objective. These strategies fall into two divisions. The first division includes the common growth strategies in minerals development: innovation in existing markets, the creation of totally new market areas, and movement into non-traditional market areas. Since these strategies typically imply intervention in new, established or non-traditional market areas the division is labelled 'interventionist strategies'. The second division, in contrast, is concerned more with the institutional framework within which development could take place. As market intervention is not implied the division is labelled 'non-interventionist strategies'. Specific strategies in this division are concerned with the time periods and investment costs involved in minerals development. In addition a residual "do-nothing" category completes the schema. The background to this classification is now briefly examined.

3:2 Non-interventionist opportunity planning

Mineral resource development, beyond minor extensions to existing production patterns, frequently involves the commitment of substantial capital resources over long time periods with the uncertain prospect of a positive cash flow only after considerable delay. Clearly therefore if existing or new techniques can be adapted to permit a shortening of the development and running-in phases of new plant the pressure for alternative allocation of resources as a result of long term uncertainty will be reduced. In practical terms this may mean for example using techniques which are not the most advanced currently available ('best practice productivity' in Chapter Two), but which by virtue of their proven capability make a relatively earlier contribution to earnings. The importance of both function (of innovation) and structure (of receiving industry) are often overlooked in this gestation period context. Earlier chapters have indicated that whilst the technical and economic benefits (function) of a proposed innovation may be beyond question innovation is retarded by the lack of associated developments necessary to enable the full benefits of the innovation to be achieved. Two methods of shortening gestation period delays are therefore suggested:

technological compromise, and structural adaptation.

The second non-interventionist strategy concerns investment costs. Minerals development is exceptionally and increasingly capital intensive. There are many uncertainties associated with such capital commitment ranging from geological uncertainties at the one extreme, through uncertainties in long term factor cost movements, to potential shifts in demand and general trading conditions. In terms of the simple production function model of Chapter Two, as a general rule an innovation with lower investment costs will tend to gain acceptance more speedily than one which involves greater initial investment for the same product, when both innovations yield similar subsequent operating costs. Clearly it is a matter of some practical compromise between high investment costs with long term uncertainty, delays in the achievement of positive cash flow, but lower eventual operating costs and a plant with more modest investment costs, shorter gestation periods but, under an alternative technology, relatively high operating costs. The establishment of such a compromise must be a matter for detailed and specific assessments of individual opportunities. The inclusion of the investment cost strategy is however aimed at avoiding the common danger of a narrow technological viewpoint typified by Ozebekhan as 'can implies ought'.[9]

The third non-interventionist strategy provides a category for the assessment of the effects of ignoring or rejecting currently perceived opportunities. The logic of this approach lies in the view that the demonstrable deficiencies in achieving satisfactory long term forecasts are a poor basis for development planning and that on balance inertia and random unforseeable events will continue to provide some opportunity for expansion.

3:3 Interventionist strategies in opportunity planning

Chapter One stressed that mineral accumulations in themselves are virtually without function except as a solid base to the earth and in certain cases as a social amenity. With subsequent refinement however mineral products are capable of fulfilling an almost limitless range of needs in a wide variety of applications. The anticipation of the specifications that surround such end use functions provides considerable scope for the continuous assessment of opportunity in various categories open to the mineral resource developer. The present study suggests three broad strategies: the creation of totally new markets for which the mineral may be a suitable raw material, development in existing traditional markets for minerals, and expansion into existing, but, for the mineral in question, non-traditional market areas. The tactics of expansion in existing traditional markets naturally tend to attract most attention although the two complementary strategies may provide equally attractive if more uncertain opportunities of which a totally new producer for example may be more disposed to take advantage. Each strategy is now introduced individually, beginning with the creation of new market areas.

Totally new market areas for a mineral deposit may arise spontaneously as a result of social change: they may also occur as a result of directed innovation.[10] Since minerals are remote from end consumer markets the interpretation of social change as an opportunity for totally new mineral products is an especially difficult and as yet not widely practised exercise. The innovation and diffusion of a well defined consumer product such as television is understandably more manageable than the diffusion of, for example, titanium as a high temperature engineering material; or to go further, dolomite as a highly adaptable raw material with a wide range of useful properties.

On balance therefore the routes to innovation under this first strategy lie either:

(i) in monitoring social change and interpreting its implications for raw material demand

or (ii) in monitoring the properties of the raw material with a view to inventing and promoting new areas of social need

An example under the first tactic could be the trend towards mass rapid transport in urban transportation systems creating opportunities for new types of material to be used in vehicle construction. Whilst in the second category a breakthrough in alloy development may sufficiently advance the limits of electrical conductivity of known materials to make long term electricity storage a practicality.

Turning next to the strategy of expansion in existing market areas. Four tactics are considered relevant here although some overlapping is involved. They are: expansion through opportunities for technical innovation, economies of scale, market segmentation and operational flexibility.

The background to a method of market expansion through price reducing technical innovation was discussed in its theoretical context in Chapter Two. The establishment of large research and development enterprises within the existing industrial structure has progressively elevated technical innovation to a position of key importance in the growth strategy of almost any large company.[11] Many of the possible solutions to the growth problems of the industries studied in Chapter Four were ultimately interpreted in terms of more effective price competition through technical innovation. The dangers of a technological imperative were however emphasised, underlining the necessity of assessing the full opportunity costs of change.

Concerning possible opportunities afforded by economies of scale it is widely recognised that possible technical advantages of size are no guarantee of efficiency, competitive advantage or entrepreneurial ability. In theory of course viewing industrial concentration simply as a stochastic process it is quite conceivable that on average there may be an underlying long term trend towards concentration of output. But such a 'random' process need not be invoked here since economies of scale, product differentiation, the use of oligopoly power, and so on wouldseem to account adequately for the very pronounced and persistent trends towards higher concentration in the industries examined. As explained in Chapter Two, whilst there is in principle no barrier to the implementation of technical advance for improving either labour or capital productivity the apparent scope for the former has been greater in recent years. Given the objective therefore of improving relative labour productivity the conventional wisdom suggests that economies of scale are primarily a function of inhomogeneities in technology with relatively greater returns accruing to the largest 'capital intensive' plants embodying techniques not suitable for small scale operation. But even so considerable caution is necessary in attributing to 'technological necessity' trends towards concentration of output. Complex interactions of other market factors such as the desire for control over price and the achievement of bargaining powers with raw materials suppliers and end consumers must also be incorporated in any overall explanation. It must be added that large capital intensive plants require sustained periods of high level capacity operation to achieve maximum economies. The conclusion is therefore that although an opportunity to innovate with appropriate technology on a large scale may achieve desirable increases in labour productivity many other counterbalancing factors must also be assessed in any overall profitability criterion.

A possible corollary of the hypothesis of economies of scale which also deserves attention is the principle of complementarity.[12] According to this principle the bulk of an industry's output is achieved using capital intensive plants producing a fairly narrow range of standardised products whilst the small specialist producer serves that residual portion of the market which may entail low volume orders to non standard specification. The small producer has typically lower fixed overhead costs than the large manufacturer and may employ appropriate alternative production techniques. This introduces the third tactic of expansion in existing markets areas, through market segmentation. For unless the minerals developer considering expansion into existing markets is able to draw on external sources of security, it is highly probable that exercise of imperfect competition amongst existing producers and consumers would act to discourage entry. Under these circumstances by exploiting the principle of complementarity the potential entrant may prefer, at least initially, to specialise in a market area not normally catered for by the large established manufacturers. Of course this type of market segmentation need not be 'artificially' stimulated, and hence qualify as market failure in the classical sense. For it may result from alternative technologies fulfilling broadly similar areas of demand with products that are not wholly interchangeable: the valve and the transistor for example, or high alumina and silica refractories. Within the 'protected' market segment there may of course be severe competition thereby strengthening the definition of the innovation and its eventual ability to diffuse into the general market area. For example the competition for sponsorship of alternative methods of steel production using direct reduction techniques may result in a far superior reduction technique than is currently available even though direct reduction is still regarded as only capable of contributing to gross steel output in special circumstances.[13]

The final tactic for expansion in existing market areas is a temporal equivalent of structural segmentation: flexibility in plant operation. Plants with high fixed costs as a proportion of their total operating costs require long periods of unbroken operation at a high level of capacity to minimise their long run average costs. Minerals developments are typically subject to numerous disturbing influences including uncertainties in long term factor cost movements, cyclical trading conditions, social and political changes, as well as technological innovation. In such circumstances it may be ultimately advantageous for the developer to consider employing a technology which provides for a compromise between high fixed costs, low operating costs, but high levels of capacity operation and a project entailing low fixed costs and high operating costs which is susceptible to intermittent operation without serious loss of profitability. Related to this concept is the multi-purpose usage of plant employing different materials to manufacture a wider range of products participating in markets with differing, and hopefully compensating, trading characteristics.

The third and final strategy for expansion concerns development of existing, but non-traditional market areas. To a certain extent this strategy includes straightforward substitution but it differs significantly from the other strategies in that what is required is the reassessment of the market role of the materials or the assessment of its suitability for existing applications for which it had not previously been considered. Three tactics are proposed (Figure 29): technical innovation, exhaustion substitution, and price substitution. Under technical innovation are covered aspects of the materials' technology which create opportunity through what Boulding calls "widening the decision agenda" and de Bono characterises as "lateral thinking or thinking aside".[14] Examples of opportunity planning here might be the exploitation of magnesium's properties as a neutron absorbant,[15] the reported usage of limestone as studio snow,[16] or the rejuvenation of the mica industry with the development of applications which no longer require massive sheet mica as a raw material.[17]

In view of the numerous current prophecies of critical resource shortages it might be held that exhaustion substitution will assume an increasing importance as a method of minerals development in non-traditional markets. It is becoming clear however that many of these prophecies were based upon long term extrapolations which did not assume that adequate forewarning could enable appropriate conservation measures to be devised. Whilst therefore prophecies of the mining of 'common rock' for infinitesimal concentrations of metals and minerals appear irresponsible it is clear from the present study that a range of techniques are frequently available and these may be adapted equally to raw material anomalies as to market peculiarities. And where absolute shortages apply a transition period may be available for progressive substitution in individual end uses. Of more immediate interest however is the final tactic of price substitution. The situations covered here are where, whether by virtue of artificial price hiatuses in the non-traditional industrys' raw material supply pattern or through long term relative price reduction through technical innovation, the receiving industry is persuaded to review its raw material requirements. An example could be where the price of zinc rose to such a level that an individual consumer, such as the diecasting industry is encouraged to shift to cheaper materials such as aluminium or magnesium.[19]

Having tentatively proposed a number of strategies relevant to long term minerals development, the immediate objective is to use this approach to structure the alternative opportunities currently available in the two industries studied in Chapter Four. The third study industry is similarly examined in the following chapter (Six), in an appropriate regional development situation. Again it is emphasised that the planning process is separate from specific investment decision processes which must necessarily incorporate for example the technical characteristics of individual deposits, the availability of investment capital and numerous other factors.

4. OPPORTUNITY PLANNING: DOLOMITE AND THE MAGNESIUM INDUSTRY

Dolomite participates indirectly in metal markets through the reduction of the mineral to magnesium metal in various processes of which the ferrosilicon route (Pidgeon process) is the most common.[20] Dolomite may also indirectly participate in the electrolytic production process through its role in the intermediate extraction of magnesia from sea water. Clearly therefore the future development of the magnesium industry could be of considerable significance in the development of dolomite. However it will be recalled that a third route to magnesium involves electrolytic extraction of the metal from evaporated brines. Brines of suitable quality are not nearly as readily available as sea water and solar preconcentration is not always practicable. On the other hand recent experience with the Pidgeon process has caused it to be regarded as at least temporarily outmoded.[21] As indicated elsewhere therefore the future for magnesium technology is seen mainly in terms of new brine based operations complementing older established sea water routes. On balance the following remarks concerning opportunities in the magnesium industry will be subject to the assessment of suitable technologies for specific development projects.

4:1 The non-interventionist strategies

41:1 Shorten innovation period

Referring to the network proposed in Figure 29, and focussing on the non-interventionist strategies the prospect of shorter innovation periods for magnesium developments could be most beneficial. The case of one major producer taking over ten years to pass from project commitment to plant construction[22] suggests that periods of up to twenty years may be required for the full effects of market entry to be realised. The complex interdependence of innovations on associated developments necessary for successful entry was described in some detail in Chapter Four and Appendix G.

Under the tactic of structural adaptation it is suggested that considerable scope exists for a realignment of the magnesium industry's traditional 'product' role in terms of a functional role which could lessen the compatability gap between existing production methods, market definitions, and proposed innovations. Schon (1971)[23] has suggested that organisations which are integrated with respect to a functional objective such as transportation energy, data processing or housing, are better placed to take advantage of opportunities resulting from social change. At the operational level shorter innovation periods and increased scope for profitable innovation appear to depend partly on internal organisational characteristics such as administrative efficiency, entrepreneurial ability and general susceptibility to change, and partly on the characteristics of innovations as perceived by potential consumers of magnesium products. These characteristics introduced in Chapter Two include relative advantage, compatability, complexity, observability and trialability, and they have been shown by Rogers (1971) and others to strongly influence the rate of diffusion of innovation.[24]

Under the tactic of technological compromise Chapter Four and Appendix E have stressed the underexploited range of magnesium technology. Various methods are suitable under alternative technical and economic operating conditions which may yield development opportunities appropriate on the one hand to specific market situations and on the other to raw material availability.

41:2 Lower investment component

The most promising opportunity under this strategy heading concerns the possible long term revival of the Pidgeon process, or adaptation of the broadly equivalent French Magnétherm, or Italian SIIM-Ravelli processes at modest output levels with relatively low investment costs.[25] Such a revival would however probably be related to the development of rapidly diversifying geographically concentrated markets which could support an effective counterpart to the mini mill concept in steel production. This strategy may also be relevant in developing or poor countries which have no established tradition of steel making yet wish to economise on foreign exchange through the development of domestic primary production in certain sectors of the metals market. Brubacker (1967) has described equivalent developments in the aluminium industry under the heading of "pots and pans markets."[26]

41:3 "Do-nothing"

Opportunities for long term expansion in the magnesium industry based on the inertia of current trends appear from the statistical extrapolations of Chapter Four to be moderately encouraging. At the simplest level extrapolations indicated a forecast base of world demand in 2000 at 1.21 million tonnes with a possible range of between 0.84 and 1.33 million tonnes.

This indicates a shortfall of between 500 thousand and one million metric tonnes over existing world supply capacity of approximately 300 thousand tonnes. On this basis there are clear opportunities for the addition of at least two major magnesium plants to existing capacity even under the most pessimistic of initial assumptions. Present trends suggest that such plants could be geared to supplying the growing needs of the aluminium industry or to expanding existing markets in diecast components particularly for the automobile industry.[27]

4:2 The interventionist strategies

42:1 Creation of new market areas

The creation of totally new market areas is frequently cited as a fundamental development priority for the magnesium industry.[28] It is widely seen as providing opportunity for subsequent expansion by a new entrant into the existing traditional market areas for magnesium and its alloys. Under the tactic of monitoring the properties of the material for suitable opportunities it is emphasised that magnesium's lightness with strength particularly in alloy form is still its greatest underexploited advantage.[29] There is an urgent need for initiative in developing these properties even before totally new properties are assessed for their market potential. It is also the case that, according to the model of diffusion of new materials in Chapter Two, creative exploitation of a material's technical characteristics occurs only at the relatively late stages of diffusion: stages not yet reached by magnesium.

The alternative tactic of monitoring social change and interpreting new roles for the material is a somewhat neglected area in the diffusion of magnesium. A long term effect of the energy crisis for example in stimulating wider sensitivity to the weight saving characteristics of structural materials could be one such opportunity for magnesium. The role of magnesium as a pyrotechnic may also be in need of revision in view of the change in character of warfare in recent years.

42:2 Expansion in existing traditional market areas

The four methods of expansion in existing market areas suggested include opportunity arising from technical innovation economies of scale, market segmentation and flexibility of operation.

In spite of the distorting influences of market failure in the magnesium industry the careful combination of appropriate technical innovations with a realistic and comprehensive evaluation of opportunity costs and benefits continues to provide a major source of opportunity for expansion in the industry. Several key problems in technology, marketing, price competitiveness and consumer education were examined in Chapter Four. The barriers to thesolution of these problems were found to be not insurmountable although the relevance of sociological and psychological variables remains hard to assess. On the other hand the technology is available to enable production costs to be lowered to a competitive level, melting costs can also be lowered using new techniques, and improved economical methods of corrosion resistance exist. The scope for changes in the international conditions of trade which have possibly tended to obscure magnesium's advantages is also presently considerable. The enlarged European community may eventually stimulate new projects within the community for the production of primary magnesium.[30]

Turning next to economies of scale, in capital intensive industries such as primary metals production the potential for profitable scale economies is as much a reflection of demand characteristics as of inherent technical production relationships. There is little evidence to suggest that the emerging technology of magnesium production or the characteristics of demand for magnesium products require certain minimum levels of output for profitable operation. Certainly plants ranging in designed capacity from 10-120 thousand t.p.a. are apparently in operation. An important 'scale' phenomenon however is the integrated nature of magnesium production either as part of larger chemicals complexes, or, through vertical and horizontal integration, by participating in a wide range of extractive, productive and manufacturing operations. It is increasingly evident that the single product approach in primary metals manufacture incurs the considerable risks of demand shifts, functional obsolescence, and of course long term capital commitment. It is anticipated therefore that any newcomer to the magnesium industry would tailor the scale of his operation to well defined characteristics of demand rather than to any imperative of scale implied on technical grounds alone.

The third strategy for expansion in existing markets concerns market segmentation. It will be recalled that the principle of complementarity has the effect of segmenting the industry from primary production through to the major end use categories. Thus the small producers are typically captives of the titanium or aluminium industries. Even the large manufacturers tend to promote market segmentation by competing under brand name 'protection'. Whilst the theoretical result of such artificial segmentation may be that of inefficiency, an earlier section suggested that the protection afforded by such segmentation could enable a new entrant to establish himself even though because of higher operating costs he finds it necessary to charge a higher price for his product. In the durable consumer goods sector for example, magnesium's technical advantages could be exploited under brand name protection serving the dual purpose of much needed consumer education.

Under the final strategy for expansion in existing markets, increased flexibility, are included several opportunities already introduced. Under technical flexibility the alternative magnesium production techniques clearly offer the opportunity to tailor technology to perceived market characteristics. The relevance of product flexibility in what is traditionally understood as a single product industry is limited to the opportunity to capitalise on new alloy developments. The need for more commercially competitive magnesium alloys has already been specified.

Thirdly, for market flexibility it was established that although magnesium products participate in a wide variety of market areas the prevalence of artificially restrictive trading conditions suggests that the opportunities for an individual producer to compensate for depressed market conditions in one sector through increased participation in another are generally limited.

42:3 Expansion in existing but non-traditional market areas

For an existing producer or new entrant in the magnesium industry contemplating expansion there are considerable practical differences between meeting the challenge of competition in existing demand categories and actively seeking out new areas of established demand in which the product has never previously competed. Three opportunity categories are suggested: technical innovation, exhaustion of alternative raw materials and price substitution.

A common problem with innovation in non-traditional markets is that of compatability. It may be an inadequate statement of the true costs of switching to an alternative material, for example, to cite only selected characteristics for the evaluation of economic benefits. Thus it has already been indicated that magnesium has many technical characteristics which could yield cost savings in non-traditional applications such as pressure die casting. But specific proposals must incorporate the investment costs involved in any changeover.[31] On a broader front security of supply, and stability of price and supply as well as technical advantages are often cited as encouraging indicators of magnesium's diffusion potential. This is particularly so in non-traditional markets which are subject to hiatuses in supply through political or other forms of intervention, or which experience rapid fluctuations in price either through real imbalance in supply and demand or through the induced effects of commodity speculation. As the model of materials diffusion suggests however, magnesium is unlikely to substitute wholesale for other materials in non-traditional market areas except in the unlikely event of a major crisis in the competing industry. Diffusion is rather seen as piecemeal innovation leading to a gradual replacement initially in a narrow range of applications.

The virtually unlimited geological availability of magnesium 'ores' was once the focus of much opportunistic speculation concerning the metal's long term development.[32] The case study conclusion was however that such appeals to geological abundance are misplaced: other technical and economic factors take precedence. A more pragmatic view of the opportunities for expansion in the substitution-by-exhaustion role arises from consideration of the geographical distribution of the raw materials for many of magnesium's substitutes. As such it may not require geological exhaustion of alternative resources in politically sensitive regions for producers and consumers to assess the universal availability of magnesium 'ores' more favourably. There are obvious implications for long term substitution in the currently uncertain situations regarding raw materials supply for plastics, aluminium, timber, copper, tin, and zinc production.

Concerning price substitution, over the long term future (to 2000) the U.S. Bureau of Mines has forecast a cheapening in the price of magnesium relative to its closest substitute, aluminium.[33] Whilst such forecasts must be treated with caution, the range of techniques available for magnesium production, the present relatively modest scale of the industry, and the artificially high price levels presently obtaining in some market sectors, tend to confirm that magnesium has substantial competitive capabilities yet to be exploited in non-traditional

TABLE 23

CHECKLIST FOR LONG TERM DEVELOPMENT IN THE MAGNESIUM INDUSTRY

STRATEGY[1]	SHORTEN INNOVATION PERIOD	LOWER INVESTMENT COSTS	'DO NOTHING'	CREATE TOTALLY NEW MARKET AREAS	EXPAND IN EXISTING MARKET AREAS	EXPAND IN EXISTING BUT NON-TRADITIONAL MARKET AREAS
MOST PROMISING METHODS	Functional Re-alignment, Technological Compromise	Mini Mill Concept	Captive Supply	Exploitation of weight saving characteristics	Resolution of key technical problems Complementarity concept	Exploitation of shortages of alter-native commodities
OVERALL RANKING[2]	1	4	5	3	2	6
PAGE REFERENCE	182	184	184	185-6	186-8	189-191
OVERALL RECOM-MENDATION FOR FUTURE WORK[3]	1	2	3	1	1	3

Notes:

1 See Figure 29 for a list of strategies and tactics
2 Overall ranking in terms of fertility in generation of opportunities, see text references
3 Key: 1 = strongly recommended for future work at both strategic and specific project levels
2 = specific tactic(s) worth following up
3 = marginal interest at present

market areas. Again it must be noted that basic price comparisons do not incorporate the essential notion of the costs of change but as a first approximation present trends do indicate a favourable relative cheapening of magnesium especially in 'volume' applications.

4:3 Conclusions: dolomite and the magnesium industry

The foregoing discussion has attempted a systematic correlation of current opportunities for long term development in the magnesium industry. Clearly this process of structuring alternative and to some extent complementary opportunities can only be understoood as a first step in any subsequent assessment of specific mineral deposits or investment proposals, beyond the scope of the present study. Similarly, abstraction from specific proposals has involved a great deal of simplification not as yet adequately supported by theoretical analysis. With these limitations in mind Table 23 summarises the relevance of various strategies in the long term development of the magnesium industry according to their perceived fertility in the generation of the opportunities described. Also included in this table is a checklist of those methodological concepts which were found to be particularly promising for future development and an overall recommendation for further detailed research and development.

5. OPPORTUNITY PLANNING: DOLOMITE AND THE REFRACTORIES INDUSTRY

Dolomite participates indirectly in metal markets through the production of magnesium. As a raw material for industrial applications however the range of markets is much wider. When applying the proposed scheme (Figure 29) for opportunity planning therefore it is emphasised that future opportunities for dolomite to serve in industrial applications may well arise in existing or new demand categories not examined in the present study (c.f. Figure 12). However it is believed that the principles governing the mineral's use in such alternative applications are typified by its role in the basic refractories industry.

5:1 Non-interventionist strategies

Under the first non-interventionist strategy: shortening innovation/gestation periods it is clear that the refractories industry is already relatively efficient in the diffusion of innovation within its existing, functional, structure. The industry has long since evolved from the single through the multi-product stages[34] to an adaptive role entailing the provision of whatever materials are perceived as suitable for the provision of heat resistant linings for reaction vessels. The large manufacturers of refractory products can now react relatively swiftly to changes in trading conditions and in accordance with the modeldiscussed in Chapter Four undertake to produce materials which compromise between both the producer's and the consumer's technical and economic objectives.

At the advancing fringe of research and development in the refractories industry the communication of innovations and co-operation in non-confidential technical matters is instrumental in preventing the development of educational and psychological barriers.[35] It also effectively lowers the diffusion period for new products.

Concentration in the steel industry has probably assisted in this respect. For present purposes therefore it is concluded that the opportunities for innovation on the basis of shortening innovation/gestation periods either through technological compromise or structural adaptation are minimal in the industry's already relatively efficient framework for diffusion.

The second strategy concerns the investment component of innovation. The structural and behavioural characteristics of the refractories industry were examined in detail in Chapter Three, and the principle of complementarity was indicated as having considerable significance in the trend towards rationalisation and concentration. Whilst the current oligopolistic structure has resulted in considerable technical rivalry amongst the large manufacturers further concentration, to place the U.K. industry on a strong European competitive footing, remains a long term possibility.[36] In the residual market areas not catered for by the large manufacturers the present study suggests practical opportunities for innovation in high quality dolomite refractory production. The current trends towards increasing absolute purity and strength at high temperatures suggest that some of the traditional U.K. sources of dolomite are increasingly inferior in technical quality.[37] These deficiencies will become more apparent as the steel industry attempts to refine its refractory purchasing policies to provide for a more sensitive operation of the selection model advocated in Figure 25. Although such opportunities for entry into refractories manufacture are by no means on the scale of the existing major manufacturers the residual but potentially promising market situations in such specialist roles may enable appropriately higher prices to be charged and may entail lower overhead and capital cost burdens than a strategy of entry on a grand scale.

Under the third, residual, non-interventionist strategy it will be recalled that the statistical trends in refractories consumption indicated various shifts in demand which occurred in part as a result of technological change and technical improvements in the steel industry over the past fifteen years. In particular the innovation and diffusion of basic oxygen steelmaking has resulted in considerable opportunities for dolomite to displace other basic refractories as the major lining material for L.D. steelmaking vessels. Under the inertia of present trends therefore it is suggested that dolomite will increase in significance as the L.D. diffuses further in spite of improved operating practices resulting in decreasing unit consumption. But over the long term this situation will only be maintained if current price differentials especially between dolomite and synthetic magnesia persist.

5.2 The interventionist strategies

52:1 Creation of new markets

The creation of totally new market areas for refractories would depend on the emergence of fundamentally new high temperature processing or manufacturing situations requiring refractories. It is easily overlooked that the particularly arduous operating conditions experienced in the steel industry, although providing insight into the conditions determining the demand for refractories in general, are comparatively extreme and not commonly experienced amongst the majority of other relatively small, irregular, consumers of refractories. It also seems probable that new processes comparable to steel conversion by oxidation are unlikely to be adopted with such high 'waste' energy coefficients. New industries will also be reluctant to waste increasingly costly energy resources on the destruction of expensive refractory linings. The revolutionary float glass process for example incorporates extremely durable zircon based refractories as the lining for the melting chamber. In such a continuous process premature lining failure is particularly undesirable. It is also significant that a number of new iron and steelmaking processes have recently been discarded or delayed at least partly because of their high levels of refractory consumption: the continuous ironmaking process (CIP), the Kaldo and Rotor and spray and continuous steelmaking process being current examples.[38]

The conclusion for totally new refractory applications is therefore that even if such new areas were to emerge as a result of social change, the current outlook for energy suggests that economy in its usage will tend to reduce the scope for basic refractories in such end uses.

52:2 Expansion in existing market areas

The four tactics considered under this heading are technical innovation, economies of scale, market segmentation and flexibility. In the first case considerable effort is now devoted by all the major refractories producers to improving their products' technical and economic competitive abilities in existing traditional markets. Since the steel industry is by far the largest single customer for refractories and is likely to remain so even over the long term, it is understandable that major research and development effort should be concentrated in this sector. It is increasingly apparent that, subject to the operation of the model of refractory selection proposed in Chapter Four, consumers are over the long term willing to pay for improvements in performance specifications. But again it is necessary to stress that characteristics of the innovation such as compatability and observability (Rogers), are vital in the overall calculation of relative advantage.[39] Hence in a steelplant situation innovations resulting in marginal improvements of say two or three heats in the campaign life may be offset by costly rescheduling problems elsewhere in the plant such that only innovations which are perceived as significant by the steelmaker can be profitably considered. This goes some way to explaining why innovations are not triggered with each buoyant phase of the steel cycle, and accords reasonably with the hypothesis of diffusion in that a 'crisis' is required before the developing innovation can break through successfully. It is therefore suggested that a potential entrant must assess such aspects of his raw materials as technical premiums (especially high purity and hot strength) in terms of the minimum increment in service performance necessary to justify the associated 'costs of disruption'. For otherwise it is improbable that the entrant would be able to match the service provided by existing producers.

Under the second tactic of economies of scale it is clear that there have been significant moves towards concentration in the refractories industry at least in part to achieve economies of scale in manufacturing operations. The increasingly diverse range of end products now available, whilst a source of frustration to those who would benefit from homogenisation and standardisation is a source of opportunity to a potential entrant wishing to exploit the complementarity principle. Although considerable productivity improvements have been achieved in refractory manufacture most of the processes involved are still carried out on a batch basis. Where semi automation is technically feasible as in the tunnel kiln firing of bricks or in the sea water magnesia process relatively greater throughputs are achievable with larger individual units. But again the effect of cyclical trading conditions is to recommend extreme caution in the pursuit of such scale economies if the costly accumulation of stockholdings is to be minimised; if prohibitively high fixed costs are not to be incurred; and if the honouring of large raw materials contracts is not to result in severe short term cash flow problems. On balance therefore it is concluded that the technology of refractory manufacture is susceptible to division without necessarily incurring a loss in competitive ability at relatively small output levels and with a possible gain in flexibility of production operations.

The refractories industry provides numerous examples of small specialist producers who compete in isolated areas of the overall market where the major manufacturers may not have the relevant expertise or the desire to participate in irregular, low volume markets possibly involving relatively labour intensive production methods.[40] Certain refractory shapes still have to be moulded by hand for example, or high chemical purity specifications may necessitate the development of a special refractory for occasional application in the glass industry. It is important to emphasise that firms participating in these isolated market sectors are not necessarily contributing to market failure in the classical sense. They are frequently highly competitive amongst themselves and perform the useful role of complementing the large manufacturer's range of products and services. The potential role of high quality dolomite refractories has already been mentioned. It is suggested that such a potential demand could be specifically exploited through entry into refractories production under a specialist role in such a 'protected' market sector.

Finally under the heading of flexibility opportunities for entry through market, product, or technical flexibility are considered. It will be recalled that the organisation of the refractories industry to fulfil a specific social function, the provision of heat resistant linings for reaction vessels, implies that wherever such applications arise the industry will adjust to providing the necessary materials. It is clear therefore that unless the new producer has interests outwith the refractories industry the scope for manoeuvre between markets during adverse trading conditions is not encouraging and under the present industry structure likely to remain so. As has already been discussed there is however considerable scope for product flexibility in refractories manufacture even within quite narrowly specified areas of the total market as for example within specific temperature ranges or varied chemical conditions of operating environment and so on. Again however the specialist is particularly susceptible to general fluctuations in trading conditions and care must be taken to ensure that unusually profitable ventures during buoyant trading periods may not experience equally extreme losses during the inevitable periods of depressed demand. And lastly under technical flexibility it has already been noted that the technology of the refractories industry is not a priori limited to output levels above a specified minimum although the technical characteristics of some elements such as the operation of kilns sets some limits on the potential for intermittent operations.

52:3 Expansion in existing, but non-traditional market areas

Three expansionary methods are considered under this heading: technological innovation, exhaustion substitution and price substitution. The functional definition of the refractories industry tends to obscure attempts to identify opportunities for refractories to serve in market areas which were already in existence but which had not previously used refractories. The strict analogy with the magnesium industry would be where an industry employing a heat using process which had not previously used refractories, is persuaded to innovate such materials either because of advances in refractories performance, or through exhaustion of competitive materials, or through favourable price comparisons with refractories.

In practice such opportunities are rare in the refractories industry in comparison with the weaker case of substitution resulting from technical change in a traditional consuming industry which necessitates a shift in the type of refractory product consumed. As a generalisation there have been widespread incentives in many heatusing primary processing industries to increase output through virtually continuous operation and higher average processing temperatures. This has in many industries (including steel, glass, cement, copper), resulted in a progression partly or wholly from low alumina to silica, to high alumina, and eventually to basic refractories. It clearly requires analysis of individual technologies in consuming industries to determine the rate of advance along this trend in future years. It is also uncertain as to whether there are ultimate, technical, limits to the performance of refractories in service conditions. Very few refractories, with the possible exception of silica, can be made to maintain their mechanical functions to within even a wide margin of their constituents theoretical fusion points. It is therefore provisionally concluded that there will continue to be scope for the innovation of technically superior if more expensive refractory products where warranted by change in the operating conditions of the consuming industries. The prospects, however, of building a strategy of entry to refractories production solely on the basis of technical innovation creating demand in non-traditional market sectors, are not seen as presently encouraging.

Most refractory raw materials are geologically available in unlimited quantities. Of the closest potential substitutes for dolomite however in existing traditional applications, natural magnesite is becoming increasingly difficult and expensive to produce to the high levels of chemical purity now demanded. Sea water magnesia on the other hand is only limited by the purity of the dolomite used in its extraction. Current evidence suggests that the long term advantage will lie with the synthetic materials with the limited exception of some outstanding natural cryptocrystalline magnesites.[41] Indeed where the current price differential between dolomite and magnesia based refractories shifts towards a more equal relationship it is anticipated that in spite of geological availability and far from substituting for other materials in non-traditional applications dolomite will be increasingly displaced in many of its own traditional refractory applications. Attention has already been drawn to the alternative long term possibility that simple mineralogically based product definitions of magnesite, periclase and dolomite may be subsumed in a trend towards the production of refractories with varying calcium and magnesium contents according to technical and economic optima for specific applications. Whilst therefore the opportunity for substitution through geological exhaustion is viewed as unimportant even in the long term future of the basic refractories industry,it is suggested that present trends in respect of purity and mechanical properties will make some deposits effectively obsolete whereas others will acquire identifiable technical premiums.[42]

The major preoccupation under the final tactic, price substitution, in common with the other tactics under the overall strategy is not with substitution of refractories for other materials but rather with the circumstances in which one refractory product substitutes for another. Whilst refractories cannot be selected solely on the basis of cost minimisation,since technical considerations intervene,it may be that in some areas of the industry informal pricing policies have acted to maintain prices at artifically high levels, giving a potential entrant limited scope for defraying his costs of entry provided it is in a 'protected' market sector

TABLE 24

CHECKLIST FOR LONG TERM DEVELOPMENT: DOLOMITE AND THE REFRACTORIES INDUSTRY

STRATEGY[1]	SHORTEN INNOVATION PERIOD	LOWER INVESTMENT COSTS	'DO NOTHING'	CREATE TOTALLY NEW MARKET AREAS	EXPAND IN EXISTING MARKET AREAS	EXPAND IN EXISTING BUT NON-TRADITIONAL MARKET AREAS
MOST PROMISING METHODS[2]	-	Develop Specialist Roles	Exploit natural development of dolomite in L.D. steelmaking	-	Complementarity Principle Technical flexibility	Higher purity raw materials Technical substitution
OVERALL RANKING	6	3	2	5	1	4
PAGE REFERENCES	193	194	195	195-6	196-200	200-203
OVERALL RECOMMENDATION FOR FUTURE WORK[3]	3	2	2	3	1	2

Notes

1 Refer to figure 29
2 Based on fertility in generation of opportunities, see text references
3 Key: 1 = strongly recommended for future work at strategic and specific project levels
2 = specific tactic(s) worth following up
3 = marginal interest at present

which is not likely to attract retaliatory measures from established producers.

5:3 Conclusions: dolomite and the refractories industry

In so far as the development of the world steel industry to the end of the present century can be forecast largely in terms of the existing LD process, and in so far as the present price differentials for refractory products are maintained, dolomite has a secure and growing long term importance as a refractory raw material. Further work is however necessary to determine whether the simple analytical method employed is applicable to dolomite in non refractory industrial applications and to other industrial minerals in general. It is also concluded that the present structure of the refractories industry already provides for the efficient generation and diffusion of innovation. On balance therefore it is suggested that practical opportunities for entry into dolomite refractory production will be limited to the exploitation of high quality dolomite materials for specialist roles in the refractories industry. A checklist of opportunities and recommendations is provided in Table 24, whilst specific implications for possible minerals developments in the Highlands of Scotland are reviewed in the following chapter.

CHAPTER SIX

MINERAL RESOURCE DEVELOPMENT IN THE HIGHLANDS

1. INTRODUCTION AND OBJECTIVES

As was indicated in the Preface, the present study in technological economics arose from the problem of identifying those factors which constrain long term minerals development in the Highlands of Scotland. Earlier chapters have ranged over the whole scheme of minerals production from raw materials to end consumer in the belief that some of the technological economic relationships examined could be of wider significance. For the present, however, it will be recalled that the three case study industries were chosen partly because of their common dependence, in varying degrees, on the mineral dolomite as a raw material. As the Highlands of Scotland contain considerable geological reserves of the mineral, an opportunity is therefore afforded of contrasting the raw materials requirements of three very different minerals consuming industries and of interpreting these requirements as opportunities for potential minerals developments in the Highlands.[1] A first major objective of the chapter is to propose a check list of factors which are relevant to long term minerals development problems.

Whilst it is clearly beyond the scope of this study to present a comprehensive plan for specific development projects, a second objective is to determine how the opportunity planning network proposed in Chapter Five could generate development opportunities relevant to the Highlands situation. For this purpose the third case study, that of the bulk materials industry, is again taken up and the practical problems of long term planning in a rapidly changing regional situation are examined.

As is well known the past three years have witnessed an unprecedented surge in oil exploration and development activity in Scotland such that there is now considerable speculation as to the long term on-shore implications of such work.[2] There are clearly great uncertainties attached to any forecast of the impact of oil and oil related development which, in the last analysis are partly geological and partly political. As such therefore no attempt can be made to construct a minerals development plan which incorporates in a comprehensive manner the anticipated impact of oil development. However throughout the chapter attempts are made to deduce sectoral implications and a small number of directly related opportunities are identified.

Finally it is worth noting that, almost since the present study began, the terms of reference for development in the Highlands have changed considerably. To quote a recent report:

> 'The area's economy has traditionally been based on agriculture, forestry and fishing, but recent prospects have arisen for economic growth based on new industries such as tourism and those based on North Sea oil exploration ... The effect of oil will be to induce further dramatic growth, particularly in the Moray Firth area and the Shetlands, resulting in substantial immigration. The problems will not be those of generating growth but of controlling it. For this reason it will probably be undesirable before 1985 to allow any developments such as refineries in the Moray Firth, or Shetlands, or rig assembly plants on the West Coast, which are not strictly necessary to achieve the objective of a fast rate of exploitation, or are not technically necessary. Such developments will only exacerbate what are likely to be difficult economic and social problems."[3]

TABLE 25

CHECKLIST OF FACTORS INFLUENCING MINERALS DEVELOPMENT IN THE HIGHLANDS OF SCOTLAND

1. Geological availability, assessment, and technical specifications.
2. Time periods involved in minerals development.
3. The Investment Criterion: The costs and risks of minerals development
4. Technical Advance and the Opportunity Costs of Change
5. Factor cost movements
6. Demand characteristics
7. General Trading Conditions
8. Specific Market Characteristics
9. The availability of capital
10. Transport Costs
11. The characteristics of substitute materials
12. The stage of diffusion of a mineral material
13. Entrepreneurial ability.

2. THE CONSTRAINTS ON LONG TERM MINERALS DEVELOPMENT IN THE HIGHLANDS

From empirical studies of minerals consuming industries (Chapters Three and Four), and an examination of relevant theoretical problems including the diffusion of new materials, opportunity costs of change and long term forecasting (Chapter Two), a preliminary check list of factors which are believed to influence minerals development is abstracted in Table 25. At the outset the purpose of this table is to aid the entrepreneurial minerals developer. However alternative interpretations representative of national and regional governmental and local community values and norms must also be anticipated in any specific development plan.[4] This emphasises the conclusion that in practice every minerals development exercise is unique and involves substantial elements of risk. For example no mineral deposit can be precisely assessed in terms of its economically recoverable reserves over the life of the prospect because of the changing definition of such reserves (Chapter One). And over the long term demand characteristics for minerals at the end of the chain of production tend to be particularly volatile. The following remarks are therefore intended as a characterisation of the general problems that may constrain minerals development in the Highlands and do not refer to specific ventures.

2:1 Geological availability, assessment, and technical specifications

Firstly (Table 25) there is the technical problem of the specification of a mineral resource, that is to say the definition of economically extractable reserves. Minerals and their processed derivatives are capable of fulfilling a wide variety of social functions (needs). But being relatively remote from end consumer markets there are inevitable delays in feedback of information on the particular technical characteristics of a mineral which may render it suitable for current or potential applications. This has apparently resulted in a tendency to regard technical specifications as inflexible points of departure in the assessment of new mineral prospects. As earlier chapters have suggested the effects of innovation and shifts in the structure of demand require a more flexible attitude in the assessment of mineral deposits which should ideally commence with identified areas of current or potential demand and interpret these in terms of raw materials characteristics and not vice versa. Clearly there are practical problems in achieving the necessary degree of communication. But it is apparent that many exercises in minerals development are undertaken primarily as exploration exercises which induce technical and economic evaluation only subsequent to fieldwork prospecting. The simplified pattern of activity is therefore

(i) The availability of capital (grants, subsidies, tax allowances, retained earnings etc.) to fund exploration.

(ii) A broad formulation of exploration activity.

(iii) The discovery of 'interesting' mineral accumulations

(iv) The comparison of current technical specifications with the characteristics of the new minerals prospects.

(v) Economic evaluation (markets, distribution, processing, primary extraction etc.) on the basis of reserves defined from the given technical specifications.

Although a simplified generalisation of the decision processes involved in the preliminary stages of minerals development, it is believed that this has been the background to minerals activity in the Highlands of Scotland for many decades. When it is also recalled that exploration work which does not result in favourable evaluation at stage (v) may never be made public it is clear that a significant fund of accumulated information is being wasted and that unnecessary duplication of exploration effort is involved.[5] The present study suggests that mineral resources are constantly subject to redefinition according to a complex interplay of, primarily, technical and economic factors. In this sense 'technical' specifications are never immutable and the best methods of long term minerals development planning regard both the end use application and the social function (need) served by that application as having changing implications for minerals development. For example until quite recently iron was regarded as a tolerable impurity in basic refractories (magnesite, magnesia and dolomite) since it provides a 'hard burn' or greater degree of densification during the firing stages of brick manufacture. Now however it is increasingly appreciated that the fluxing characteristics of the various iron containing minerals which aid densification during manufacture also effectively lower the fusion point of the refractory brick in service. Hence a low iron dolomite, other things being equal, is now at a technical premium although it is doubtful whether this information has yet been used to guideminerals exploration. On the other hand it is ironic that attempts to produce magnesium metal by the Pidgeon process (direct reduction with ferro - silicon) in this country failed largely because of insufficient attention to the specifications of the dolomite used for this process in its original form in Canada.[6] The conclusion therefore is that over the long term mineral resources and end use applications must be regarded as mutually self-determining with undue emphasis on one factor leading to inadequate comprehension of the effects of changes in the other.

2:2/3 Time periods, investment costs, and risk in minerals development

The general influence of long gestation periods and high risks with substantial capital commitment in minerals development projects has been examined in theoretical and practical contexts in earlier chapters. Uncertainty in respect of long term factor cost and demand movements, and general trade constraints including political intervention, restrictive practices and barriers to entry and innovation were all seen as inhibiting the commitment of risk capital in the minerals industries. Conversely the current trend is to view minerals development only in terms of major capital intensive projects in areas with poorly developing indigenous markets necessitating the situation of secondary processing and refining close to end consumer markets with only the primary extractive and processing activities located in the area of the minerals deposit. Other chapters in the present study have developed alternative schemes of minerals development planning which may entail shorter gestation periods, less capital commitment, and greater regional benefits particularly in the industrial minerals and bulk materials sectors, than is traditionally implied by minerals development. The structuring of such alternative routes to minerals development,as proposed in Chapter Five,was partly intended to encourage a wider appreciation of suitable strategies.

2:4 Technical advance and the investment criterion

The theoretical analysis of Chapter Two suggested why apparently cost lowering technical advance or technological innovation may not lead to an expansion in minerals production at the anticipated rate. Thus innovation generally, but not invariably, requires fresh additional investment and it will not be profitable for the entrepreneur to capitalise on a, nominally, cost lowering technical advance unless the overall value of the project (conveniently expressed as its present value), allowing for operating and investment costs, is greater than the value of equivalent, established, projects which are not employing the innovation but which only incur operating costs. A simple consequence of the analysis is that favourable technical comparison of a mineral deposit in the Highlands with existing 'specifications' will not in itself, guarantee a shift by established producers from traditional locations unless the costs of change are more than counterbalanced by the greater eventual revenues achievable from superior raw materials. A corollary of this conclusion is that technical advances should also be assessed in terms of any other additional innovations that may also be necessary to gain maximum benefit.[7]

2:5 Factor cost movements

Long term uncertainties as to the relative costs of labour and capital naturally tend to favour projects with short gestation and 'pay back' periods. In recent years they have also apparently favoured innovations which improve labour productivity (but which may nevertheless also save absolutely on capital[8]). There is however no a priori reason why technical advance could not be innovated to improve capital productivity and it was with this strategy in mind that the alternative technologies of magnesium production were examined (Chapter Three and Appendix E), and the principle of complementarity[9] was considered in Chapters Four and Five.

The question of labour versus capital saving developments is of considerable importance in the long term growth of the

the Highlands. Firstly it has to be emphasised that the viewpoint proposed in the preceding paragraph and in the study in general is that of the entrepreneur in minerals development. For him improvements in capital productivity can only be recommended if they contribute to his fairly narrow objective of profit maximisation in financial terms. Clearly however where some other cost benefit function takes precedence alternative developments may be favoured. Thus in recent years public sponsored development in the Highlands has been evaluated primarily in terms of jobs created per unit of investment. This policy stemmed largely from the perennial unemployment problem of the area which in itself tended to be obscured by persistent emigration of the work force to other regions of the country or abroad.[10] Against this background, from a public policy viewpoint, minerals development was seen primarily as capital intensive investment involving only minor increases in job opportunities in the region, the possible importation of skilled labour, and the export of profits and products from the area. And from the large corporations point of view investment in minerals development in the Highlands usually implied 'inferior' raw materials, expensive infrastructural investment and, less significantly perhaps, only a poorly developed local market and a relatively high rate of tax on profits. In either case therefore capital intensive minerals development projects could not be easily justified in the Highlands.

Now however, at least in certain areas of the Highlands, unemployment is far from being a problem although there are understandable premonitions that the benefits of oil development could prove transitory. The migratory trend has also been stemmed and there are signs that it will be reversed in the short to medium term future. Under these circumstances a rather different standpoint is necessary with regard to minerals development in the region. For such development regardless of its relative labour or capital intensity could help to spread the direct and indirect benefits achievable from the oil operations. Some specific opportunities illustrating this concept are included in later sections of this chapter.

2:6 Demand characteristics

Earlier chapters have questioned the reliability and utility of long term projection of historical trends in minerals production and consumption. Minerals demand forecasting is particularly unsatisfactory since minerals are usually at the end of a long production chain which branches into numerous intermediate and final market sectors all subject to differing trading conditions. The case of forecasting the demand for refractory raw materials illustrates the complexities involved: short term hiatuses in demand, medium term fluctuations due to the steel cycle, and long term trends towards decreasing total refractories consumption and displacement of one variety for another under the influence of technological innovation. Even, therefore, where complete vertical integration is achieved from raw material to consumer products, the uncertainties of demand tend to inhibit investment in minerals development. In an attempt to improve long term planning flexibility Chapter Five proposed a method of structuring alternative opportunities. The method clearly cannot remove future uncertainty but its aim is to stimulate a wider awareness of the various development strategies available, to provide greater scope for initiative in the generation of opportunity, and to promote more flexible development strategies which may accommodate currently unforeseen shifts in demand.

2:7 Trading Conditions

The general importance of trading conditions as an economic counterpart to civil legislation is easily overlooked in studying minerals development problems. In particular the influence of cartels, quotas, tariff agreements and direct political intervention may have far reaching consequences some of which have already been examined in Chapter Three. The protected position of the U.S. magnesium market, otherwise offering attractive long term development opportunities, is one such example. Similarly, government sanctioned regulation of cement prices may have far reaching consequences for the ready mix concrete and aggregates industries. On the positive side however depletion allowances, tax holidays, free depreciation, capital write offs, grants and so on may be expected to stimulate initiative in minerals development.[11] In recent years the U.K. has not generally compared favourably in otherwise equivalent opportunities with other countries such as Canada, Australia and the Irish Republic which have sought by such methods to actively encourage minerals development.[12]

2:8 Market Characteristics

Many imperfections in the functioning of markets were identified in the empirical studies of the minerals consuming industries. Perhaps the most important of these was effective, if partial, control over price such as in for example the supply of refractory grade dolomite and sea water magnesia in this country, or primary magnesium internationally. Other 'distortions' identified included barriers to entry such as high investment costs, limited access to existing markets, straightforward price discrimination and technical barriers in the form of artificial controls on the spread of knowledge. Two possibilities are open to the entrepreneur in these circumstances. He may either direct his investment to areas which are approximately, if not perfectly, competitive. Or he may choose to enter in a market segment partially isolated from the major manufacturers market. Such an isolated segment may represent a quality premium for a mineral in a specific application, brand name protection or a technical innovation effectively setting the product apart from its commoner substitutes.

2:9 Availability of Capital

Clearly the general availability of investment capital is of critical importance to long term minerals development. In their study of the economics of natural resource availability in the American economy over the last century, Barnett and Morse (1963) concluded that the effects of scarcity had been positively mitigated through the diffusion of capital intensive technological innovation and that as a consequence unit costs are still declining.[13] This view has been sharply criticised by Lovering (1969) who presents an equally extreme but opposite view that definite efficiency limits will be reached "as maximum mechanisation is achieved".[14] In either case the progressive substitution of capital for labour is admitted as an established feature of the minerals industries of the developed countries. For example in the U.K.:

> 'According to the institute of quarrying a completely mechanised crushed stone quarry with an output of one million tons of saleable stone annually would require a labour force of between 20 and 30 men. In the immediate pre and post war periods when the majority of quarries were still in private ownership the same sized labour force would have an output capability of about 25-30,000 tons".[15]

Nabseth (1974) and others have pointed out the importance of size in attracting venture capital.[16] Large organisations may indeed be able to fund new ventures out of retained earnings, and they may be able to obtain more favourable terms from the external capital market. Small companies however may be reluctant to commit themselves to high risk mineral resource development projects with lengthy gestation and pay back periods. When other factors such as marginal geological advantage, barriers to entry, unproven market potential and so on are considered it is clear that the entrepreneur wishing to develop mineral deposits in the Highlands has been in a relatively poor starting position to attract capital.

2:10 Distance from Markets

Mineral deposits in general are increasingly located in remote areas, frequently of considerable natural beauty, such that the costs of transporting primary raw materials or processed intermediate products to distant manufacturing plants or end consumer markets may be a critical element in the overall investment decision. Whether or not this is true for development in the Highlands, prohibitively high transport costs are often cited as barriers to development. For example transporting low value bulk materials such as roadstone aggregate over distances greater than about twenty miles may effectively double production costs.

On the other hand most of the developed countries of the western world are increasingly dependent on foreign sources of raw materials and they must therefore bear the cost of bulk shipping and handling at either end. But the economies of scale necessary to make shipping an attractive proposition in the Highlands would presently require expensive investment in harbour facilities. The road network of the region is also of a poor general standard, and the rail network is limited in extent.[17]

On balance it would appear that for minerals, other than bulk materials, distance from markets is now less of a constraint on practical development in the Highlands than hitherto and that the prospects of infrastructural development in the region associated with on shore oil related activities suggest that the prohibitively high fixed cost elements involved in transport from the Highlands may be considerably reduced.

2:11 and 2:12 <u>Characteristics of substitute materials and the diffusion of new materials</u>

A narrow assessment of mineral resource potential which does not include the potential effects of competitive substitution may lead to a misleadingly favourable statement of the scope for development. Market assessment should not therefore be undertaken as if, like the technical specifications mentioned earlier, end uses and the products which fulfil their functions are unchanging. A systematic method for the structuring of opportunities which could avoid such pitfalls was proposed in Chapter Five. From this it follows that a more dynamic attitude to Highland minerals development is required in which the favourable characteristics of the region resources are exploited under circumstances which view end use specifications as flexible rather than viewing such specifications as rigid and implying that Highland minerals are at best marginal substitutes for alternative established materials.

This compromise between end use and raw material characteristics is especially important during the earlier stages of diffusion of a new material.[18] Here the emphasis is on establishing the material in highly specific applications and usually it is the material which must prove its adaptability and not the application. Only during the later stages of diffusion do materials tend to establish the scope for the fulfilment of social needs: that is to say applications are adapted to the now widely established and creatively exploited properties of the material. On this basis the preliminary conclusion for Highland minerals development is that the unique or unusual characteristics of the region resources should be established and initially promoted in a fairly narrow range of specialist applications perhaps under the protection of market segmentation as discussed in Chapter Five.

2:13 Entrepreneurial ability

Although formal planning in the regional and corporate contexts tends to minimise the role of the entrepreneur there can be little doubt that the complexity of the many factors constraining minerals development cannot as yet be adequately incorporated in integrated regional development strategies or long range corporate planning directives. It may even be questioned whether these are desirable eventual objectives. For there remains considerable scope for initiative and creative management attitudes towards Highland minerals development particularly in the current period of major oil exploitation activities in the region. As is subsequently stressed therefore the traditional exploration policy of the major mining houses, seeking only internationally significant deposits of base metals and other 'high value' materials, is not conducive to the orderly development of the regions resources. Certainly such materials play an important, if increasingly capricious role in the fulfilment of many areas of social need. But in the narrow search for such deposits the equally important bulk materials and industrial minerals are too often overlooked.

As was originally discussed in Chapter One, metals fulfil and adapt to a very wide range of end use applications. They command a relatively high price and the producer need not be integrated into producer or consumer good manufacture to achieve satisfactory profitability or guarantees of security. In contrast the exploitation of minerals for a wide range of specific industrial applications such as ceramics, abrasives, agriculture, refractories, chemical processing and so on requires a closer interpretation of the consumers technical and economic objectives and the producers ability to meet those objectives. It is in this context that there remains considerable scope for the entrepreneur in the long term exploitation of Highlands minerals resources.

2:14 Interim conclusions

None of the factors in Table 25 taken alone could be said to account for the apparent lack of minerals development in the Highlands. Mineral resource development is a highly individual process and there may therefore be no universal prescription for success. Further work is necessary to assess the relevance of the thirteen factors discussed to specific development projects.

Having examined possible historic constraints on Highland minerals development it remains to suggest some future possibilities with reference to dolomite the particular mineral studied. By way of introduction however the present study suggests the following background to future developments in the region:

(i) Although the Highlands are not geologically deficient in minerals accumulations, barring the development of superior methods of prospecting particularly under peat cover, at depth in the earth's crust, or in offshore areas, the likelihood of large scale discoveries of base metal and other 'high value' deposits appears insignificant.

(ii) Mineral resource exploration and exploitation in the region continues to take place on a relatively haphazard and intermittent basis such that much valuable information is lost.

(iii) The region is now entering a period of considerable potential expansion. The traditional capital infrastructure for regional development: roads, housing, commercial and industrial premises etc., will require substantial quantities of minerals.

(iv) There are other aspects of the region's development specifically related to the needs of the oil industry which could make further exceptional demands on the raw materials base of the regional economy.

(v) The promotion of 'downstream' oil industry development in the region could also provide specific opportunities including the development of energy intensive minerals processing industries.

Points (iii) - (v) are now analysed for the study mineral dolomite.

3. DOLOMITE AS A BULK MATERIAL: A STRATEGY FOR MINERALS DEVELOPMENT IN THE HIGHLANDS

3:1 Introduction

Although the popular view of minerals development is typically one of exploitation of vein concentrations of metalliferous ores, the greatest areas of social need are for the bulk materials.[19] The common rock forming minerals are of course extensively used as essential raw materials for the construction industry. Since as a group these materials are in geological abundance, do not require sophisticated processing, and the access to their means of production is relatively unrestricted bulk materials have tended to command a low market price relative to industrial minerals and metals.

However the relative abundance of such materials in the Highlands of Scotland must be understood at least partly in terms of increasingly acute shortages of such materials in other regions and in terms of economic premiums now achievable for materials with particular technical characteristics. The technical background to bulk materials supply and an analysis of the structure of the industry, the distribution of end uses and the market behaviour of producers was presented in Chapter Three. The aim of this section is therefore to illustrate alternative futures for the industry primarily in a regional context using the opportunity planning network proposed in Chapter Five. As with the two other case studies assessed in Chapter Five the opportunities for long term development are summarised under the six strategy headings noted in figure 29. Before discussing these however it is necessary to summarise the statistical background. Some simple trend projections of demand for the U.K., Scotland and the Highlands are to be found in Appendix D.

3:2 <u>Statistical background</u>

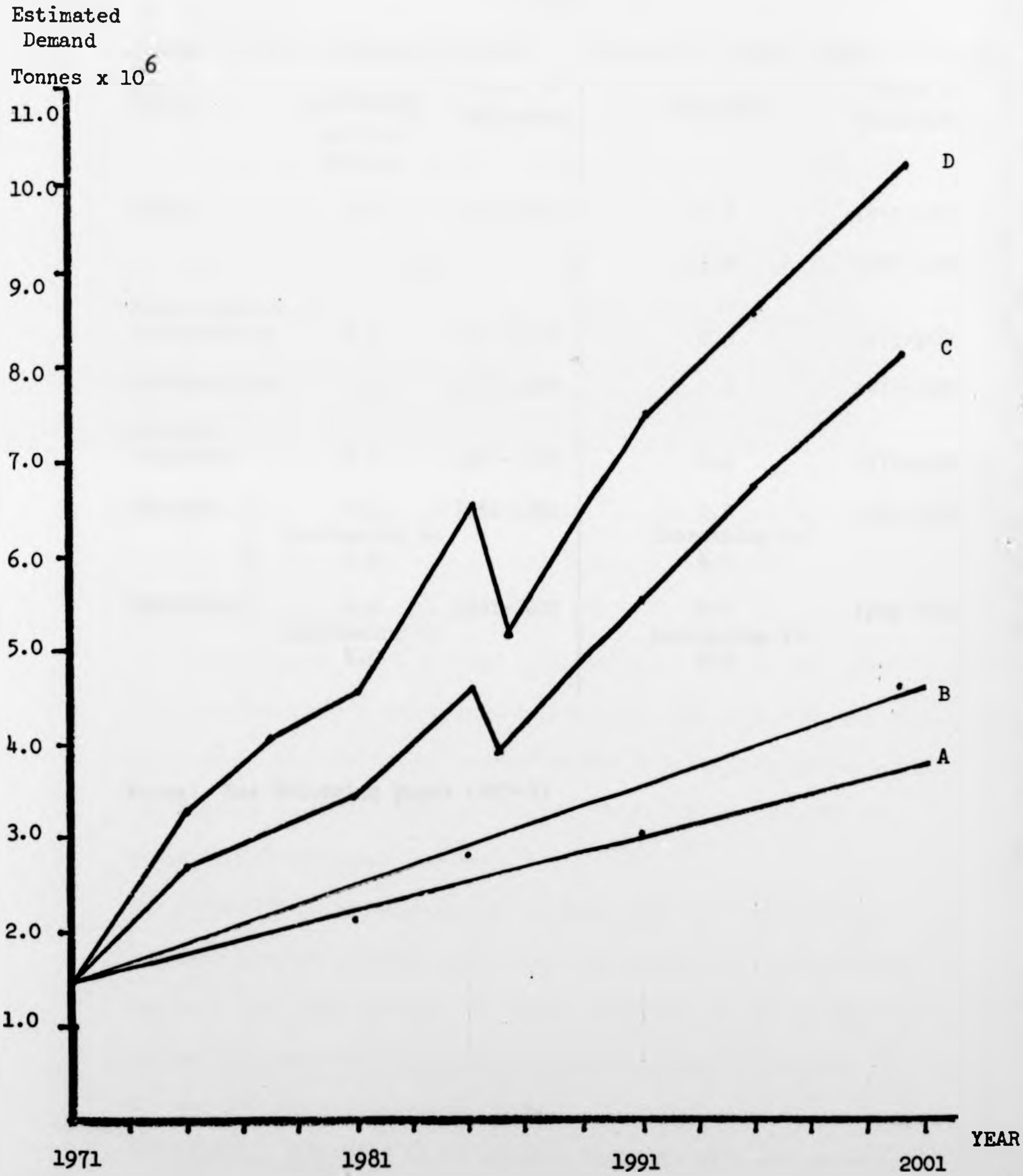
The limited statistical information available on consumption of aggregates, particularly at the regional level does not encourage long term extrapolation. But the general trend appears to be for the demand for aggregates to grow at a faster rate than population reflecting increasing urbanisation, the motorways programme and increased industrialisation. There is no clear guarantee that this trend will continue over the forecast period to the end of this century. In so far as it can be extrapolated the current secular trends towards exploitation of 'marginal' aggregates and offshore deposits of sand and gravel should be noted.

From the available information the following scenario is suggested. There are two basic conflicts emerging in the national supply of aggregates which suggest that such materials will have to be increasingly supplied at higher prices from more remote areas. In the first case much urbanised land overlies important reserves of sand and gravel and quarrying activity is also regarded as increasingly undesirable in urban areas. Secondly sources of crushed rock aggregates tend to occur in areas of natural beauty and the environmentalist lobby is likely to create severe problems in meeting increments in demand from new sources in such areas. Against this background the Highlands of Scotland occupy between one sixth and one fifth of the area of Great Britain, yet currently supply less than one per cent of the country's requirements for aggregates. It would appear that if U.K. demand for aggregates continues to grow at the present rate exporting of such materials from the Highlands will acquire a greater significance in the region's development.

From Appendix D, on the basis of natural increases in population and making certain assumptions about emigration, a population correlated forecast of the demand for aggregates in the Highlands by the end of the century of between 4 and 4.6 million tonnes seems plausible. But it is also clear that historical trends are not likely to be a reliable guide to future demand in the region, partly for reasons just discussed and partly because of the on shore impact of oil related developments in the area. The quantitative effects of both groups of factors should be considered in detail but on the limited information presently available no firm impression of likely additional requirements can be formed. Consider the impact of oil for example. Firstly it is expected that public sector construction work in the provision of roads, houses, commercial and industrial premises, and social amenities will accelerate particularly in the next ten year period to 1985. The development of the A9 trunk road for example will require 0.5 million tonnes of aggregate for each of the five years of its reconstruction period.[20] Other major road developments are also anticipated.[21] Housing is however not as significant a consumer of aggregates. In the county of Ross and Cromarty for example an annual average of 370 houses were constructed in the period 1967 - 1971. Even if this figure is trebled to 1000 houses per annum this would still only entail 12,000 tonnes of aggregate.[22] The provision of schools, hospitals and other amenities tend to be rather more aggregate intensive but on balance the limited information available suggests that road building activity including reconstruction and repair is likely to be the major area of accelerated public sector consumption of aggregates in the Highlands at least during the earlier half of the forecast period.

A second area of accelerated demand for aggregates which must be considered is the unique demands of the on shore sectors of those industries associated with oil exploitation. The construction of harbours, concrete production platforms, coated pipes and refineries may be expected to make considerable demands

FIGURE 30: ESTIMATES OF DEMAND FOR AGGREGATES IN THE HIGHLANDS TO 2001



Note: see text for explanation of assumptions

TABLE 26

FACTORS INFLUENCING PROJECTIONS OF DEMAND FOR AGGREGATES

	Scenario 1: Low. (Graph C, Fig. 30)		Scenario 2: High. (Graph D, Fig. 30)	
Factor	Increment million tonnes	Years of Influence	Increment	Years of Influence
ROADS	0.5	1975-1985	0.5	1975-1977
			1.0	1978-1985
PUBLIC SECTOR CONSTRUCTION	0.1	1975-1985	0.3	1975-1985
HOUSEBUILDING	0.1	1975-1985	0.2	1975-1985
CONCRETE PLATFORMS	0.1	1975-1985	0.2	1975-1985
REGIONAL	0.1 increasing to 2.0	1981-1991	0.2 increasing to 4.0	1981-1991
EXPORTING	2.0 increasing to 4.0	1991-2001	4.0 increasing to 6.0	1991-2001

Notes: See following pages (227-8)

Table 26 includes the following assumptions:

For ROADS the base is taken as the likely increment in demand resulting from the major reconstruction work of the A9. It assumes that other major projects in the roadbuilding sector which would not otherwise, in the absence of oil developments in the region, have taken place, will continue to provide a similar increment in demand through to 1985. About this time it is estimated that the major construction projects associated with oil development will be largely completed.

For PUBLIC SECTOR CONSUMPTION the base is taken at approximately £1.5 million/annum of construction output which is equivalent to about 100,000 tonnes of aggregate. There is however very little information on the impact of oil development on public sector construction other than roads. It is assumed that regional expenditure in this sector could range as high as £4.5 million/annum or 300,000 tonnes of aggregate but there is little guidance on plausible ranges.

For HOUSEBUILDING it is assumed that between 8 and 16,000 extra houses/annum will be built in the Highlands region in the period 1975-1985. At a figure of approximately 12 tonnes of aggregates per house a possible range of between about 100 and 200,000 tonnes/annum increment emerges.

For PLATFORMS it is assumed that at least one and possibly two concrete platforms/annum will be constructed in the region during the peak 1975-1985 period. If these platforms are of the Condeep design then resultant aggregate consumption could be between 100 and 200,000 tonnes/annum.

For REGIONAL EXPORTING it is assumed that this will not commence until the early 80's but will accelerate through the 90's to reach between 4 and 6 million tonnes by the end of the century. It is also assumed that a hiatus will occur as the consumption of

TABLE 26 Ctd

aggregates in oil related projects declines towards the mid 80's and before regional exporting becomes established.

on the raw materials base. In particular concrete production platforms may consume over 100,000 tonnes of aggregate per unit.[23] At this stage it is difficult to forecast whether such platforms will be built on a large scale in the Highlands, or indeed what other oil related developments will actually take place. The general consensus however is that any such activity will accelerate until the mid eighties as production from established oilfields is geared up to peak levels. Thereafter emphasis may shift towards the demands of any downstream or ancilliary developments arising out of the established presence of the oil industry in the region.

Figure 30 represents four preliminary estimates of demand for aggregates in the Highlands to 2001. Graph A is a straight line DoE population correlated trend (see Appendix D), and line B is the Strathclude study 'oil-influenced' population correlated trend. Graphs C and D represent the possible influences of the following three groups of factors: road building, house building, and public construction (other than roads) due to the oil boom, specifically oil related developments such as harbours, platforms, refineries and coated pipes, and latterly the increase in regional exports of aggregate. In each case the Strathclyde population correlated estimate was used as a forecast base and estimates were made of the possible influence of the three groups of factors. The actual figures proposed are noted in Table 26. The mid 80's hiatus in both series represents the transition between the oil-boom period and increased regional exporting.

3:3 Strategies for bulk materials development in the Highlands

Some generally applicable strategies are analysed and, wherever appropriate, illustrated with reference to the potential for dolomite, the study mineral.

33:1 Non interventionist strategies (see Figure 29)

(i) Shorten innovation/gestation period

It follows from factors 2 and 3 in Table 25 and the subsequent discussion that strategies which effectively shorten a project's innovation, gestation or start-up periods, which may be relatively lengthy in minerals development, will enable an earlier positive cash flow to be achieved and, other things being equal, lend a higher nett present value to the project as a whole. Two tactical methods are considered worthwhile: firstly technological compromise, which may involve using non-best practice technology by current standards but which may entail lower capital costs and shorter delays since such techniques would be of proven ability, and secondly structural adaptation which minimises the delays involved in market entry through planned direction of the project to well established areas of demand.

On balance for the three types of minerals studies, the development of bulk materials appears to suffer least from gestation period delays once planning permission is gained.[24] Quarrying is a relatively unsophisticated operation and technical innovations do not occur at a rate which might give rise to problems in the selection of suitable innovations. However the recent development of transportable quarrying equipment as a means of shortening the pre production period merits further investigation. There may be a trade-off between the relatively low capital costs of such equipment and the ability to install plant at short notice to respond to local surges in demand, and the cost of building land: a factor which the quarry products industry has traditionally and consistently undervalued.

(ii) Lowering investment costs

The importance of this strategy follows from the discussion of Factors 4, 5 and 9 in Table 25. For bulk materials production the complementary roles of the small local producer and the large nationally organised and diversified supplier of aggregates imply very different investment conditions. The former typically has relatively low fixed costs of operation and is well suited to respond to fluctuating demand characteristics usually operating on a marginal 'cost-plus' basis. The national supplier however is better able to supply a comprehensive range of standard materials to specification. He can also supply a wide range of services being often integrated forward into markets or diversified into associated activities and is better able to fund projects internally or attract external sources of funds for large capital intensive projects which may yield economies of scale.

In the Highlands it appears that although the major national producers were not previously committed in the area, recent developments have resulted in a 'consolidation and rationalisation' of the regional structure of the industry. Even amongst the large producers however it is admitted that profitable large scale operations in growing markets will not reduce the role of the local producer particularly those who are able to exploit technical premiums in residual market areas. By way of illustration of one such potential role the neglected characteristics of dolomite as a high grade concrete aggregate are examined in Appendix H.

(iii) 'Do-nothing'

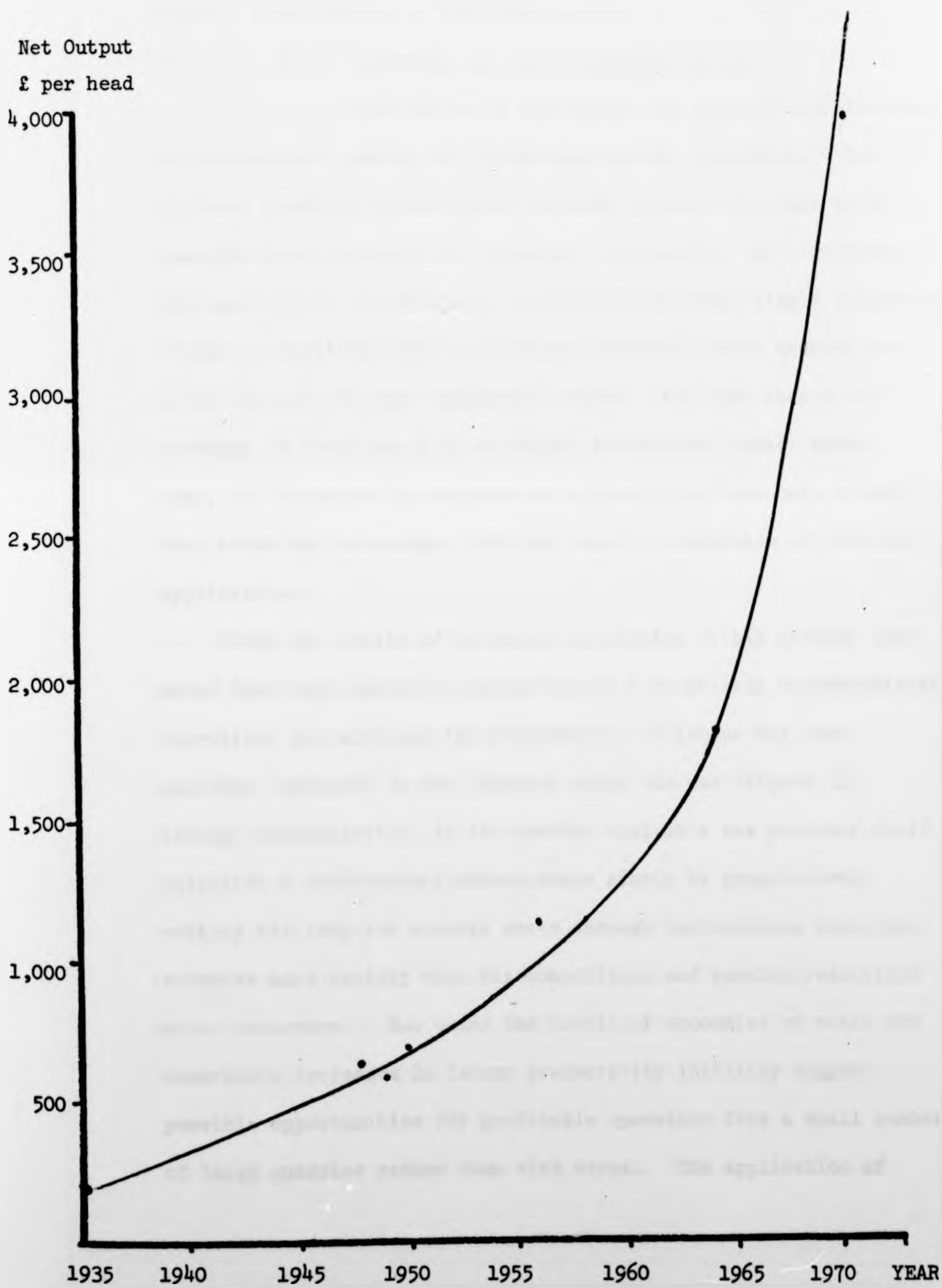
The rapid and fundamental changes taking place in the Highlands suggest that the demand for aggregates will continue to grow at an encouraging rate throughout the forecast period. Straightforward shortfalls in supply could therefore present suitable opportunities for expansion. Further work is first necessary to improve and disaggregate the limited statistical information available.

33:2 Interventionist strategies (Figure 29)

(i) Creation of totally new market areas

Traditionally bulk materials are used whenever there is a need for a cheap, durable, space filler in construction work. This is an essentially functional definition for bulk materials as proposed in Chapter One. As such it requires either totally new areas of social need to create totally new market areas for bulk materials, or a realisation of hitherto unexploited properties inherent in particular bulk materials which suggest totally new applications. In the latter case bulk materials become, in effect, industrial minerals. The former case however is illustrated by the invention of concrete production platforms for use in the oil industry. This has created totally new opportunities for bulk materials, although strictly their overall function remains the same. In view of the novelty of this application it is clearly necessary to assess the service conditions of such platforms and interpret these in terms of desirable performance optima in suitable concretes. This in turn provides an opportunity to assess the properties and peculiarities of Scottish sources of concrete aggregates. As is concluded in Appendix H dolomite is an excellent yet curiously neglected

FIGURE 31: MOVEMENTS IN NET OUTPUT PER HEAD IN THE BULK MATERIALS INDUSTRY



Data Source: Censuses of Production unadjusted
(SIC minimumlist 102)

concrete aggregate yielding finished materials which are technically superior to most Scottish concretes which are unusually susceptible to shrinkage on drying resulting, in certain cases, in structural defects. Further, local work should be undertaken to assess the overall significance of this opportunity.

(ii) Expansion in existing market areas

The choice of aggregates for specific applications is frequently a matter of traditional, local, prejudice. For various, possibly psychological reasons dolomite has come to be regarded as an inferior or 'marginal' aggregate. As a roadstone aggregate where abradability is the most important single criterion dolomite admittedly does not compare favourably with granite and other igneous and some metamorphic rocks. For this reason the strategy of development by expanding in existing market areas must, for dolomite, be regarded as a question of economic rather than technical advantage, with the possible exception of concrete applications.

Under the tactic of technical innovation it has already been noted that bulk materials production is a relatively unsophisticated operation, and although the productivity of labour has been markedly increased in the industry since the war (Figure 31) through mechanisation, it is doubtful whether a new producer could establish a satisfactory market share simply by progressively cutting his long run average costs through implementing technical advances more rapidly than his competitors and passing reductions on to consumers. But under the tactic of economies of scale the remarkable increases in labour productivity initially suggest possible opportunities for profitable operation from a small number of large quarries rather than vice versa. The application of relatively greater amounts of capital per man to achieve such economies tends to require a high and consistent level of capacity operation if the substantial resultant fixed costs are to be defrayed in an acceptable manner. Whilst the Highlands have not traditionally provided such scope for very large scale operations (> 1 million tonnes per annum) the demand projections in Figure 30 recommend further investigation of local potential. In particular the following points should be examined: the trade off between a large quarry with low operating costs but higher unit distribution costs (since the quarry serves a relatively larger area), and a number of small quarries with higher (variable) operating costs but a small distribution radius and lower unit distribution costs. And secondly the social costs and benefits of 'concentrated' operations should be considered. Whether from an environmental view point it is less 'costly' to concentrate quarrying operations and gain in social amenity in areas of natural beauty or whether more dispersed operations would result in lower social costs in respect of lighter lorries, less dust and other forms of pollution etc., is an open question.

A further tactic for expansion in existing markets is through some form of market segmentation: perhaps through brand name appeal, unusually efficient sales servicing, or through specifically catering for specialist demand. The relevance of this tactic in the early stages of diffusion of new materials has already been stressed.[25] For dolomite some of the advantages of market segmentation could arise during the early stages of its promotion as a concrete aggregate with a technical premium (Appendix H).

To complete the review of expansionary tactics in existing markets the concept of flexibility is introduced. This includes technical, market, and product flexibility. Under technical flexibility the advantage of divisibility in quarrying operations, that is to say the ability to respond to fluctuating demand conditions without overall loss of profitability, again recommends caution in the single minded pursuit of economies of scale. Under market flexibility the underlying homogeneity of quarry products does not encourage speculation but the trend towards technical differentiation and away from the simple provision of a bulk product may provide future opportunities. In such circumstances of course the definitions of bulk material and industrial mineral tend to merge. For example dolomite is a mineral with a wide range of technical properties which could be used to advantage in widening its present range of end uses from bulk material to metal products. In the Highlands the only established dolomite quarry divides its output between roadstone and agricultural applications. Such (limited) market flexibility can usually only be achieved with substantial investment in additional plant and equipment. It is therefore desirable that such market flexibility does not result in a doubled recession during periods of depressed trading: the chosen markets should be compensatory as well as complementary.

Finally under product flexibility it has often been suggested that quarrying equipment could be adapted to process a wide variety of different raw materials.[26] The resultant wider product range will however be subject to the same profitability considerations as market flexibility. Thus there is a trade-off between potentially improved competitiveness in established market areas through product additions, and the investment costs incurred in such expansion which will have to be defrayed under varying trading conditions.

(iii) Expansion in existing but non traditional market areas

Bulk materials are defined in terms of their function: the provision of bulk. And hence expansion into existing but non traditional market areas lacks the significance that it may have for the product-defined metals or application-defined industrial minerals. Where bulk materials take on the technical attributes of industrial minerals however this strategy is more fruitful in the generation of opportunities. Dolomite's technical advantages as a raw material for refractory manufacture has already been examined but there are a wide variety of industrial applications which individually only account for a tiny proportion of total annual consumption of the mineral (see Figure 11). Lamars' (1961) study of the uses of limestone and dolomite included over sixty end use categories which, for dolomite, ranged from the manufacture of glass, high magnesia cements, and chemicals to applications in water treatment, oil well drilling and insecticide dusts.[27] Many of the applications notedin Lamars study are now obsolete. But re-examination of the technical basis of such applications may yield useful indications as to the mineral's potential in non traditional applications. For example dolomite has long been used in small amounts for acid neutralisation. Recent concern with the high sulphur content of flue emissions from factory chimneys and the imposition of pollution controls suggests a possible increase in the uses of dolomite as an absorbent and neutraliser in this non traditional role.

33:4 Interim conclusion

The preceding paragraphs have attempted a systematic presentation of a wide range of opportunities for the development of dolomite as a bulk material. Further work either in an entrepreneurial or public policy role is required to isolate individually profitable projects. In either case of course the full social and economic costs and benefits of any such ventures in the Highlands must be assessed if the established pattern of piecemeal development in the pursuit of short term profitability is to be avoided.

4. CONCLUDING NOTES ON POSSIBLE DOLOMITE/MAGNESIUM/REFRACTORY DEVELOPMENTS IN THE HIGHLANDS

4:1 Magnesium metal

The widespread occurrence of high quality dolomite in the Highlands area and the advent of hydroelectric power in the region have been a long established incentive for the possible production of primary magnesium metal in the region. A working party in 1954, and under the auspices of the Scottish Council (Dev. and Ind.),[28] reported that whilst the sea water route was not of any great significance at the time "the ferrosilicon process on the other hand is suitable and may be economic". The group mentioned the possibility of using quartzite as well as dolomite from the north west Highlands and, interestingly, noted the ability of the process to perform equally well on electricity, fuel oil or gas. More recently (1972) an engineering group at Edinburgh University have investigated the possibility of adapting the Dow sea water process for use in the Highlands.[29] As an engineering study their report was not primarily concerned with alternative competing technologies or market conditions but it is still a useful exercise in the adaptation of the process to the regional situation. On balance however the present study suggests.

(i) That the ferrosilicon (Pidgeon) process suffers from a number of fundamental drawbacks the most relevant of which is that it requires raw materials of the highest purity which would almost certainly not be available in the Highlands. The process is also labour intensive, not easily scaled up, and batch type operations are necessary.

(ii) That the overall costs (Appendix E) of both the ferrosilicon and sea water (Dow) processes are significantly greater than for a brine based plant of equivalent output.

Nevertheless further research and development may produce advances in direct reduction or sea water magnesium technology which could yield an economically attractive alternative to the brine based process under certain market conditions. Further it will be recalled that magnesium reduction is invariably energy intensive (see Chapter Four note 39). Whilst not wishing to speculate in an extremely uncertain area it is conceivable that recent oil related developments in the Highlands region could ultimately result in the availability of 'cheap' refinery gas as a possible energy source. In addition, the importance of the aluminium industry as the major growth area in magnesium consumption (see Chapter Three), and the established presence of this industry in the Highlands presents an as yet hypothetical market which deserves further assessment. There are considerable dangers inherent in such *a priori* reasoning however, not least the erratic fortunes of the aluminium industry in recent years. But it is worth noting that a similar venture has been examined for the use of waste refinery gases in Saudi Arabia,[30] and also that the development of a Scottish non ferrous metals industry was accorded a high priority in a recent study of Scotland's future.[31]

4:2 Dolomite as a basic refractory raw material

The rapidly growing significance of dolomite as a basic refractory raw material was examined in detail in Chapters Three, Four and Five. It was concluded that the mineral will continue as a major refractory for the lining of the basic oxygen steel converter (BOS) which is likely to retain its prominence as the major general purpose steelmaking vessel throughout the forecast period. The analysis of market structure, behaviour, and pricing policy in the refractories industry suggested that despite this encouraging forecast, entry to refractories production on a scale comparable to that of the small number of established producers of basic refractories would not be profitable at this stage. Nevertheless, in Chapter five it was suggested that a residual but important sector of the market for high quality dolomite or dolomite/magnesia intermediate products remains to be fulfilled. Preliminary study (Appendix A) suggests that at least one source of dolomite in the Highlands contains considerable resources of refractory grade dolomite which compare favourably with alternative UK sources on technical grounds. However, as was mentioned earlier in this chapter for the relatively low value industrial minerals, and as a refractory it will be recalled that dolomite is the least expensive basic material, the costs of transport to the current centres of consumption in the UK could more than outweigh any technical premium attributable to Highlands source of dolomite.[32]

4:3 Dolomite as a bulk material

Prospects for the development of Highlands deposits of dolomite as a bulk material are considered in two sectors:

Firstly overall growth in the market for bulk materials and secondly the prospects for applications in which dolomite may possess a technical premium.

As regards the general growth in demand for bulk materials in the Highlands,prospects over the short to medium term were found to be generally favourable. Large nationally structured enterprises have already moved into the area but it is anticipated that growth will be on such a scale that,provided planning problems can be overcome,there will be scope for additional quarries up to the maximum scales operated elsewhere in the country (> 1 million tonnes per annum). The small local producer was also seen as retaining competitive advantages particularly during cyclical trading conditions or where specialist demand has to be catered for.

Concerning the second possibility,it was concluded that dolomite is a much neglected raw material for application in concrete manufacture. A specialist role in the provision of high quality concrete aggregates for oil production platform manufacture should be further investigated (c.f. Appendix H).

CHAPTER SEVEN

CONCLUSIONS

The purpose of this chapter is to review briefly the contributory themes of the previous six chapters and to abstract where appropriate some preliminary conclusions. In view of the absence of precedent for the present study such conclusions must remain tentative until further research is undertaken, the overall objective being to propose a generally applicable theory of minerals development.

The topics covered in earlier chapters can be broadly classified as follows: firstly contributions to a theory of minerals development; secondly technological economic studies of selected minerals industries: and thirdly contributions to an understanding of the problems of long term minerals development in the Highlands of Scotland. These three areas are now individually reviewed.

At the outset it was noted that whilst there were many unidisciplinary approaches to minerals development none had yet comprehensively expressed the essentially technological <u>and</u> economic features which distinguish mineral resources from deposits. Geologists at one extreme tended to minimise the importance of economic variables whilst economists were often insensitive to the possibilities and implications of technological change. Chapter one therefore proposed an interdisciplinary definition of minerals resources which could form a basis for hypotheses of long term minerals development problems.

In chapter two, three key areas of theory were examined for their possible relevance to minerals development problems. It was emphasised that, as minerals are often relatively remote from the ultimate sources of their demand, the analysis should ideally range over the whole minerals production function and not concentrate on isolated sectors. In the event however a compromise was necessary. The three key areas of theory examined were concerned with, firstly, a hypothesis of the relations between technological innovation, market structure and the opportunity costs of change as an abstraction of the investment problem that typically faces the entrepreneur in minerals development. Secondly theories of innovation and diffusion were examined for their implications for derived minerals demand patterns and a model of the diffusion of new materials was proposed. And thirdly methods of technological and economic forecasting were reviewed and the problems in their common application to long term minerals development planning examined.

In the first place the replacement/net investment model was found to have limited but significant applications in clarifying why manufacturers using established raw materials are not easily persuaded to innovate new sources of raw materials on technical grounds alone. It was concluded that the operating costs of a new process incorporating such improved materials would have to be sufficiently less than established processes to defray the fixed costs of investment involved in the change over. For a totally new entrant innovation was found to be potentially much more complicated, in that issues of market structure and behaviour tended to impose additional deterrents on the commitment of capital. Together, however, the replacement/net investment model and the proposed model of diffusion suggested a range of strategies which the intending entrant or established producer contemplating innovation could maintain under review, ready to capitalise on specific opportunities when favourable combinations of external variables occur. The structuring of such opportunities, proposed in chapter five, was called opportunity planning. Having applied the suggested planning network to the study industries it was concluded that the model provided a useful base for temporary elimination of some strategies whilst others could be followed up in specific development projects. For example, the principle of complementarity suggested a practical means of gaining entry to industries characterised by tightly oligopolistic supply structures through exploiting unusual or unique minerals characteristics in specialist applications not easily catered for by the established large scale producers. Other strategies included reviewing the developing technology of a primary consuming industry for techniques particularly suited to individual mineral or market peculiarities, or monitoring the properties of the raw material with a view to developing totally new market areas, and so on. Throughout the emphasis was on promoting a flexible approach to long term minerals development. Without minimising the 'last resort' significance of demand extrapolations the implications of possible departures from such trends should be continually assessed to generate as wide a range of opportunities as possible.

Turning next to the industry investigations it has already been noted that although there may be many levels in the production hierarchy from minerals to end consumer some analytical compromise had to be adopted. In the event three primary processing industries were chosen to illustrate and contrast the complex interactions of technical and economic variables under the headings metals, industrial minerals and bulk materials. The industries were specifically chosen for their potential common dependence on the mineral dolomite as a raw material. Not surprisingly it was found that simple extrapolation of current demand relations for dolomite would be a poor guide to the minerals' underlying potential in each of the three mineral categories. For the first study, the magnesium metal industry, it was concluded that the industry's key problems: unfavourable price comparisons, unenterprising marketing policies, persistent technical problems and the psychological barriers against the metal, were at least partly attributable to the industry's long standing monopoly structure. Substantially improved price ratios between magnesium and its closest substitutes were found to be feasible even under existing technology. The scope for initiative in innovating the metal in new, established and non-traditional areas was found to be very encouraging and the technical problems have, in theory at least, been largely resolved. The long term future should also see a revised public conception of the metals utility, particularly if and when it diffuses into major or non traditional uses such as in structural engineering and motor vehicle manufacture. However, although the potential for magnesium and its products is encouraging, given a more competitive supply structure, the implications for dolomite in this role are not so immediately promising. It was concluded that in the long term significant cost advantages rest with the brine based production technique which does not involve dolomite as a raw material feedstock, although under special, local, circumstances there may be a role for a revised improved direct reduction alternative employing dolomite.

Overall the magnesium study illustrated the tremendous practical complexity of planning minerals development for metals industries which tend to be dislocated from the very many applications open to such materials at later stages in the overall production function. In the second study the basic refractories industry, it was found that a much closer correspondence between producers and ultimate consumers' technical and economic objectives was required. Thus, in spite of similar complications in market structure and producer behaviour, it was found that the desired features of end products in specific industrial applications could be related to raw materials characteristics in a firmly interdisciplinary manner. The conditions under which improved refractory products could be expected to be innovated were identified and the particular role of dolomite in the new generation of basic oxygen steel plants was concluded to be of critical importance in the long term development of the mineral in this industrial role. It is important that other industrial applications of dolomite also be examined to determine whether the characteristics of the mineral's application in the refractories industry can also be established in other industrial roles.

Finally the role of dolomite as a bulk material was examined. Here the emphasis was found to be on the functional role of the material, that is to say the simple provision of structural volume. The scope for differentiation at the product stage was not promising and any special properties relevant to particular applications tend to reclassify the material as an industrial mineral. Once again the background of emerging oligopoly was detected in the industry although the persistent role of the small producer was concluded to offer potential opportunity for "protected entry" particularly where an individual materials' technical premium could be exploited.

The third area of contribution of the present study concerned the problems and prospects for minerals development in the Highlands of Scotland, examined in chapter six. Whilst it was concluded that no single factor could alone account for the retarded development of mineral raw materials in the region, thirteen factors were suggested by the earlier theoretical and empirical analyses as having collective long term significance. It was also stressed that the basis for regional development in the Highlands had been recently influenced to a considerable degree by the exploitation of and exploration for oil in the area. There may therefore be considerable additional direct and indirect demands for bulk materials development in the region. It was concluded that substantial changes in historical demand patterns could be anticipated giving rise to a range of applications for bulk materials in the construction of roads, houses, industrial and commercial premises and possibly harbours, refineries and concrete production platforms. In addition over the long term, national shortages of aggregates were seen as an accelerating influence on the exporting of bulk materials from the Highlands region. Finally a small number of special opportunities for specifically 'dolomite-related' developments in the region in the metals and industrial minerals sectors werealso discussed.

In conclusion the present study represents a first attempt to bridge a well established gap between the traditional technological and economic approaches to minerals development problems. The wide ranging nature of the study has left considerable gaps in the coverage. The implications of raw materials scarcity, the effects of political, social and psychological variables, the details of minerals development financing, 'downstream' market structures and behaviour in metals industries: these are all areas in need of further detailed research before an adequately comprehensive theory of minerals development can be proposed. The present study has of necessity tended to limit its horizons for competitive substitution to essentially static comparisons with the closest alternative materials - for example magnesium to primary and secondary aluminium. Thus whilst there are firm grounds for anticipating competitive improvements in the subject industries it is also clear that competing industries will not react in an entirely passive manner to encroachment. Further work aimed at a broader, more dynamic, assessment of the principles of competitive substitution is necessary.

Finally there is the problematical issues of values. The study has attempted to assume the role of a private entrepreneur considering minerals development as an investment alternative. Although a range of opportunities open to such an investor have been shown to be worthy of detailed investigation in specific projects it was also clear from the analysis that minerals industries in general are increasingly dominated by multi national corporations who may have substantially different motives in minerals development which go beyond the scope of this study. Similarly the "planning of opportunities" for public policy formulation, which may include optimising a social welfare function rather than the neoclassicial profitability criterion, may lead to important departures from, or additions to, the range of strategies discussed. It is important therefore that this study be viewed as providing a first synthesis of the technological and economic variables which together render minerals development profitable subject to individual, institutional, or social value configurations.

NOTES

CHAPTER ONE

1. Particularly amongst prophets of Malthusian shortages. For a similar definition of resources to that postulated here see Fisher J.L. (1953), Natural Resources and technological change, Land Economics (1953) 29, 58. For more recent formulations see Cameron, E. (ed) (1973). The mineral position of the United States 1975-2000, University of Wisconsin, in press, or Lovering, T.S. Mineral Resources from the Land, in Resources and Man, (1969), Freeman.

2. For an elementary introduction to the production function concept see Samuelson, P., Economics (6th Edn), pp 528-536.

3. Ibid.

4. For a recent discussion of these factors see Brunner, E. (1974), Some shortcomings in the economic analysis of technological change, Omega (1974) 2, pp 33-41. It is of course critically important to distinguish between the law of diminishing returns and economies of scale. The former applies to cases where some, perhaps only one, of the factors of production are varied and some are fixed. This increase in some inputs relative to other inputs which are fixed will cause total output to increase. But after a point the extra output resulting from the same addition of extra inputs, because of the increasing difficulty of achieving smooth interchangeability, is likely to become less and less. This is diminishing returns. On the other hand if all factors are increased at the same time in the same degree it may occur that the resultant increase in output is more than increased by a greater margin than the factor increases. In other words if all inputs are doubled output is more than doubled. This phenomenon is increasing returns to, or economies of, scale.

5. A term originally coined by Bertalanffy, L. von., (1950). The theory of open systems in physics and biology. Science, (1950) 111, 23-9.

6. Salter, W.E.G. (1966). Productivity and Technical Change. Cambridge U.P. (2nd Edition).

7. For a discussion of the definition of diffusion see Ray, G.F. (1974), Introduction, in Nabseth, L. and Ray, G.F. (eds), The diffusion of new industrial processes. Cambridge U.P.

8. Relevant contributions include:

   Smith, A. An inquiry into the nature and causes of the wealth of nations, Modern Library Edn., New York, 1937. pp 181, 213-214.

   Mill, J.S. (1881), The Principles of political economy. 5th London Edn. p 583.

   Marshall, A. The Principles of economics. 8th London Edn. pp 483-489.

   Gray, L.C. (1914). Rent Under the assumption of exhaustibility. Q.J.E. (1914), pp 466-489.

   Hotelling, H. (1931). The Economics of exhaustible resources, J.P.E. (1931), pp 137-175.

Gordon, R.L. (1965). Conservation and the theory of exhaustible resources. Canad. Jour. Econ. Pol. Sci. (1965), pp 365-379.

Lockner, A.O. (1962). The Economic effects of a progressive net profits tax on decision-making by the mining firm. Land Economics (1962) 38, 341-9.

Murdoch, J.C. (1956). Diminishing returns and the depletion of mines, Land Economics, 32, 313-7.

Heal, G. (1974). Economic aspects of natural resource depletion. Paper delivered at EESG/IG conference on natural resource depletion, London, January 1974.

Kay, J.A. and Mirrlees (1974). The desirability of natural resource depletion. Paper deliverd at EESG/IG conference on natural resource depletion, London, January 1974.

9. See for example:-

Forrester, J.W. (1971), World Dynamics, Cambridge, Mass.
Meadows, D.H. et. al. (1972), The limits to growth, New York, Universe Books.
Nordhaus, W.D. (1973), World Dynamics, Measurement without Data, Economic Journal (1973), 1156-1183.
Jahoda, M. ed. (1973), Thinking about the future, Chatto and Windus.
Beckerman, W. (1974), In defense of economic growth, Cape.

10. See for example:-

Heath, K.C.G. and Kalcov, G. (1971), Graphical valuation methods for use in prospecting and exploration, Trans. Inst. Min. Metall. (1971), 80, A45-50.

Halls, J.L. et. al. (1969), Determination of optimum ore reserves and plant size by incremental financial analysis. Trans. Inst. Min. Metall. (1968), 78, A20-26.

Groundwater, T.R. (1967), Role of discounted cash flow methods in the appraisal of capital projects, Trans. Inst. Min. Metall. (1967), 76, A67-82.

11. But see for example:-

Corner, D.C. and Stafford, D.C. (1972). The China and Ball Clay Industries. Univ. of Exeter, Dept. Econ.

12. e.g. The Coed Y Brennin public enquiry into RTZ's exploration application.

13. cf. for example the Journal Economic Geology.

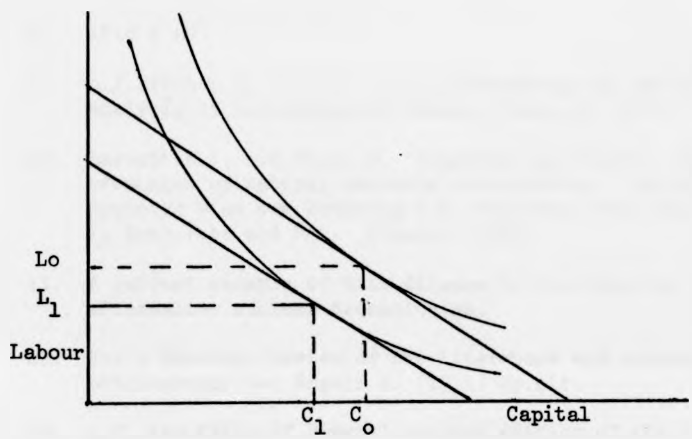
14. But see, for example: Long range planning in the Mining Industry, Longrange Planning (1969), September 7, 6-9.

CHAPTER TWO

1. Salter W.E.G. (1966), Productivity and Technical Change. Cambridge Univ. Press. 2nd edn.

2. Rogers E. (1962), The Diffusion of Innovations. Free Press Glencoe. Rogers E. (1971), The Communication of Innovations. The Free Press. Schon D. (1971), Beyond the Stable State. Temple Smith.

3. Under constant factor cost conditions these are represented graphically as follows:



The rate of technical advance, Tr is given as: $Tr = \dfrac{\frac{dL}{dt}w + \frac{dc}{dt}g}{Lw + Cg}$

The bias of technical advance, Dr is given as:

$$Dr = \frac{d(C/L)}{dt} - \frac{L}{C}$$

where w = wage rate for Labour, L
g = capital costs for capital, C
t = time

(Salter op.cit. p.30-33)

For the effect of technical advance on the substitutability of the factors of production a third time dimension should be added and elasticity should be measured relative to stipulated portions of the curve. Under these conditions the elasticity of substitution at time t and at constant factor prices is given by:

$$\frac{d(C/L)}{C/L} \cdot \frac{r}{dr} \quad \text{(ibid p.34)}$$

4. ibid, p 52

5. For a definition of best practice productivity see page Chapter One.

6. The simple model incorporates the following assumptions:

(i) The production plant is an homogeneous, indivible unit
(ii) Labour is homogeneous and of equal skill and efficiency
(iii) All capital involved in new techniques is specialised
(iv) All plants work at designed normal capacity
(v) Managerial efficiency is constant and equal in all plants
(vi) The industry is perfectly competitive
(vii) All factor markets are "approximately competitive"
(viii) All plants have short run marginal costs that are constant or falling as far as designed capacity and thereafter rise sharply

7. ibid p 81

8. ibid p 89

9. c.f.Brunner E. (1974). Some shortcomings in the economic analysis of technological change, Omega 2, 33-41

10. Barnett H.J. and Morse C. Scarcity and Growth: the economics of natural resource availability. For an opposing view see Lovering T.S. Resources from the Land in Resources and Man. Freeman (1969).

11. A current example of this dilemma is the decision over alternative nuclear technologies.

12. For a thorough review of the literature and comprehensive bibliography see Rogers E. (1971) op.cit.

13. c.f. the title of Rogers' revised edition of the Diffusion of Innovations: the communication of innovation.

14. c.f. Nabseth I.U. and Ray G.F. (eds) (1974). The Diffusion of New Industrial Processes. Cambridge Univ. Press, especially Chapter 6, Basic oxygen steelmaking. Also Mansfield E. (1968a). The economics of technological change, Norton, especially Chapter 4.

15. Rogers E. (1971) op.cit. p 337

16. ibid p 103

17. Mansfield E. (1968a), The Economics of Technological Change, Norton, especially Chapter Four., and Mansfield E. (1968b), Industrial Research and Technological Innovation, Norton.

18. Including Lynn F. (1966), An investigation of the rate of development and diffusion of technology in our modern industrial society, Rep. Nat. Comm. Tech., Automation and Economic Progress, Freeman C., Research and Development in Electronic Capital Goods, Nat. Inst. Econ. Rev. (1965), November,and Saville, A., Mining Machine Industry, Iron and Coal Trades Review (1958), Sept 19.

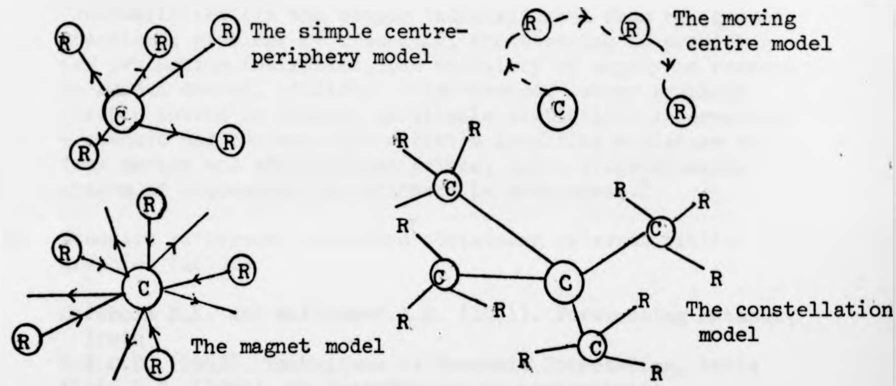
19. "Four principal factors seem to govern how rapidly the innovation level of utilisation approaches this ultimate or equilibrium level: (1) the extent of economic advantage of the innovation over older methods or products, (2) the extent of uncertainty associated with using the innovation when it first appears, (3) the extent of commitment required to try out the innovation, and (4) the rate of reduction of the initial uncertainty regarding the innovation's performance" (1968a), p 119.

20. ibid p 126

21. ibid p 113

22. ibid pp 138-9 and 280

23. Schon (1971), cites three variants of the simple centre-periphery model which are nevertheless conceptually equivalent: (pp.83-86)



24. ibid p 37

25. ibid p 138

26. Schofield M. Industrial magnesium attains its centenary. Light Metals and Metals Industry (1964), Oct. 44-45

27. Hardy C.W. BoS refractories, a question of continuity, Refractories Journal (1972), November, 9-17

28. Laming J. Refractory raw materials and performance, Refractories Journal

29. Schofield M. op.cit.

30. McDivitt J.E. (1965). Minerals and Men, Johns Hopkins Press, pp 114-116

31. c.f. Hanawalt J.D. The industrial significance of the basic characteristics of magnesium. Metal Progress (1946), March, pp 548-552.

32. c.f. Schon D. (1971), op.cit. Chapter 4.

33. c.f. All-basic furnace sub-committee of BISRA and Brit. Ceram. Res. Assocn. Cooperative trials on all basic furnace refractories. J.I.S.I. (1957), March, 304-328.

34. As for example in Kay J.A. and Mirrlees, The desirability of natural resource depletion, proc. EESG/IES Conference on Natural Resource Depletion, London, 1974, p 23 - "We confess to having provided no forecasts of the very long run effects of natural resource depletion. Such forecasts would have very little basis and therefore enormous errors. They are neither a necessary nor sufficient basis for policy recommendations."

35. c.f. Blackett G.H. Some non statistical observations about the minerals industries. Canadian Institute of Mining: Special volume No 12 (1970). p 37:

"Instabilities (in the copper industry) stem from management practices, problems of financing, the time lag in providing new production facilities, the inability of supply to respond to sudden demand, political interference, labour problems, erratic shifts in demand, unreliable statistical information, a chaotic and confused price system involving a mixture of free market and administered prices, and a discriminatory system of allocation to customers in some areas."

36. Standard references consulted containing relevant bibliographies include:

Chisholm R.K. and Whittaker A.R. (1971). Forecasting Methods, Irwin
O.E.C.D. (1963). Techniques of Economic Forecasting, Paris
Klein L.R. (1962). An introduction to econometrics, Eaglewood Cliffs
Theil H. (1961). Economic Forecasts and policy. North Holland Publishing Co.
Butler W.F. and Kavesh R.A. (1966). How Business Economists Forecast. Prentice Hall

37. Standard references consulted containing relevant bibliographies include:

Jantsch E. (1967). Technological Forecasting in perspective, O.E.C.D.
Ayers R.U. (1969). Technological Forecasting and long range planning. McGraw Hill
Quinn J.B. Technological forecasting. Harvard Business Review (1967), March/April, 89-100
Roberts E.D. Exploratory and normative technological forecasting: a critical appraisal. Technological forecasting (1969) 1
Wills G. et. al. (1969). Technological forecasting and corporate strategy. Bradford U.P.

38. Gabor D. (1963). Inventing the future, Secker and Warburg

39. c.f. Jantsch E. (1972). Technological planning and social futures, p 79:

    "Much of good forecasting is done without the explicit use of techniques. Techniques just serve to augment the capability of the forecaster and in general follow the basic thinking procedure which the human brain is following intuitively".

40. c.f. Chisholm R.K. and Whittaker G.A. (1971) op.cit. Chapter 4.

41. A full treatment of these techniques is to be found in Ayers R.U. op.cit.

42. Roberts E.P. (1969) op.cit.

43. Jantsch E. (1967). op.cit. pp 171-174.

44. Rosenzweig J.E. (1957). The demand for aluminium. Univ. of Illinois Bulletin 54 No 65.

45. The use of relevance trees is not by any means peculiar to technological forecasting. Developed by C. West Churchmann and others (c.f. Churchmann C.W. et.al., Introduction to Operations Research, Wiley N.Y. (1957)) they have since been widely used in operations research, decision theory, investment appraisal etc.

46. The calculation of relevance numbers is explained in detail in Jantsch E. (1967) op.cit.

CHAPTER THREE

1. Major references consulted in the preparation of this case study include:

   Paone J. in U.S. Bureau of Mines, Mineral Facts and Problems, Magnesium, (Washington 1970)

   Charles River Associates, Economic Analysis of the Magnesium Industry. Report prepared for G.S.A. June 1967.

   Emley, E.F. (1966) Principles of Magnesium Technology. Pergamon

   Roberts C.S. (1960) Magnesium and its alloys. Wiley

   Comstock H.B. (1964) Magnesium and Magnesium Compounds. A materials survey. U.S. Bureau of Mines

   Elkins, D.A. et. al. (1967). An economic and technical evaluation of magnesium production methods. Part 2. Carbothermic methods. Report of Investigation 6946, U.S. Bureau of Mines.

   Dean, K.C. et. al. (1965) An economic and technical evaluation of magnesium production methods. Part 1. Metallothermic methods. Report of Investigation 6656, U.S. Bureau of Mines.

2. See for example:

   Anon. Salt Lake Magnesium Plant, Light Metal Age (1970)April p.5

   Strickland, J.R. Preparing for the change, Metal Bulletin (1971), May 13 - 18

   Campbell, G. An exciting future for magnesium, Metals and Materials (1971), May, especially 169-170

   Church, F.L. Magnesium: Super marketing needed ... Modern Metals, (1971), August, 42-58.

3. In particular during 1971-2 substantial but undisclosed quantities of Russian magnesium were made available in the west at prices ranging between £230 - 240/long ton or about £30 below then current world prices. The Department of Trade and Industry imposed a special £62 anti-dumping duty (c.f. Financial Times, Tuesday, April 18, 1972).

4. See Table 5A, Appendix C.

5. c.f. Strickland, J.R. op. cit. p.16

6. The total power resources of the Norsk Hydro group amount (1972) to 7.7 Billion KWH per annum. (Financial Times Survey, Tuesday, April 11, 1972, 28-29).

7. One other potential contributor to US markets may be the American Magnesium Company who in 1968 built a 30,000 short t.p.a. magnesium plant using brines as a feedstock at Snyder in Texas. The plant experienced severe commissioning problems including atmospheric pollution. It was closed in 1971 by the Clean Air Commission and has not since produced more than a fraction of its rated output. (Church F. L. Magnesium, Modern Metals (1968) July, 31-47 and American Bureau of Metal Statistics, Annual Statistics 1972, 120.

8. For over twenty of these years Dow was literally the only US producer of magnesium. (Comstock H B op. cit., 99)

9. Metallgesellschaft. A G Metals Statistics, 1970.

10. Comstock H B op.cit., p.20

11. The Dow Story, Dow Chemical Co., p. 178, et seq.

12. ibid

13. Norsk Hydro's entry in 1950-51 was initially at the relatively small scale level of 12,000 tonnes. It is believed that in recent years the plant's major customer has been Volkswagenwerk A G

14. As of late 1974 the plant at Rowley, Utah, was believed to be operating at approximately 10% of capacity (45,000 tonnes)

15. ibid. Alcoa have a renewed interest in magnesium production, (1974) and Kaiser Aluminium is known to have recently considered entry.

16. During the war 15 primary magnesium plants were built in the US alone, world production peaked at 184,000 short tons in 1943, but by 1945 it was reduced to under 45,000 tons.

17. c.f. Hanawalt J D. The industrial significant of the basic characteristics of magnesium, Metal Progress (1946) 548-552, and Warrington H G. What's the matter with Maggie? Light Metal Age (1962) December, 5-6.

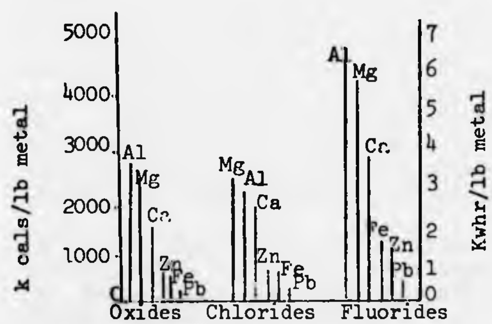
18. The surprising fact is that per capita consumption of magnesium for general engineering purposes is still higher in Germany than in any other country:

	Tonnes	per Capita (Kg)
U.K.	1250	0.02
Germany	35,000	0.60
		0.10 (excluding Volkswagon)
U.S.A.	14,000	0.09

Source: Campbell G. op. cit. p.172

19. It should be enphasised that the following analysis does not include the role of technology in the 'human' side of the enterprise where distinctions between technological innovation and improved resource allocation tend to be rather vague (e.g. impact of operations research, large scale data processing, mass advertising etc.).

20. Emley E.F. op. cit. 26-32. The relevant free energy information is summarised in the following diagram:



Minimum energy.required to liberate lb of metal from various oxides and halides at 15°C

ibid. p.26

21. Brubacker, S. (1967), Trends in the World Aluminium Industry, JHUP.

22. In an electrolyte consisting of Mg F_2, Ca F_2 and Ba F_2 for example the solubility of MgO is still only 0.1% approx. such that the prospects at the outset for such an electrolyte are not very encouraging. (Emley E.F. op. cit., 28.) Were such a suitable electrolyte for MgO electrolysis to be successfully developed the implications for the sea water process could be crucial. As it is, the brine based processes starting already with a dilute $MgCl_2$ feedstock appear to have the advantage.

23. Emley, E.F. op. cit., 31

24. Dolomite contains a theoretical 13% of Mg, Magnesite ($MgCO_3$), 29% Bricite ($Mg(OH)_2$), 42% and Olivine $(Mg,Fe)_2SiO_4$, 19% (Comstock, H.B. op. cit., 27)

25. c.f. Strickland, J.R. op. cit.

26. Lithium containing electrolytes are believed to have diffused to all the major electrolytic producers.

27. Elkins, D.A. et. al. Economic Aspects of Magnesium Production <u>in</u> Electrometallurgy (AIME) Proceedings of Extractive Metallurgy Division Symposium on Electrometallurgy (1968) December, 173-184

28. It is believed that this role is peculiar to the Magnox generation of nuclear reactors. The containers are manufactured by Magnesium Elektron Limited in the U.K.

29. Lasch L. The market potential of magnesium and its alloys, Metals and Materials (1968), March, 81-90.

30. Anon. Design. Magnesium Elektron Limited.

31. The problem of melting losses during primary fabrication should however be mentioned. This has been a serious drawback in the diffusion of magnesium. Because of magnesiums reactivity melts have to be covered in a crust of flux and poured under sulphur. To put this problem in perspective a recent review stated that a 15 lb aluminium casting showed a metal loss of 2.5% whilst a 10lb magnesium castings metal loss was 10%. (Church F.L. (1972) op. cit., 50). More recently however the Battelle research institute have shown that a small addition (0.1%) of suplhur hexa-fluoride reduces melt losses and renders flux unnecessary. (Fisher P.A. Magnesium Elektron Ltd., pers. comm.)

32. AZ91 - Aluminium 9%, Zinc 1%. Aluminium confers strength and refines the cast structure of magnesium, zinc has much the same effects, manganese is used to confer strength (Emley, E.F. op. cit., 230-231).

33. In the sense of it being a large well defined market which illustrates magnesium's role most adequately. The data in Table 7, Appendix C, are the most recent available for breakdown by end use for magnesium in industrial structural categories of the U.S. market. As the date is 1963 however it is difficult to place great reliance on these figures as estimates of present market segmentation not least perhaps because they were supplied by Dow Chemical.

34. Over 30,000 tonnes/annum in the late 1960s and early 1970s. See,

    Boehner L.C. Magnesium in the Volkswagen, Modern Metals (1969) December, 44-5, 48.

    Anon. Magnesium in the Volkswagen, Light Metals (1961) August, 221 - 224.

    Fisher P.A. Modern manufacturing uses of magnesium alloys, Engineering Materials and Design (1970), March, 295-300.

    Anon. Porsche sold on magnesium, Modern Metals, (1970) September, 47-51

35. A comprehensive review of magnesium as a chemical is contained in an article under this title by Hock A. L. in Chemistry and Industry (1971), 16th January, 78-82. Of particular interest is the use of magnesium for desulphurising steel and in the production of nodular cast iron.

36. A thorough discussion of the relative inelasticity of demand for magnesium by the aluminium industry and in particular of the phenomenon of the 'kinked' demand curve is to be found in Charles River Associates report (op. cit. pp 97-105). Their conclusion was that the pricing behaviour which "appears to be consistent with the facts is that the price structure of magnesium is designed to maximise profits while minimising the chances of entry into the magnesium industry".

37. ibid p. 116

38. U.S. tariffs were still 20% ad valorem in 1972.E.E.C. tariffs are currently (1973), 8%.

39. Miska W.S. (1970) Refractory use Patterns in the iron and steel industry of the U.S., U.S. Bureau of Mines Information Circular, No. IC 8382, 3.

40. Kusler D.J. and Clarke R.A. (1969). The impact of changing technology on refractories consumption. U.S. Bureau of Mines Information Circular, 3.

41. c.f. Shaw K. (1972) Refractories and their uses, Applied Science publishers: "In the periodic system there are only nine elements with melting points of 1000-1500°C, there are 15 elements with melting points of 1500-2000°C and 10 elements with melting points in excess of 2000°C. In any refractory system, increasing the number of elements tends to lower the maximum fusion point of the compounds involved, and the probability of forming a refractory material from two simple oxides is almost twice as great as that of forming such a material from three oxides. Of the 9,200 binary compounds that can possibly be formulated out of the 22 refractory oxides only 1010 are refractory, i.e. 11%".

42. This may seem surprising to anyone who has witnessed the relining of a steel furnace. Aside from demarcation disputes involved in any innovation in this labour intensive 'craft' occupation there are severe technical problems associated with casting, moulding, or gunning linings into place as with ready mix concrete. One of the most significant problems is the setting agent in the refractory concrete which can also act as a fluxing agent seriously reducing the potential lining life. Nevertheless patching up linings by gunning is widely practised particularly in the United States.

43. The following are major references consulted for this case study:

Chesters J.H. (1973) Steelplant Refractories, 3rd Edn.

Alper A.M. (ed) 1972) High Temperature Oxides, Part 1, Magnesia, Lime and Chrome Refractories, Academic Press.

Anon. The U.K. Refractories Industry, Industrial Minerals (1972) October.

43. Laming J. Materials for high temperature engineering.
cont Institute of Refractories Engineers (1971) October.

Hardy, C. BOS refractories - a question of continuity. Refractories Journal (1972) November, 9-17.

Norton F.H. (1968) Refractories, McGraw Hill, 4th Edition

44. Most of the dolomite imports come from Spain and are used in glass manufacture (Pilkington Co., pers. comm.)

45. Based on various personal communications from the refractories industry. An earlier estimate appears in a consultancy report for the Highlands and Islands Development Board.

46. In addition to the references in notes 43, c.f.

Gilpin, W.C. and Spencer D.R.F. New Developments in dead burnt magnesite and dead burnt dolomite. Refractories Journal (1972) April, 4-20.

Laming J. Raw Materials and Refractory Performance. Refractories Journal.

Cummings R.G. and Bichan H.R. Economic appraisal of British carbonate deposits. IMM special volume.

Anon. Magnesite and Sea Water Magnesia, Industrial Minerals (1970) December, 9-31.

Worrell, W.A. Raw Materials. Institute of Ceramics, Text Book Series Vol. 1

47. The process is very similar to that used in the preliminary stages of magnesium metal production via the sea water route.

48. c.f. Laming J. <u>in</u> Alper, A.M. (ed) op. cit., 146-148.

49. c.f. Kappemeyer K.K. and Hubble D.H. <u>in</u> Alper A.M. (ed) op. cit. 20-23

50. c.f. Hayhurst A. and Laming J. The effect of firing temperature on the properties of chrome magnesite bricks. Refractories Journal (1963) March, 80-92, 115.

51. It should be mentioned that one of the cheapest methods of quality control is through careful selection of raw materials. There has been considerable traditional rivalry between alternative source and types of raw material which is typified by the competiton between natural and synthetic magnesia which still remains unresolved to the interim benefit of the ultimate consumer (c.f. Anon. Magnesite and sea water magnesia: a fruitful rivalry Industrial Minerals (1970), December 9-31. Anon. Magnesia meets the challenge, Industrial Minerals (1967) November, 8-12 and Anon. Swing to sea water magnesia. Industrial Minerals (1969) December 7,40) For many years magnesite was deemed to be preferable in steelmaking applications. The puzzling deficiency of synthetic

magnesias, in terms of their hot strength, was eventually traced to the presence of small amounts of boron which act as a flux thereby reducing the strength of the finished brick at high temperatures (c.f. Gilpin W.C. Problems in the production of sea water magnesite, Refractories Journal (1959), January and Gilpin W.C. & Spencer D.R.F. (1972) op. cit.) The removal or non-precipitation of boron gave sea water magnesia a new degree of commercial attractiveness. During the sixties however it was found that new sources of natural (cryptocrystalline) magnesite could yield bricks with superior wear characteristics because of the close interlocking of the constituent grains and increased firing temperatures. The new raw material sources were developed in Greece, Turkey and Spain (c.f. Anon. Basic refractory materials, Industrial Minerals (1972), August, 23-30). But again, new sources of very high purity sea water magnesia have been recently developed in Sardinia, Israel and Japan and various innovations in brick manufacture, most notably a two stage intermediate pelletising process, have resulted in even higher hot strength bricks with superior performance characteristics (c.f. Gilpin W.C. & Spencer D.R.F. (1972) op. cit.). It would be unwise to suggest that raw materials competition is now largely exhausted. Given that chemical purity is a desirable objective however it is probable that the greater degree of selectivity achievable with the sea water process will lend it long term advantages over 'natural' products.

52. Laming, J. (Pickford Holland Ltd. - pers. comm.)

53. References for this section include: Kusler D.S. and Clarke R.G. op. cit., Miska W.S. op. cit., Kappemeyer K.K. and Hubble D.H. Steelplant refractories in the seventies. Ceramic Bulletin (1972) 51. (7), 568 - 573. Richardson H.M. Refractories Today - Journ. Inst. Full. (1968), 87-93. Jeffers P.F. Refractories blast off for the seventies, Brick and Clay Record (1970) January, 33-37. Richardson H.M. Production and use of refractories in Britain. (1970). J. Brit Ceram. Soc. 7,No.1. Rigby, G.R. Future Trends in U.K. Refractory materials for steel production, Refractories Journal (1971), January 26-30. Richardson H.M. Changes in the usage of refractories in the iron and steel industry. In Fact No. 69 (1968), March, 9-12. Debenham W.S. The role of refractories in steels future, Blast Furnace and Steel Plant (1969), February, 169-173.

54. Thus, for example, glass tank regenerators are relined on average once every five years, cement kilns perhaps every two years, and basic oxygen steel furnaces every three weeks.

55. Anon. Refractories in Western Europe. Industrial Minerals, (1973) February, 9-27.

56. c.f. Rowley, C.K. (1972) Steel and Public Policy, McGraw Hill, 80-83.

57. c.f. Appendix F. It has also been a source of some incentive to diversify out of refractories. Thus the Steetley company has acquired the chemicals concern Berk Ltd., and extensive minerals and manufacturing interests particularly in Canada and Australia. G.R. Stein is now part of the large Hepworth Group of companies whose major interests include the manufacture of sewerage and drainage pipes and white clayware.

58. Mainly related to the fluxing effects of complex chrome containing spinel compounds (see Hayhurst and Laming (1963) op. cit.)

59. op. cit.

60. Bailey J. (B.S.C. - personal comm.) c.f. Bailey J. The commercial aspects of refractory purchasing. Refractories Journal (1973) January 9-15.

61. That is availability to make steel.

62. ForchheimerO.L. and Charlton BOF linings in the U.S.A.: A Survey, Refractories Journal (1969), 92-96. The price information contained in this article is now obviously out of date although it is still believed that the "relativities" argument is valid.

63. This section is mainly derived from discussion with individuals in the quarry products industry. Some of the more important references to be acknowledged include:

Peters R.H. (1971), The Quarry Products Industry, Hoare and Co., Govett, Investment Research. Quarrying in Somerset, Somerset County Council (1971).

Anon. Redland Guide to the Construction Industry, Annual

64. The announcement (or informal hint) of major public construction activity commonly results in a rush to establish supply points close to the intended development.

65. Please A. and Pike D.C. The demand for road aggregates, Ministry of Transport, RRL, Report LR 185 (1965).

66. Colver, H. Many new Applications in Concrete: A Financial Times Survey (1974) February 27, p.32.

CHAPTER FOUR

1. c.f. Brubacker, S (1966), Trends in the World Aluminium Industry. Free Press, and Rosenzweig, J E (1957), The demand for aluminium: a case study in long range forecasting. University of Illinois Bulletin 54, no 63. Rosenzweig (p. 67) presents some comparisons of price differentials between aluminium, copper and steel on a 'volume' basis showing that aluminium has long been considerably cheaper than copper but, on average, five times as expensive as steel.

2. See statistical Appendix C for data.

3. See Table 8 for examples in the US export trade.

4. See pp. 16-22

5. Notably the aerospace, chemical, sacrificial and many small miscellaneous sectors.

6. A recent example being the construction of an aluminium smelter in Bahrein to make use of 'waste' natural gas.

7. Details are to be found in US Bureau of Mines Minerals Yearbook (1968) vol. 1, p. 674.

8. It is believed that the licenses on the original Dow and IG - MEL reduction processes have now expired (P A Fisher, pers. comm.)

9. The build up of expertise in the production of magnesium in the USSR should not be overlooked. Although a non traditional source of technical knowledge it is believed that a recent US entrant, the American Magnesium Company employed soviet experts to assist in the solution of serious pre production problems. The plant was closed down in 1971 as a result of a court order alleging excessive environmental pollution.

9A. Reported in American Bureau of Metal Statistics Annual (1971) p. 120. Very recently Dow has announced renewed expansion plans probably for a brine based plant using lithium enriched electrolytes. The location of this plant has yet to be announced.

9B. P A Fisher (pers. comm.)

9C. c.f. Paone J, (1970) op. cit.

9D. It is interesting to note however that National Lead's recent entry may have been influenced by their long standing interest in 'captive' magnesium production through their ownership of the Titanium Metals Corporation (c.p. Table 3)

9E. National Lead's projected commitment was forecast in 1970 as $ 70 million (Light Metal Age (1970) April, 5.)

9F. American Bureau of Metal Statistics Annual (1971, p. 120

10. Over the last eighteen months of course the situation has been rather different particularly with respect to zinc which was at one time trading at prices over £1000/tonne. Plastics too have experienced a hiatus in their raw material costs.

11. Nelson K E. Imagine it die cast - in magnesium, Precision Metal (1970), May 41-43, 100, July, 59-61, August, 40-41.

12. The alternative technology would involve high alumina clays and some unspecified 'direct' reduction alternative.

13. Estimate based on wartime US Plancor operations, see Comstock H B, op. cit.

14. The mini mill concept is essentially a scrap recycling process and therefore not directly comparable with the direct reduction routes discussed. It is perhaps worth noting that the U.K.'s only magnesium producer Magnesium Elcktron Limited, constructed a Pidgeon process plant at Hopton in Derbyshire in 1966. The operation was generally considered a technical and economic failure and the plant was subsequently dismantled. The company now concentrates on scrap recycling of Volkswagen engine and gearbox parts imported from the continent, (P.C. Fisher, pers.comm.)

15. Specifically higher strength steels and larger capacity retorts. See Dean, K.C. et. al. (1965), An economic and technical evaluation of magnesium production methods. Part 1. Metallothermic. U.S. Bureau of Mines, Rep. Inv. 6656.

16. c.f. Church, F.L., Modern Metals (1971), August, 49-50.

17. P.A. Fisher, pers.comm.

18. Fisher, P.A. Modern Manufacturing uses of magnesium alloys, Engineering Materials and Design (1970), March 295-300.

19. Solid magnesium must be first melted at 650°C before it will burn. Finely divided magnesium burns brilliantly and highly exothermically.

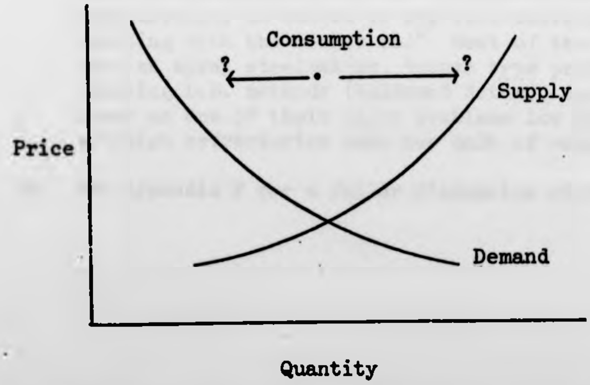
20. Charles Rivers Associates, Economic Analysis of the Magnesium Industry. Report prepared for G.S.A. June 1967.

21. Throughout this chapter the convention X = year where X = 0 at 1900 is used, and Y is always taken as the forecast demand or consumption variable. Subscripts are used to identify the commodity.

22. Paone, J. Magnesium in Mineral Facts and Problems, U.S. Bureau of Mines (1968), 621-638.

23. op.cit., pp 136-141

24. It is widely agreed that the assessment of a supply and demand curve for any industry, except where one function is completely inelastic, is normally impracticable. The problem can be illustrated graphically:



Data is normally collected as consumption information which may represent shipments, shipments and stock movements, or some other figure. At any one time it is clearly impossible to work out on the supply side how much could be supplied at a given price except over a very narrow range since in the short term supply is largely inflexible. But the more serious problem arises from the difficulty of identification of the supply and demand elements of consumption data (c.f. Rowley, C.K. (1971), Steel and Public Policy, McGraw Hill, p.76).

25. It is important to note that although the terms elastic and inelastic are used without qualification it follows from the definition of the term that, except in the case of a constant elasticity (rectangular hyperbola E = 1) E = 0 complete inelasticity or E = infinity, completely elastic, the price/quantity range over which elasticity is measured should also be specified. Thus a straight line is elastic near its top, inelastic near its bottom and has E = 1 at its halfway point.

26. U.S. Bureau of Mines (1968), op.cit. p.634.

27. ibid, p 635.

28. c.f. Hoch, A.L., Magnesium as a chemical, Chemistry and Industry (1971), January 16, 78-82.

29. Miska, W.S. (1970), Refractory Use Patterns, U.S. Bureau of Mines, Inf. Circ. 8382, p.3.

30. Cited in Rowley, C.K. (1972), Steel and Public Policy, McGraw Hill.

31. c.f. Chesters, J.H. The case for continuity in extractive metallurgy. 8th Sir Julius Wemher Memorial Lecture, Institute of Mining and Metallurgy, October 1971" --- the original cost savings of the L.D. process compared with the open hearth for common qualities of steel was as high as £2 per ton of product. When it is realised that the modern BOF vessel only requires an expenditure on refractories of approximately 25p/ton of steel, compared with nearly £1.25 for the open hearth, it will be seen that half the gain of the L.D. is due to its extraordinarily low refractories cost - the reasons for which are only now becoming apparent. Any (new) process which involves a refractories cost substantially in excess of 25p will therefore be starting with the brakes on!" Most of the 'new' methods such as spray steelmaking, trough type processes, the rotating L.D. methods (Kaldoand Rotor), do in fact incur as one of their major problems low lining life and high refractories cost per unit of output.

32. See Appendix F for a fuller discussion of this process.

33. c.f. All basic furnace sub committee of BISRA and Brit. Ceram. Res. Asscn. Co-operative trials on all basic furnace refractories, J .I.S.I. (1957), March, 304-328.

34. Hayhurst, A. and Laming, J. The effects of firing temperature on the properties of chrome magnesite bricks, Refractories Journal (1963), March, 80-92, 115.

35. Richardson, H.M. Production and Use of Refractories in Britain. Trans. Brit. Ceram. Soc. (1969), p.25. The decline referred to primarily concerns the consumption of dolomite refractories per ton of steel product. Absolute tonnages consumed also showed a slight decrease throughout the period (see Fig. 19). The background to the 'learning curve' for dolomite refractories in the BOS is analysed in Carr, K. et. al. (1965), A study of oxygen convertor linings, ISI., Macnamara, J. Operating factors that affect basic oxygen furnace lining life, Open Hearth Proceedings (1970), 74-81 and Beechan, C.R. et. al. How physical properties affect BOS refractory performance, Journal of Metals, (1971), September, 26-31.

36. Bailey, J. The commercial aspects - Refractory purchasing. Refractories Journal (1973), January, 9-15.

37. Hardy, C. BOS refractories - A question of continuity. Refractories Journal (1972), November 9-17.

38. The calculation on which this forecast is based as is follows:

<u>Steel Production 1986</u> (million tonnes)

	L.D. (80%)	Electric Arc (20%)	Total
High	28.8	7.2	36
Low	22.4	5.6	28
Estimated Refractory Consumption (ex Hardy) lbs/tonne	3	8.5	

Refractory Consumption in thousand tonnes

High	82.7	61.1	143.8	Average 129.3 (1968 = 216.8)
Low	67.1	47.6	114.7	

39. A rough comparison is afforded by the following table:

Energy Requirements for large industrial processes

	Tons of oil equivalent per ton of product
Magnesium refining	7
Aluminium refining	4.5

39.(Continued)

	Tons of oil equivalent per ton of product
Copper refining	1.2
Plastics manufacture	2
Glass manufacture	0.5-1.0
Zinc refining	0.5
Iron and steelmaking	0.2-0.4
Paper manufacture	0.2-0.4

1 ton of oil equivalent = 12,500 kwh, Source Financial Times Energy Survey

40. Notwithstanding the recently advanced notion of nuclear steelmaking.

41. C. Hardy, pers.comm. This is apparently because vessel turbulence is reduced, refining takes place faster because of the more intimate mixture of oxygen with the charge, and more carbon monoxide can be burnt closer to the charge. The jet of oxygen is enclosed in a jet of propane to prevent excessive refractory wear at the point of entry.

CHAPTER FIVE

1. These definitions, and others, are contained in, The perspectives of planning, Proceedings of Symposium, Bellagio, O.E.C.D. 1969.

2. c.f. Churchman, C.W. (1961), Prediction and Optimal Decision, Prentice-Hall Inc., especially Chapter 14.

3. Von Hayek, F. (1943), The road to serfdom, 26.

4. ibid, p 28

5. For a recent statement of this philosophy in relation to minerals development c.f. Kay, J.A. and Mirrlees, The desirability of natural resource depletion, EESQ/IES conference paper, London, 1974.

6. c.f. Katz, D. and Kahn, R.L. Common characteristics of open systems in Emery, E.F. (ed) (1969), Systems Thinking.

7. Fisher, J.L. Natural resources and technological change, Land Economics (1953), 29, 58. The fluidity of the definition of mineral resources is often overlooked not least in the recent prophecies of medium term resource shortages. A more recent statement of Fisher's definition is to be found in Cameron (ed) (1974), The mineral position of the United States (1975-2000).

8. As originally proposed by Churchman, C.W. (1960), Operations Research, Wiley.

9. Ozebekhan, H. The triumph of technology: can implies ought. Technological Forecasting (1969), 1.

10. c.f. Rogers, E.M. and Shoemaker, F.F. (1971), The Communication of Innovations, Free Press, p 9.

11. c.f. Mansfield, F. (1968), The economics of technological change, Norton, especially pp 53-61.

12. This principle is suggested by Elisabeth Brunner in Some shortcomings in the economic analysis of technological change, Omega (1974), 2, 33-41.

13. c.f. Cartwright, F. The challenge to the blast furnace, New Scientist, (1972) 4 May, 252-255. Cartwright points out that for a conventional output of 8-9 million t.p.a. of steel a total of seven production units are required (including 2 blast furnaces, a sinter strand, a coke oven battery, and three L.D. converters). For direct reduction to produce an equivalent output today 25 units would be required: nine direct reduction units and sixteen electric arc furnaces. Some interesting cost comparisons are also presented.

14. Boulding, K.E. The Ethics of rational decision, cited in Loasby, B.J., Long range formal planning in perspective, Journal of Management Studies (1967) October, 300-308.

15. The basis of the metals usage in the 'canning' of uranium.

16. Lamar, J.E., (1961), The uses of limestone and dolomite, Illinois State Geological Survey, Circular 321, 41 p.p.

17. Anon., The Beoil schist as a possible source of mica, I.G.S. report.

18. e.g. Lovering, T.S. Mineral Resources from the land in Resources and Man, (1969), Nat. Acad. Sci/Nat. Res. Coun., and of course the much popularised Limits to Growth Study (Meadows D.et.al) and its U.K. counterpart, Blueprint for Survival.

19. Note that this need not be a permanent shift in relative price differentials: a short term crisis can precipitate long term reallocations of productive resources. The role of crisis is examined in the study of diffusion in Chapter Two.

20. See Appendix E for details, including costs, of the various alternative production techniques.

21. c.f. Campbell, G. An exciting future for magnesium, Metals and Materials (1971), May.

22. The National Lead Companies' Great Salt Lake project.

23. Schon, D. (1971), Beyond the Stable State, Temple Smith, Chapter 3, the Evolution of the business firm.

24. Rogers, E.M. and Shoemaker, F.F. (1971), op.cit., See Chapter Two for a fuller discussion.

25. See Appendix E for a statement of costs for various processes.

26. Brubaker, S., (1967), Trends in the World Aluminium Industry, JHUP.

27. These assertions require further elaboration as follows:

a) "---during 1967 the U.S. produced nearly 3 million metric tons of primary aluminium and used nearly 30,000 tons of magnesium as an alloy ingredient - a ratio of about 0.96 to 1%.
In contrast France produced 366,000 tons of primary aluminium and used only 2350 tons of magnesium for a ratio of about 0.64%. By 1969 the French ratio had edged upward to about 0.69%, still far short of the U.S. record.
By 1980, worldwide production of aluminium is expected to reach 20 million metric tons. If the world-wide ratio of magnesium goes as high as 0.75% this calls for about 150,000 tons of magnesium".
Meschter, E. Modern Metals (1970), July, 67.

b) "While the specifications for vehicles vary widely the average standard American auto is made up approximately as follows:

Average American Car		Average European Car (Drive Magazine (1974) Summer)
2775 lbs	iron and steel (frame, engine, body)	1405 + 283 lbs
100 lbs	aluminium (components, some engines)	30 lbs
50 lbs	copper (radiators and electrical)	20 lbs
25 lbs	lead (battery)	10 lbs (excluding battery weight)
50 lbs	zinc (castings, galvanising and tyres)	30 lbs
100 lbs	glass (windscreen and windows)	50 lbs
250 lbs	rubber and plastics (tyres and fittings)	80 lbs (rubber)
150 lbs	miscellaneous (fabric, insulation etc)	72 lbs (cardboard, plastics and padding)
3500 lbs	TOTAL	1980 lbs

Morgan, J.D. Jnr., Future use of minerals: the Question of Demand in Cameron, E. ed., (1974), op.cit.

28. c.f. Reports of meeting of the U.S. Magnesium Association, e.g. Modern Metals (1968), July.

29. "--- exemplified best by the remark often made by Dr Willard Dow, one of the pioneers of magnesium: 'When seeking out potential new uses for magnesium, he would say 'look for anything that has to be pushed, pulled, picked up, carried or otherwise moved'", Lasch, L. The market potential of magnesium and its alloys, Metals and Materials, (1968), March, 89.

30. Particularly in view of Norway's recent decision to remain outside the community and despite quota arrangements.

31. c.f. Appendix G.

32. c.f. Warrington, H.G. An economic appraisal of the magnesium industry, Light Metal Age (1962), December 5, 6.

33. Paone, J., Magnesium, in Mineral Facts and Problems (1970), U.S. Bureau of Mines.

34. c.f. Schon, D. (1971), op.cit., Chapter 3.

35. The trade organisations, notably the Refractories Association and the British Ceramic Research Association, are particularly active in these areas.

36. There is also the apparent 'anomaly' that the largest producer

of refractories does not control any of its sources of basic raw materials, whereas the existing major supplier of these raw materials is currently diversifying away from the refractories and into the general chemicals industry.

37. One major source of refractory grade dolomite in the U.K. for example contains up to 5% Fe_2O_3 which is now regarded as an undesirable impurity particularly if passed on in the sea water process, but which at one time was favoured because it was known to aid densification during firing.

38. It should not be understood from this that such processes are obsolete: they may have a specialist role dependent on local conditions. In particular however the Kaldo and Rotor processes, at one time considered direct potential substitutes for the L.D. in bulk steelmaking, are now reserved (as was the electric arc furnace at one time) for the production of special quality steels.

39. Rogers, E.M. and Shoemaker, F.F. (1971), op.cit.

40. See Table 9 for a recent summary of refractory manufacturers.

41. c.f. Gilpin, W.C. and Spencer, D.R.F., New developments in dead burnt magnesite and dead burnt dolomite, Refractories Journal (1972), April, 4-20.

42. An abstraction of the method of identifying such premiums is discussed in Appendix F.

CHAPTER SIX

1. c.f. Appendix A

2. c.f. I.M.E.G. (1972), A study of the potential benefits to British Industry from North Sea Oil, Department of Trade and Industry; North Sea Report, supplement to Investors Chronicle/Petroleum Times (1974) May 3, Scottish Development Department (1973), Production Platform Towers; Construction sites.

3. Scottish Council (Dev. and Ind.) (1973), A future for Scotland, 173-174

4. Particularly where the social net benefits of development have to be considered. Public policy implications are not explored in this chapter although they are of urgent importance in the Highlands region. In this context the attempts of Ross and Cromarty County Council to define a minerals policy are exemplary: "To safeguard the environment and to minimise inconvenience to residents from noise, dust and heavy vehicles all applications for permission to extract minerals will be determined in accordance with the following principles. New workings will not be allowed unless sufficient evidence can be shown by the operator that a demand exists which cannot be met satisfactorily (i.e. either for type and quality of material or for economic reasons) from the existing workings and sites with planning permission." In addition eight categories under which minerals working would normally be prohibited are listed, nine conditions of working, three conditions for restoration and reinstatement of land, and four conditions governing associated activities. Ross and Cromarty County Planning Officer, pers. comm.

5. All these problems were highlighted at a recent symposium on Scottish Minerals Resources held in Dundee under the auspices of the British Association, October 1973

6. P. A. Fisher, pers. comm.

7. c.f. Mansfield E., (1969), The Economics of technological change, Chapter 3, p.105 "If the expected returns exceed those obtainable from other investments by an amount that is large enough to justify the risks and if the disadvantages of waiting outweigh the advantages, the firm should introduce the innovation. Otherwise it should wait. Pioneering is a risky business; whether it pays off is often a matter of timing.

8. c.f. Salter, W. (1966), Productivity and technical change, Cambridge UP p.33

9. c.f. Note 12, Chapter Five.

10. For a more comprehensive analysis of the traditional problems of the Highlands see Darling F. (1955), West Highland Survey, OUP especially pp.358-363.

11. c.f. Ridge J. Minerals from Abroad <u>in</u> Cameron E. ed. (1973), The Mineral position of the United States 1975-2000, Wisconsin UP.

12. ibid

13. Barnett H.J. and Morse C. (1963) Scarcity and Growth, the economics of natural resource availability, JHP, Ch.8: The unit cost of extractive products.

14. Lovering T.S. Mineral Resources from the Land in Resources and Man, Freeman (1969) p.125

15. Quarrying in Somerset (1971), Somerset County Council, p.107

16. Nabseth L. Conclusions, in Nabseth L. and Ray G. A. eds (1974), The Diffusion of new industrial processes, Cambridge UP.

17. For discussion of transport problems in the Highlands and Scotland see: Transport in the Highlands and Islands (1972), HIDB; Transport, A plan for Scotland (1974), Transport Action Scotland.

18. See Chapter two for a discussion of the diffusion of new materials.

19. c.f.:

Approximate annual per capita consumption of certain materials in the U.K. (1970)

	Tonnage	% change 1961-71
Sand, gravel, stone	4	+ 75
Coal	3	- 33
Oil and Gas	1.7	+ 100
Bricks	0.5	- 15
Iron and Steel	0.5	+ 33
Cement	0.3	+ 25
Wood	0.3	
Plastics	0.02	+ 160
Copper	0.01	
Lead/Zinc	0.01	
Aluminium	0.007	+ 40

Sources: Davies D., Chemistry and Industry (1973) Dec. 15

20. Lawson G., pers. comm.

21. c.f. Lawson G., Transport in the Highlands and Islands, a paper given at Mull Transport Seminar, October 1972.

22. Ross and Cromarty, County and Planning and Development Committee: Policy for Minerals Extraction: Further report, July 1972.

23. This estimate, given at the Drumbuie enquiry, applies to platforms of the McAlpine - Sea Tank design. Other designs in concrete are less aggregate intensive.

24. Industry sources suggest periods of between two and five years as average estimates for quarrying projects.

25. See discussion in Chapter Two

26. For an engineering background to the problems of 'multiple utilisation' see Jones G K., Engineering for Industrial Minerals treatment plant, Industrial Minerals (1971) June 37, 43, August 33-43, October 43-50 and December 39-50

27. Lamar J E (1961). The uses of limestone and dolomite, Illinois State Geological Survey Circular 321

28. Butler A S et al (1954) Dolomite in Scotland, Scot. Council (Dev. and Ind.)

29. Campbell J D et al (1972), Preliminary report of Chemical Engineering 4 Design Group 'A', School of Eng. Sci., Edinburgh

30. Seifert W W et al (1973) Energy and Development: A Case Study, MIT report No. 25 pp. 105-113, Magnesium

31. A future for Scotland (1973), op. cit

32. Information on transport costs in the UK suffers from the disadvantage that the recent escalation in energy costs, labour charges, and inflation render most published information useless other than for purely comparative purposes. Bearing this in mind preliminary investigation suggest the following scale of charges for alternative means of transport of dolomite from Eriboll to the north industrial midlands which is taken as the present centre of distribution of refractories to the UK steel industry:

Method	Cost £/tonne	Remarks
Road	£18.00	
Rail	£7-8.00	The nearest railhead, Lairg is approximately 55 miles from Eriboll
Ship	£4.00	Contract shipping for 2-2,500 tonne load; includes element of £3.50 approx. for handling and road freight from Runcorn to Midlands area

(pers comm., J Daniels., R.R.Co. Figures relate to June 1973)

As order of magnitude indications these figures do not compare favourably with the available price information for basic refractories presented in Table 12. Clearly only bulk shipping can be considered as an economic alternative although in any specific proposals measures would have to be taken to minimise handling and 'local' freight by road. Capital costs involved in the construction of loading facilities in the Highlands could also be considerable. In conclusion it is estimated that, at the crudest level, dolomite from the Highlands would have to be capable of exercising a minimum technical premium of the order of £5/tonne over comparative materials. For a recent study of similar transport problems in the china clay industry c.f. Corner D C and Stafford D (1972). The China Clay Industry. University of Exeter especially Ch. 6., Long distance transport costs. Details of operating costs in road freight transport are to be found in Edwards S L and Bayliss B T (1970) Operating costs in road freight transport, Department of the Environment.

APPENDICES

APPENDIX A

Dolomite

The purposes of this Appendix are:

1) To explain the choice of dolomite as a study mineral
2) To describe briefly its mineralogical and geological characteristics
3) To review its occurrence in the Highlands of Scotland
4) To present some new analyses of selected material

1. Background to the selection of dolomite

At the outset it was clear that either a limited number of minerals could be analysed in some detail, or that the study could be confined to broad generalisations. In the absence of any secure foundation for such generalisations however the former course was chosen. It was also obvious that very different conditions governed the use of mineral groups such as the bulk materials and metalliferous ores (see Chapter One). On the basis of the mineral classification eventually adopted it appeared necessary to include three minerals to adequately cover the range of applications. It was also desired to include a mineral which occurred in the Highlands of Scotland in significant quantities since the eventual aims of the study were to follow up the theoretical and empirical studies with some conclusions on the general problems of minerals exploitation in a regional context. The literature on Highland minerals was reviewed in detail[1*] and

---

* Refers to notes at end of Appendix

seven possible study minerals were identified. These included dolomite, potash, glass sand, base metal ores (copper - lead - zinc), alkali feldspar, mica and quartzite. From this short list, dolomite alone was eventually selected because of its:

(i) Multi category end use applications

Dolomite is a multi-purpose mineral. It can be processed to yield, either directly or indirectly, its magnesium metal content. It also possesses certain physical, chemical, and mechanical properties which render it suitable for a wide range of industrial applications. And it is also widely used as a general purpose bulk material. By keeping therefore to this single study mineral it was anticipated that inter-industry comparisons might be easier, whilst unnecessary duplication of background work could be avoided.

(ii) Geological abundance

Without prejudicing the adopted definition of mineral resources, deposits of dolomite are geologically extremely abundant. To a certain extent this freed the analysis from the economic implications of natural scarcity although as a consequence the approaches adopted would have to be cautiously applied to other development problems, particularly those concerning metalliferous minerals.

(iii) Satisfactory literature

The basic literature on many Highland minerals appeared unsatisfactory whereas in at least two of the major dolomite consuming industries [2] the literature was found to be reasonably comprehensive.

(iv) Absence of commercial evaluation

The study mineral had to be carefully chosen to avoid topicality and possible conflicts of interest with commercial concerns, whilst at the same time avoiding the study of a mineral with a low probability of ever achieving commercial potential.

2. The basic mineralogical and geological characteristics of dolomite

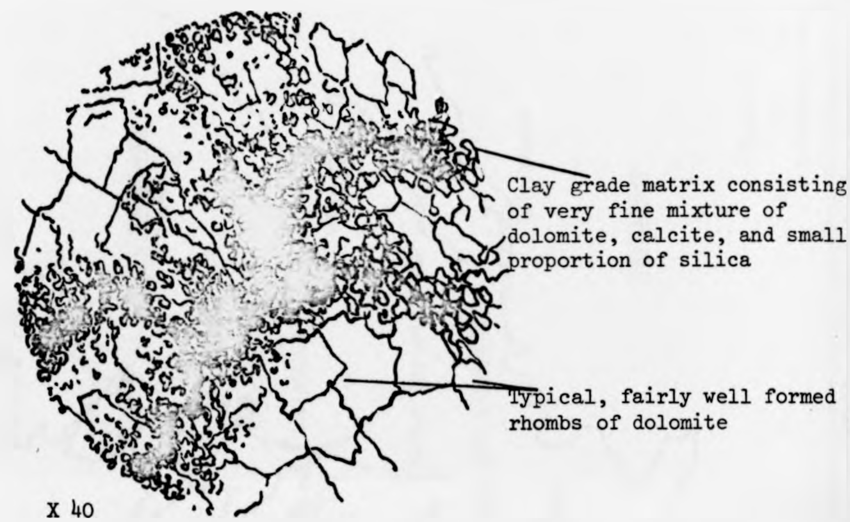
The mineral dolomite is the double carbonate of magnesium and calcium: Ca, $Mg(CO_3)_2$ or $CaCO_3$. $MgCO_3$. In the theoretically pure state the mineral dolomite would consist of 45.73% $MgCO_3$ and 54.27% $CaCO_3$ by weight which is equivalent to 21.87 MgO, 30.43 CaO and 47.71 CO_2 by weight (= 13% Mg by weight).

Most dolomite rocks however contain various impurities which may result from the chemistry of the depositional environment for primary materials or alternatively through subsequent metasomatic alteration or even physical reworking. It is important to stress that such impurities may be virtually impossible to remove without involving sophisticated ore dressing techniques. For example Deeretal., note that 'There is a continuous replacement of Mg by Fe^{2+} through ankerite towards Ca Fe $(CO_3)_2$' in many dolomites. Carr et al., have also drawn attention to the presence of various complex ferrites and silicates in manufactured dolomite products[4].

In addition to the chemical purity of natural dolomites the textural composition of such materials is increasingly recognised as having important implications for end product performance particularly in the refractories industry. The implication for the present investigation is therefore that chemical analysis alone may be an insufficient guide to the technical potential of a particular deposit and the analytical results quoted in this appendix should be interpreted in this light.

It would appear that the Durness Limestone Formation in the lower Palaeozoic strata of the Highlands, which is of particular interest for the present study is, in its purer horizons, composed almost entirely of a cryptocrystalline dolomite mud, sporadically veined with calcite (see Fig. A1). That the dolomite is at least penecontemporaneous

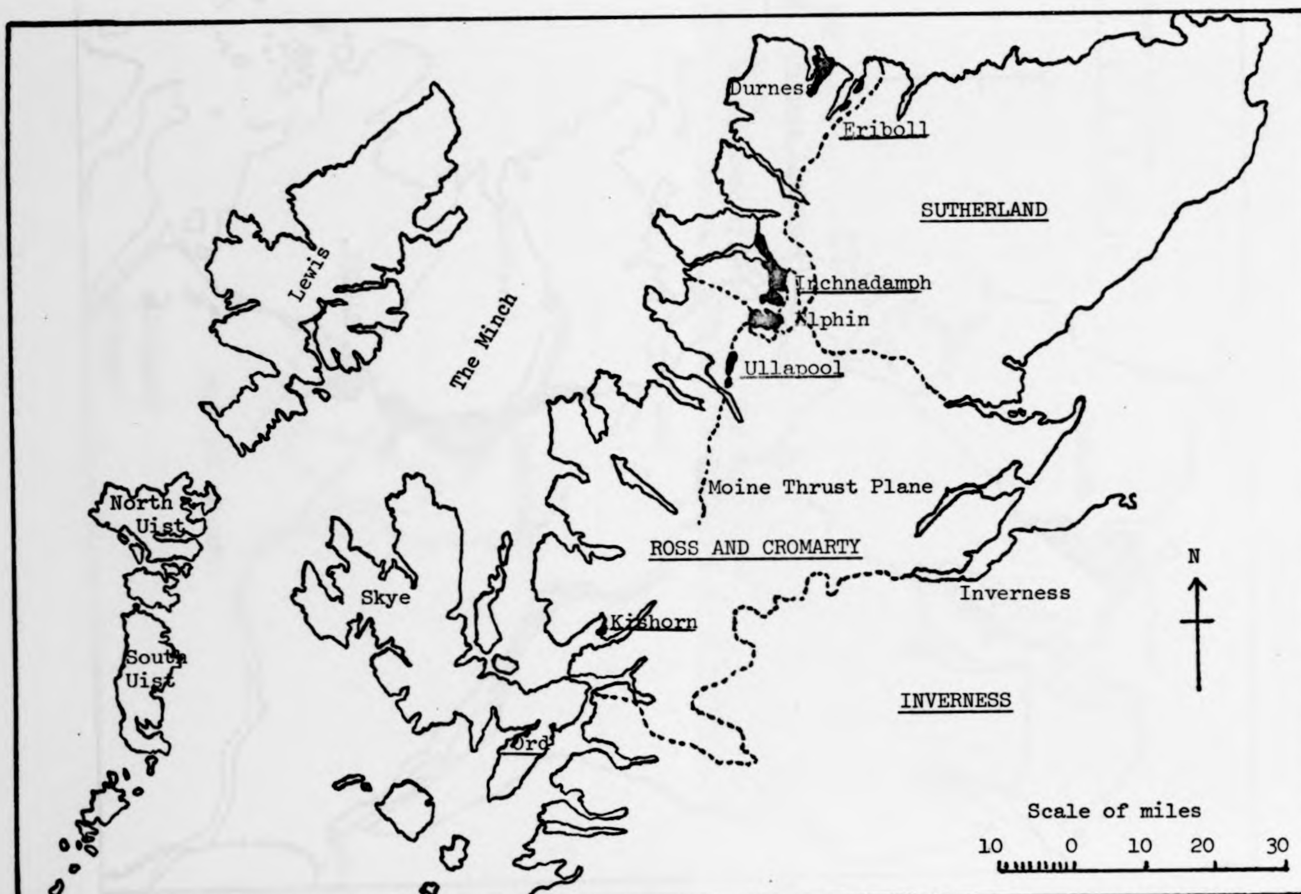
FIGURE A1: PETROGRAPHY OF SAMPLE OF ERIBOLL DOLOMITE



DESCRIPTION

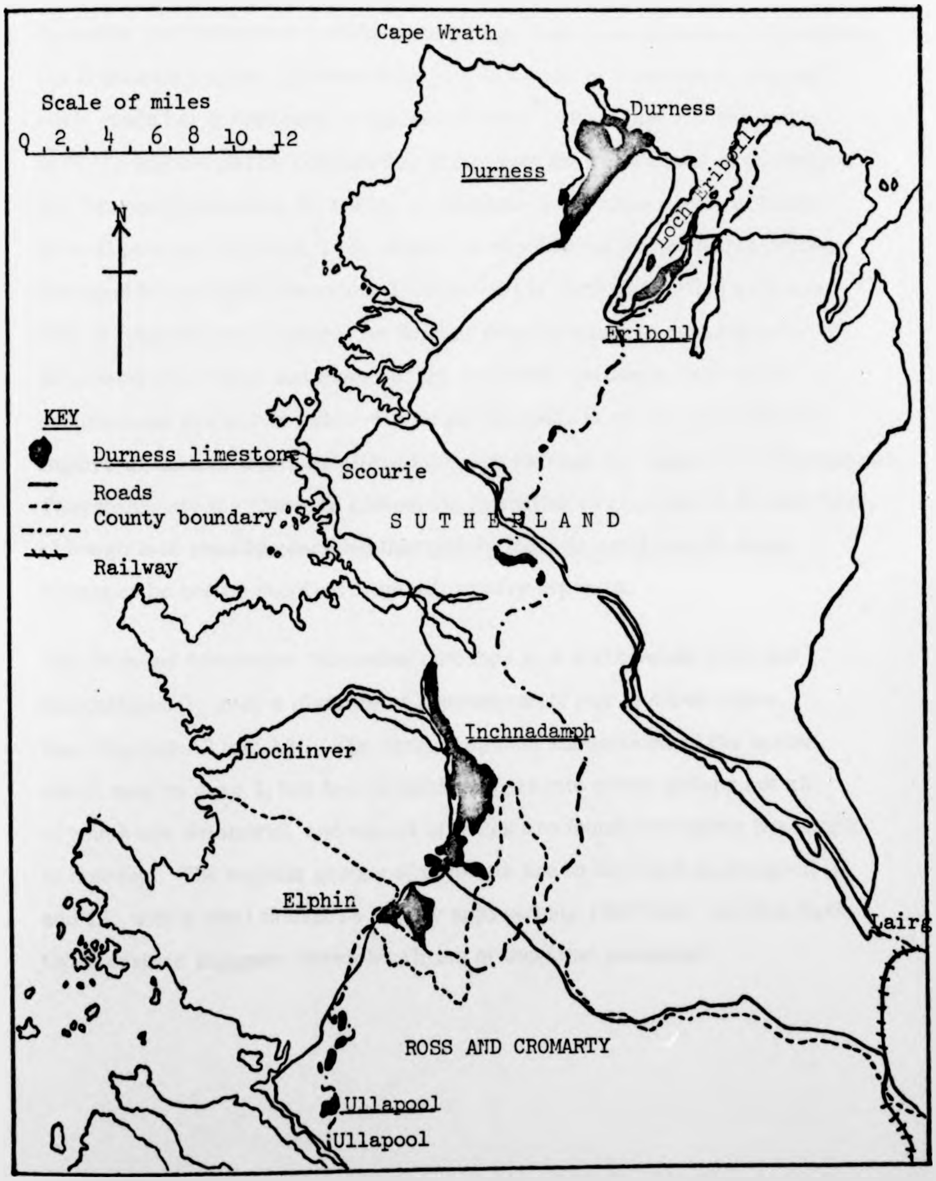
In this section the characteristic texture of the specimen is that of well formed angular rhombs of dolomite set in a clay grade matrix consisting of a very fine mixture of dolomite, calcite, and a small proportion of silica. Very occasional specks of iron oxide can be identified. The specimen is remarkably homogeneous there being a general absence of fractures, cleavage and secondary veining.

FIGURE A2: REGIONAL LOCATION OF HIGHLANDS DOLOMITE



Source: Adapted from Robertson, T. et. (1942), op.cit.

FIGURE A3: REGIONAL LOCATION OF NORTHWEST HIGHLANDS DOLOMITE



Source: Adapted from Robertson, T. et. al., (1942), op.cit.

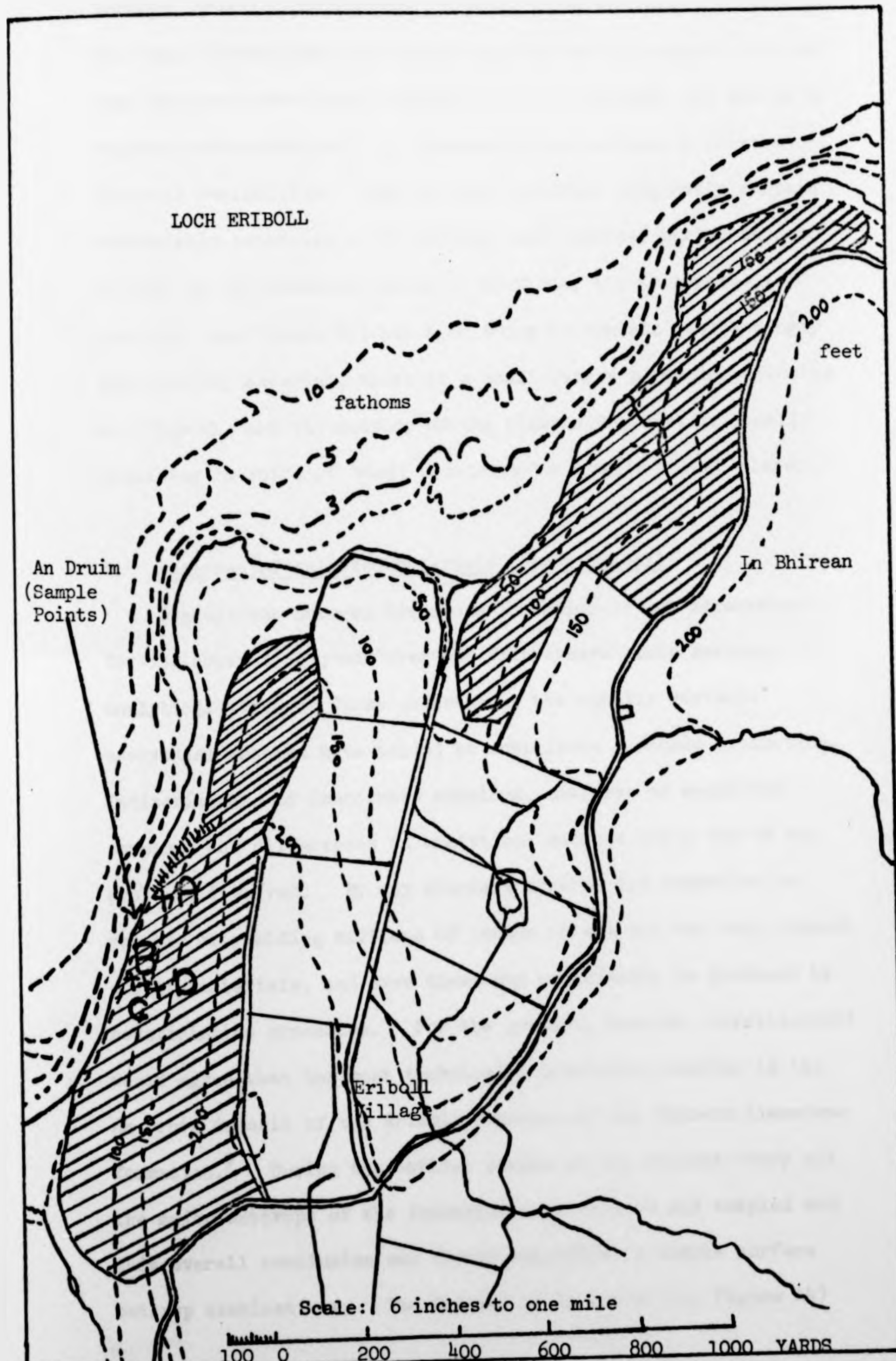
is confirmed by the fact that the dolomite horizons lie between unaltered limestones without major unconformity.

3. The occurrence of dolomite in the Highlands of Scotland

Dolomite rock occurs in a wide variety of geological environments throughout the Highlands region: sediments ranging in age from Lewisian to recent shell sands being recorded in various studies[6]. Although no formation is of the highest purity consistently throughout its occurrence in the region the Durness Limestone formation of Cambro-Ordovician age is of major if local potential interest[7]. In passing it should also be noted that certain horizons of the Appin limestone (Dalradian) in the Ballachulish area are also of high technical quality but further detailed work is necessary to determine the nature and extent of the dolomitic horizons. All other occurrences are either relatively small and local in extent, excessively impure or inconsistent, or altered through thermal or regional metamorphism. Therefore only the Durness Limestone formation is considered further here, although it is readily conceded that purely local demand may in some instances be better supplied from alternative deposits.

The Durness Limestone formation outcrops in a north-south direction discontinuously over a distance of approximately one hundred miles (see Figures A2 and A3). The stratigraphical subdivision of the series, which may be over 2,500 feet in thickness, is into seven groups not all of which are dolomitic, and not all of which are found throughout the length of outcrop. The highest grades of dolomite are to be found in groups I, II and III, with a total thickness locally approaching 1000 feet. On this basis the literature suggests seven localities of technical potential:

FIGURE A4: LOCATION OF DOLOMITE DEPOSITS, LOCH ERIBOLL



Source: Adapted from Butler, A.S. et. al. (1954), op.cit.

Durness, Eriboll, Inchnadamph, Elphin, Ullapool, Kishorn and Skye.[8] The Skye, Inchnadamph and Elphin deposits are of a poorer quality than the remainder being affected partly by thermal and partly by regional metamorphism. The deposits also indicate a greater inherent variability. The Durness dolomites frequently contain appreciable quanities of silica and their general purity is not as high as the remaining three. Of these, the Loch Eriboll district (see Figure A4) has been found to contain outstandingly high quality material, there is a small quarry producing dolomite at Ullapool, and the quality of the Kishorn deposits is locally promising in spite of their proximity to a major thrust plane.

4. Analyses of selected material: Loch Eriboll

Overall the Durness Limestone formation is not remarkable for its consistency, and over the fifty years since serious analytical work was first undertaken, the equally variable analytical results have tended to complicate economic evaluation. Indiscriminate or inaccurate sampling, analyses of weathered samples, and differences in analytical methods are a few of the problems involved. By any standard however the formation is capable of yielding millions of tonnes of all but the very highest quality materials, and even these may conceivably be produced by beneficiation processes. For the present, however, investigators would agree that the most technically promising locality is the An Druim deposit of the Eriboll sequence of the Durness Limestone formation.[9] During the earlier stages of the present study all the major outcrops of the formation were visited and sampled and this overall conclusion was firmly supported in simple surface outcrop examinations. The deposit of An Druim (see Figure A4) is unusually undisturbed and flat lying, the characteristically buff coloured dolomite outcropping is homogeneous strata forming cliffs up to 20 metres in height on the seaward side of the hill (i.e. to the west). Purely for the purposes of inter laboratory comparison a number of samples were carefully collected from selected horizons. These were subsequently divided and sent to the six separate laboratories that had kindly agreed to analyse the samples. The results of their analyses compare in general favourably, both amongst themselves and with earlier results from the same deposit[10] (see Table A1). Further reconnaissance also confirmed that the other major outcrop of dolomite in the Eriboll area, at Inbhirean (see Fig. A4) shows evidence of faulting and locally more intense tectonic disturbance.

Finally an average of the analytical results from An Druim is compared with same refractory grade dolomites in Table A2. Some of these are pelletised (i.e. beneficiated) materials.

Notes

1. For a comprehensive bibliography and a general summary of the mineral potential of the Highlands, see Berridge, N G., A Summary of the mineral resources of the Crofter Counties of Scotland, London HMSO (1969) Institute of Geological Sciences Report No. 69/5

2. The magnesium and basic refractories industries

3. Deer W A et al., An introduction to the rock forming minerals (1965) p. 489

4. Phases such as brownmillerite, tricalcium silicate, dicalcium ferrite and tricalcium aluminate were suggested as being instrumental in the lowering of the temperature of liquid formation in tarred dolomite refractories by approximately 900^{o}c. (Carr et al., (1964), op. cit pp 513 and 518)

6. c.f. Robertson T. et al. (1942) Geological Survey, Wartime Pamphlet No. 13. The Limestones of Scotland Area VII

7. c.f. Butler A.S. et al (1954) Dolomite in Scotland. Scot. Coun. (Devel. & Ind.)

8. ibid

9. ibid and Robertson Research Company Reports Nos. 273 and 433

10. ibid

Table A1 - Analytical results: An Druim samples
(See figure A4)

	Sample A				Sample B					
	1	3	4	5(1)	1	3	4	5(1)	5(2)	5(3)
MgO	20.9	21.4	21.2	21.6	21.3	21.5	21.2	21.7	21.8	22.0
CaO	30.3	30.0	30.0	29.3	30.4	30.1	30.3	29.3	29.6	29.6
SiO_2	1.1	1.0	1.1	1.1	0.6	0.6	0.8	0.9	0.6	0.6
TiO_2	0.03	^	0.02	^	0.02	^	0.02	^	^	^
Al_2O_3	0.5	0.4	0.4	0.5	0.2	0.3	0.3	0.4	0.3	0.3
Fe_2O_3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3
Na_2O	^	tr	0.02	<0.02	^	tr	0.04	<0.02	<0.02	<0.02
K_2O	^	0.2	0.03	^	^	0.1	0.04	^	^	^
BaO	^	^	<0.01	^	^	^	<0.01	^	^	^
MnO	0.02	^	0.02	0.01	0.02	^	0.02	0.01	0.02	0.01
Cr_2O_3	0.01	^	^	^	0.01	^	^	^	^	^
Loss	46.9	46.7	46.9	47.2	47.9	47.1	47.0	47.1	47.7	47.3

	Sample C						Sample D					
	1	3	4	5(1)	5(2)	5(3)	1	3	4	5(1)	5(2)	5(3)
MgO	21.2	21.5	21.1	22.1	22.1	21.7	21.1	21.5	21.6	21.8	21.7	21.8
CaO	30.4	30.4	30.3	29.4	29.4	29.4	30.1	30.1	30.0	29.3	29.3	29.4
SiO_2	0.4	0.3	0.5	0.5	0.5	0.7	0.9	0.6	0.6	1.2	0.7	0.8
TiO_2	0.02	^	0.01	^	^	^	0.02	^	0.01	^	^	^
Al_2O_3	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.3
Fe_2O_3	0.3	0.2	0.3	0.4	0.3	0.3	0.4	0.3	0.2	0.3	0.3	0.4
Na_2O	^	0.1	0.04	<0.02	0.02	<0.02	^	0.2	0.03	<0.02	<0.02	<0.02
K_2O	^	0.1	<0.01	^	^	^	^	0.1	0.02	^	^	^
BaO	^	^	<0.01	^	^	^	^	^	<0.01	^	^	^
MnO	0.02	^	0.02	0.02	0.02	0.01	0.02	^	0.02	0.01	0.02	0.02
Cr_2O_3	0.01	^	^	^	^	^	0.01	^	^	^	^	^
Loss	47.4	47.3	47.6	47.4	47.3	47.2	47.2	47.0	47.3	47.4	47.5	47.6

	Samples HB (source R.R. Co. Report No. 273)											
	120	121	122	123	124	125	126	127	128	129	130A	13[illegible]
MgO	19.3	20.6	21.5	21.1	21.4	21.2	21.3	21.2	21.7	21.0	21.7	21.[illegible]
CaO	27.3	30.5	30.0	30.2	30.2	30.5	30.0	30.5	29.7	30.0	29.9	29.[illegible]
	Acid insoluble											
SiO_2	10.6	1.4	0.9	1.3	0.6	0.7	0.6	0.4	0.9	0.8	0.7	0.[illegible]
TiO_2	^	^	^	^	^	^	^	^	^	^	^	^
Al_2O_3	0.9	0.4	0.2	0.3	0.1	0.2	0.2	0.1	0.3	0.1	0.2	0.[illegible]
Fe_2O_3	0.8	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.[illegible]
Na_2O	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.[illegible]
K_2O	0.1	0.1	0.1	0.1	0.4	0.1	0.1	0.4	0.4	0.4	0.4	0.[illegible]
BaO	^	^	^	^	^	^	^	^	^	^	^	^
MnO	^	^	^	^	^	^	^	^	^	^	^	^
Cr_2O_3	^	^	^	^	^	^	^	^	^	^	^	^
Loss	40.7	43.7	47.7	46.4	46.9	46.7	47.3	47.2	40.6	47.1	40.8	46.[illegible]

^ = nil

tr = trace

Table A2 - Comparison of various dolomites - refractory grade materials

Loss free chemical analysis (wt %)[3]

Origin	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Eriboll[2]	41.10	56.40	1.30	0.60	0.60
South Yorkshire	36.85	57.60	1.64	1.21	2.70
North Derbyshire	40.57	56.80	1.30	0.45	0.88
North Derbyshire[1]	41.30	56.70	1.00	0.30	0.70
Belgium	42.70	56.40	0.30	0.25	0.35
Germany	42.14	55.06	1.50	0.30	1.00
Italy	41.65	56.10	0.28	0.92	1.05
Japan	33.30	62.50	3.00	0.60	0.60
U.S.A.[1]	41.20	58.00	0.10	0.20	0.50

1. Pelletised material
2. Average of samples A - D recalculated to loss free percentage on basis of average calculated loss.
3. Data source for all except Eriboll results: Gilpin W.C. and Spencer D.R.F., Refractories Journal (1972) April, page 16.

Conclusion:

The Eriboll dolomite compares favourably with other U.K. sources of the material in respect of high MgO content, low iron and silica impurities.

APPENDIX B

THE PROBABILITY CONCEPT IN FORECASTING

The purpose of this appendix is to examine briefly the logical basis of forecasting techniques which employ statistical theory as a quantitative methodology. In the development of the art of forecasting a criterion of objectivity has latterly come to be associated with such assessments of the 'probability' of a forecast. Areas where probability theory, through the medium of statistical analysis, has exerted an influence include correlation and regression theory, morphological analysis and decision theory based on relevance numbers.

Whilst all statements concerning the future are probability statements it is clear that some are better testable than others. Quantitative techniques usually seek to improve the most elementary qualitative expression of degrees of uncertainty attached to alternative possible futures. But as Popper (1972) has put it,

> "Obviously what we want is to understand how such non physical things as purposes, deliberations, plans, decisions, theories, intentions and values can play a part in bringing about physical changes in the physical world".[1]

As will be seen the formal incorporation of these intangibles is not easily achieved with existing methodology.

Many quantitative techniques in forecasting rely on statistical theory. This in turn is derived from a theory of objective probability based on the relative frequency theory as postulated by Von Mises.[2] This rests on the following axioms:

(i) The axiom of convergence: As an event sequence becomes longer and longer, the frequency sequence shall tend towards a definite limit

(ii) The axiom of randomness: Frequency sequences are such that no gambling system could ever be successfully applied to them, they are completely random.

As such the formal task of statistical forecasting based on the frequency theory is to calculate probabilities which are given from those which are not. However some rather awkward implications for forecasting are implied in the above axioms, namely:

(i) Individual events do not entail other events in the total sequence

(ii) The classes of events are defined as to be mutually exclusive

(iii) There is a fundamental contradiction between what is effectively a requirement for a closed system (implied by the limit theorem) and the axiom of randomness.

It might also be added that forecasting is more appropriately directed towards the assessment of the relative likelihood of <u>specific</u> events at some future time. An initial basis for such specific predictions might be derived within the relative frequency theory by counting the number of times say B followed A in a sequence (n(B,A)) such that the probability of B given A over N observations would be $\frac{n(B,A)}{N}$. Unfortunately to compute n(B,A) it is necessary to be omniscient over the sequence of interest which leads to the absurd conclusion that the only way to predict is to know the outcomes with certainty. If on the other hand we restore the randomness criterion as a means of event selection the ability to make assertions as to the outcome of specific events based on their general relative frequency is lost.

In the event statistical theory employs a compromise. It starts from the assumption that for each value of the independent variable the data are distributed in a known manner about a mean. It also assumes that the historical association of these mean values will, given a 'plausible' theory of correspondence, provide justification for continuation of the trend in proportion to the degree to which the data conform to the adopted distribution. In practice it is commonly assumed that data are randomly or normally distributed and most methods of trend analysis are based on this assumption.

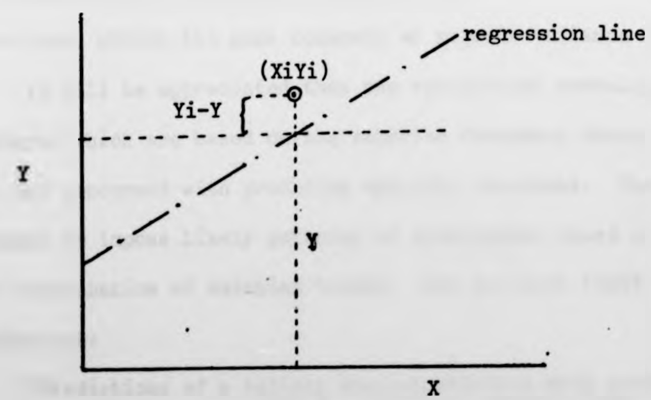
The method of quantitative forecasting is possibly best considered in three steps:

(i) Time independent curve fitting

(ii) Time independent error assessment

(iii) Time dependent curve fitting

In time independent curve fitting the method of least squares mechanically minimises the errors with no prior supposition as to the distribution of y for a given x. In the simplest case; where linear regression is the chosen method, coefficients of the equation $y = a + b\ (x-\bar{x})$ are computed such that the sum of all squares of deviation of all points $x_i\ y_i$ from the line are minimised in the direction of the y axis:



Thus deviation of point $x_i y_i = y_i - (a + b(x_i - \bar{x}))$ ($\bar{x}$ = average value of x)

where $y = a + b\,(x_i - \bar{x})$

Therefore sum of squares of deviation $D = \sum_{i=0}^{i} (y_i + (a + b(x_i - \bar{x})))^2$

The sum of the squares is minimised when $\frac{dD}{da} = 0$ and $\frac{dD}{db} = 0$

which is obtained when $a = \bar{y}$ average value of y and $b = \frac{\sum x_i y_i - n\bar{x}\bar{y}}{\sum (x_i)^2 - n(\bar{x})^2}$

Predictive error assessment for this time independent relation between y and x can however only be achieved if an a priori supposition is made of the frequency distribution of y for a given x. In the absence of empirical evidence it is common to assume that f(x) is normally distributed and that the least squares regression line links the mean values of these distributions. The variance about the regression line is estimated by S^2 where $S^2 = \frac{1}{n-2} \left(\sum (y_i - \bar{y})^2 - \frac{\left(\sum \left[(x_i - \bar{x})(y_i - \bar{y})\right]\right)^2}{\sum (x_i - \bar{x})^2} \right)$

Thus it is possible to predict the probability of x assuming a chosen future value to any desired confidence limit. It is important to note that this variance is a function of the specification of the normal distribution and not, a priori, for the actual historical variance of the data.

Finally for time dependent curve fitting and error assessment it is necessary to assume constancy of the regression equation over time, whilst the same comments as regards variance apply.

It will be appreciated that the statistical techniques employed which are based on the relative frequency theory are not concerned with producing specific forecasts. They attempt to impose likely patterns of development based on the continuation of existing trends. But as Hayek (1967) points out:

> "Predictions of a pattern are nevertheless both testable and valuable. Since the theory tells us under which

> general conditions a pattern will form itself, it will enable us to create such conditions and to observe whether a pattern of the kind predicted will appear."[3]

The conclusion is therefore that great attention needs to be paid to the theory underlying the facts (empirical data) selected for prediction. Or alternatively, where comprehensive theories are lacking care must be exercised in assuming that the chosen correlation does not represent spurious coincidence of phenomena.

APPENDIX B

Notes

1. Popper, K.R. (1972), Objective Knowledge, OUP, p. 229
2. c.f. Popper, K.R. (1968) (2 ed), Logic of Scientific Discovery, Hutchinson, Chapter 8, probability.
3. Hayek, F.A. (1967), Studies in politics, philosophy and economics, Routledge, p. 36.

APPENDIX C

Statistical Data for the magnesium and basic refractories industry

1. Magnesium Metal

The data is divided into two parts. Firstly raw data on magnesium production (Table C1), secondary magnesium production (Table C2), imports (Table C4), and exports (Table C3) are recorded and supplemented with a cross-section of world trade in magnesium for 1969 (Tables C5: A-D), and a breakdown of magnesium consumption in the only market for which such figures are available, the U.S.A. (Tables C6 and C7).

In the second part the raw data is presented in graph form to illustrate comparative growth rates. Figure C1 illustrates the growth of magnesium production, figure C2 describes the relationship between the magnesium structural market as a percentage of total U.S. magnesium consumption. Consumption of magnesium in non-structural markets in the U.S. is represented in figure C3. Figure C4 illustrates consumption of primary magnesium in U.S. structural markets and figure C5 distribution of U.S. primary magnesium consumption between structural and non-structural markets.

2. The Basic Refractories Industry

The data for the basic refractories industry is also divided into two sections. Firstly data on raw materials production including U.K. production of dolomite (Table C8), U.K. imports of dolomite (Table C9), and sea water magnesia/magnesite (Table C10), and U.K. exports of magnesite/magnesia (Table C11). In the second part, statistics of trade in finished refractory products are recorded. Table C12 deals with U.K. production and deliveries of refractory bricks and shapes. U.K. imports of various types of refractory goods are detailed in Table C13, and Tables C14 and C15 record U.K. exports by type and destination.

WORLD PRODUCTION OF PRIMARY MAGNESIUM **Table C1**

In Metric Tons

Country	1915-1924 av	1925-1934 av	1935-1939 av	1940-1944 av	1945-1949 av	1950-1955 av	1956	1957	1958	1959
Australia	-	-	-	231	776	-	-	-	-	-
Canada	-	-	-	1,724	E	4,925	5,706	7,588	6,165	3,534
China	-	-	-	-	NR	NR	NR	NR	NR	NR
Formosa	-	-	-	454	E	E	-	E	998[e]	998[e]
France			1,632	1,619	611	998	1,505	1,591	1,721	1,758
Germany: East	E)	1,904	11,880	29,930)	907	E	NR	NR	NR	NR
West	))			))	-	-	100	299	599	499
Italy	-	-	E	1,751	E	1,109	3,733	3,782	4,179	4,499
Japan	-	-	-	2,794	E	E	78	418	1,003	1,563
Korea	-	-	-	544	E	E	-	-	-	-
Norway	-	-	-	1,215	E	3,111	7,425	8,620	9,189	9,640
Poland	-	-	-	-	-	NR	NR	NR	NR	NR
Switzerland	-	E	E	472[e]	272[e]	E				
U.S.S.R.	-	-	463	2,268[e]	E	12,700[e]	16,240	17,050	17,600	19,950
U.K.	-	-	2,720	12,700	3,374	5,706	3,685	3,474	2,441	2,229
U.S.A.	54	454	2,358	74,730	13,070	58,410	61,980	73,700	27,300	28,150
World Total	871	3,538	19,950	131,400	30,840	88,240	101,000	116,800	71,200	74,840

WORLD PRODUCTION OF PRIMARY MAGNESIUM

Table C1
(Continued)

In Thousands of Metric Tons

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
-	-	-	-	-	-	-	-	-	-	-	-	-
6.6	7.0	8.6	9.1	9.2	10.2	7.0	9.1	10.1	10.6	8.7	6.6	5.3
1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	1.0^{e}	2.0^{e}	2.0^{e}
NR	NR	-?	-?	-?	-?	-?	-?	-?	-?	-?	-?	-?
2.1	2.1	2.2	1.8	0.9	2.8	3.4	4.2	4.5	4.4	4.6	7.2	6.8
NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	-
0.3	0.4	0.5	0.5	0.5	0.5	0.2	-	-	-	-	-	-
5.4	5.6	5.6	5.5	6.0	6.3	6.5	6.3	7.4	7.1	7.6	8.4	9.1
2.1	2.2	2.1	2.4	2.9	3.8	5.3	6.7	5.7	9.4	9.8	9.7	10.9
-	-	-	-	-	-	-	-	-	-	-	-	-
13.0	14.6	14.9	20.6	24.9	26.4	25.8	30.5	31.3	31.3	35.3	36.1	36.5
0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
											-	-
25.0^{e}	31.0^{e}	32.0^{e}	32.0^{e}	32.0^{e}	34.0^{e}	35.0^{e}	40.0^{e}	42.0^{e}	45.0^{e}	45.0^{e}	45.0^{e}	50.0^{e}
1.5	3.0	2.7	2.5	2.5	0.8	-	-	-	-	-	-	-
36.4	37.0	62.6	68.8	72.1	73.8	72.4	88.4	89.2	90.6	101.6	112.0	109.6
93.6	104.1	132.5	144.5	152.3	159.9	156.9	186.5	191.5	199.5	214.1	227.3	230.5

Table C1
(Continued)

WORLD PRODUCTION OF PRIMARY MAGNESIUM

In Thousands of Metric Tons

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
-	-	-	-	-	-	-	-	-	-	-	-	-
6.6	7.0	8.6	9.1	9.2	10.2	7.0	9.1	10.1	10.6	8.7	6.6	5.3
1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	1.0^e	2.0^e	2.0^e
NR	NR	-?	-?	-?	-?	-?	-?	-?	-?	-?	-?	-?
2.1	2.1	2.2	1.8	0.9	2.8	3.4	4.2	4.5	4.4	4.6	7.2	6.8
NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	-
0.3	0.4	0.5	0.5	0.5	0.5	0.2	-	-	-	-	-	-
5.4	5.6	5.6	5.5	6.0	6.3	6.5	6.3	7.4	7.1	7.6	8.4	9.1
2.1	2.2	2.1	2.4	2.9	3.8	5.3	6.7	5.7	9.4	9.8	9.7	10.9
-	-	-	-	-	-	-	-	-	-	-	-	-
13.0	14.6	14.9	20.6	24.9	26.4	25.8	30.5	31.3	31.3	35.3	36.1	36.5
0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
											-	-
25.0^e	31.0^e	32.0^e	32.0^e	32.0^e	34.0^e	35.0^e	40.0^e	42.0^e	45.0^e	45.0^e	45.0^e	50.0^e
1.5	3.0	2.7	2.5	2.5	0.8	-	-	-	-	-	-	-
36.4	37.0	62.6	68.8	72.1	73.8	72.4	88.4	89.2	90.6	101.6	112.0	109.6
93.6	104.1	132.5	144.5	152.3	159.9	156.9	186.5	191.5	199.5	214.1	227.3	230.5

Notes on Table C1: World Production of Primary Magnesium

1. Wherever possible primary production figures are quoted. However for France and the U.K. from 1915-1960 remelt alloy production is included.

2. The following signs are used in the table:

E	estimate is included in world total
e	estimated figure
NR	no production reported
-	nil

3. The following sources were used:

For 1915-1960: Magnesium: a materials survey. U.S. Bureau of Mines Information Circular

For 1961-1972: Four sources were consulted: U.N. Statistical Yearbook, U.S. Bureau of Mines Minerals Yearbook, U.S. Bureau of Metal Statistics, and Metallgesellschaft

In view of the slight disparity between some published figures, it was decided to use Metallgesellschaft's figures for the period 1961-1972.

Table C2

World Production of Secondary Magnesium (metric tons x 10^3)

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Germany	1.9	2.5	2.8	2.7	2.6	1.7	1.3	2.2	2.6	2.1	1.9	1.8	n.a.
Japan	3.0	2.8	1.5	1.4	2.2	4.2	5.2	7.7	6.1	6.4	9.2	7.1	4.8
U.K.	2.2	2.3	2.3	2.2	2.3	4.6	3.8	4.1	3.6	2.9	2.8	2.5	n.a.
U.S.A.	9.4	7.4	8.7	8.4	10.7	12.4	13.7	12.2	14.1	11.8	11.4	13.5	13.6
TOTAL	16.5	15.0	15.3	14.7	17.8	22.9	24.0	26.7	26.4	26.4	25.3	24.9	
% of Primary Prodn	17.6	14.4	11.5	10.2	11.7	13.5	15.3	15.1	13.8	13.2	11.8	11.0	

Source: Metallgesellschaft Annual

Table C3: Exports of Magnesium by Country (metric tons x 10^3)

	1966	1967	1968	1969	1970
U.K. (Mg and Alloys)	1.2	1.1	0.9	1.1	0.9
Canada (value £m)	1.2	1.3	1.6	1.8	2.2
France (incl. alloys and scrap)	0.1	0.2	0.3	0.7	0.7
Germany	1.0	0.3	1.0	2.3	1.7
Italy	4.6	3.2	7.1	4.9	3.8
Netherlands	0.3	0.3	0.3	0.6	0.4
Norway	30.4	30.1	n.a.	n.a.	n.a.
U.S.S.R.	8.1	8.5	14.5	15.0	16.8
U.S.A. (incl. alloys and scrap)	13.5	10.9	16.7	24.8	32.4
Japan	0.1	0.1	0.1	1.0	0.1
TOTAL (excluding Canada)	59.3	54.7	70.9[e]	85.4[e]	91.8[e]

e = estimate for Norway included

Source: I.G.S. Summary of Minerals Industries Annual

Table C4: Imports of Magnesium by Country (metric tons x 10^3)

	1966	1967	1968	1969	1970
U.K. (incl. alloys, unwrought)	4.9	6.2	6.2	5.7	5.5
Canada - metals	2.7	1.4	2.2	1.8	1.8
alloys	0.3	0.2	0.3	0.4	0.2
India	0.1	0.1	0.1	0.2	0.1
Australia (metals and alloys)	0.9	1.1	0.6	1.1	1.6
New Zealand	Tonnes 14	2	7	22	n
Austria	0.5	0.6	0.9	2.8	4.0
Belgium/Luxembourg	1.1	0.6	0.9	1.1	1.6
France (incl. alloys and scrap)	1.1	1.1	1.3	1.3	2.8
Germany (incl. alloys and scrap)	35.9	32.8	41.9	50.1	53.1
Greece	Tonnes 13	56	163	78	188
Netherlands	0.4	0.5	0.5	1.0	1.0
Poland	0.3	0.5	0.4	0.7	0.7
Spain	0.4	0.3	0.3	0.7	0.6
Sweden	0.4	0.7	0.7	0.7	0.6
Switzerland	0.7	1.0	0.8	1.1	1.5
Yugoslavia	0.5	0.5	0.4	0.6	0.9
Mexico	0.0	0.3	0.8	0.7	1.4
U.S.	1.0	6.6	2.1	2.1	1.3
Brazil	2.8	2.0	3.1	5.2	6.8
Japan	1.7	0.8	0.4	0.1	2.2
TOTAL	56.3	61.9	63.9	78.4	87.7

Source: I.G.S. Summary of Minerals Industries

Table C5 (A)

A review of world trade in magnesium metal in 1969 (Thousand Metric Tons)

Country	Primary Prod-uction	Secondary Prod-uction	Imports	Exports	Consumpt-ion Reported	Notes
West Germany	nil	2.1	50.1	2.2	47.9	
Belgium/Luxem-bourg	nil	nil	1.1	0.08	1.1	
France	4.4	nil	1.3	0.7	5.3	
Italy	7.1	nil	0.2	4.9	2.8	
Netherlands	nil	nil	1.0	0.6	0.4	
Total E.E.C.	11.5	2.1	53.7	8.5	57.5	
U.K.	nil	2.9	5.7	1.1	7.8	
Yugoslavia	nil	nil	0.6	nil	0.5	
Norway	31.3	nil	3.5^{e}	n.a.	0.5	
Austria	nil	nil	2.8	n.a.	0.5	
Sweden	nil	nil	0.7	nil	0.7	
Switzerland	nil	nil	1.1	n.a.	1.0	
Other Europe	nil	nil	1.4^{e}	n.a.	1.0	
Total Europe	42.5	5.0	69.5^{e}	46.1^{e}	69.5	
India	nil	nil	0.2	n.a.	0.1	
Japan	9.4	6.4	0.5	1.0	8.0	consumption figure ex-cludes sec-ondary prod
Total Asia	9.4	6.4	0.7	1.1	8.1	
Africa: Rep of S.A.	nil	nil	n.a.	n.a.	0.4	
U.S.A.	90.6	11.8	2.1	24.8	86.3	consumption figure ex-cludes sec-ondary prod
Brazil	nil	nil	5.2	n.a.	5.1	
Canada	10.6	nil	2.2	1.8*	3.0	*value of £m
Mexico	nil	nil	0.7	n.a.	1.0	
America	101.2	11.8	10.2	34.6^{e}	95.4	
Western Coun.	153.1	23.2	80.8^{e}	81.8^{e}	174.9	
U.S.S.R.	45.0^{e}	nil	nil	15.0	30.0	
Poland	0.3^{e}	nil	n.a.	n.a.	0.7^{e}	
China	1.0^{e}	nil	n.a.	0.4^{e}	1.0^{e}	
Other Eas.	nil^{e}	nil^{e}	n.a.	n.a.	4.4^{e}	
Eastern Cntrs.	46.3^{e}	nil^{e}	4.4^{e}	15.4^{e}	36.1^{e}	
Total World	199.4^{e}	23.2^{e}	85.2^{e}	97.2^{e}	211.0^{e}	

Note on Table C5 (A)

Sources: Primary Production, Secondary Production and Reported Consumption: Metallgesellschaft 71 edn.

Imports and Exports: Statistical Summary of the Mineral Industry 1966-1970, I.G.S.

Table C5 (B)

Review of world trade in Magnesium Metal in 1969 ctd

Breakdown of Import Data by Country (Thousand metric tons)

Country	Total Imported	Country of Origin
West Germany	50.1	22.6 Norway, 13.9 U.S. 4.8 U.S.S.R., 4.4 Italy, 2.7 Canada, 0.1 U.K.
U.K.	5.7 incl. alloys	3.4 Norway, 2.0 Canada
Brazil	5.2	2.4 U.S.
Austria	2.8	n.a. probably from Norway and U.S.
East Germany	n.a.	2.5 U.S.S.R.
Canada	2.2 incl. alloys	2.1 U.S.
U.S.A.	2.1	0.3 U.K., remainder Canada and small amounts from several others
Czechoslavakia	n.a.	1.6 U.S.S.R.
France	1.3 incl. alloys and scrap	0.6 Canada, 0.1 Italy, 0.1 Norway, 0.2 U.S.
Belgium/Luxembourg	1.1	0.2 U.S., 0.6 U.S.S.R.
Switzerland	1.1	n.a. probably from Norway
Australia	1.0 metal and powder	0.8 U.S.
Netherlands	1.0	1.1 U.S.
Japan	0.9	0.2 U.S., 0.4 China, 0.04 U.K., 0.08 Belgium/ Luxembourg, 0.2 W.G.
Mexico	0.7	0.3 U.S.
Poland	0.7	n.a. probably from U.S.S.R.
Sweden	0.7	0.04 U.S. remainder probably from Norway
Yugoslavia	0.6	n.a. probably from U.S.S.R.
Hungary	0.3	n.a. probably from U.S.S.R.
India	0.2	0.1 U.S.
Venezuela	n.a.	0.2 U.S.
Miscellaneous		
New Zealand	0.02	0.01 from U.S.
Greece	0.01	n.a.
Surinam	n.a.	0.05 from U.S.
Israel	n.a.	0.02 from U.S.
Colombia	n.a.	0.03 from U.S.
South Africa	n.a.	0.04 from U.S.
Phillipines	n.a.	0.002 from U.S.

Sources: U.S. Bureau of Mines Minerals Yearbook 1969
I.G.S. Review of the Minerals Industry 1966-70

Table C5 (C) - Review of World Trade in Magnesium for 1969 ctd.

Breakdown of Export Data by Country (Thousand Metric Tons)

Country	Total Exported	Destination	
U.S.A.	24.8	Argentina	.128
		Australia	.786
		Belg/Lux	.212
		Brazil	2.4
		Canada	2.1
		Colombia	.025
		France	.118
		West Germany	14.5
		India	.096
		Israel	.019
		Italy	.201
		Japan	.206
		Mexico	.277
		Netherlands	1.1
		New Zealand	.062
		Norway	.076
		Philippines	.002
		South Africa	.042
		Spain	.400
		Surinam	.049
		Sweden	.040
		U.K.	.494
		Venezuela	.172
		Other	.044
Norway	N.A.	Estimated at approx. 30.0 mainly to West Germany	
U.S.S.R.	15.0	Czechoslovakia	1.6
		East Germany	2.5
		West Germany	4.4
		Norway	3.4
		Belg/Lux	0.6
		Hungary	0.3
Canada	Value £m 1.8 estimated at approx 9.0 mainly to U.S.A.		
Italy	4.9	West Germany	4.3
West Germany	2.2	N.A.	
U.K.	1.1	France	0.2
		West Germany	0.1
		U.S.	0.3
Japan	1.0	N.A.	
France (incl. alloys & Scrap)	0.7	N.A.	
Netherlands	0.6	N.A.	
China	0.4	N.A.	

Sources: U.S. Bureau of Mines, Minerals Yearbook 1969
I.G.S. Review of the Minerals Industry 1966-70

Table C5 (D) - Review of World Trade in Magnesium for 1969 ctd

1. Breakdown of Reported U.S. Consumption for 1969 (Thousand Metric Tons)

End Use Category		Amount
Structural Products	(Castings	9.48
	(Sheet	
	(Extrusions)	
	(Forgings)	11.89
Total Structural Products		21.37
Distributional and Sacrifical	(Reducing Agent	6.68
	(Aluminium Alloys	33.91
	(Other Alloys	
	(Scavenger & Deoxidiser	
	(Chemical	
	(Cathodic Protection	5.52
	(Other	18.70
Total Distributional and Sacrificial		64.81
Total Reported Consumption		86.18

2. Breakdown of Reported West Germany Consumption for 1969

Total Reported Consumption 47.9

Of which:

Structural Applications	41.0 app.	Special Category 10%; General Engineering 90%
Aluminium Alloying	6.0 app.	
Chemical/Sacrificial	0.9 app.	

3. Breakdown of Reported U.K. Consumption for 1969

Total Reported Consumption 7.8

Structural Applications	3.6 app.	Special Category 60%; General Engineering 40%
Alloying Aluminium	2.3 app.	
Chemical/Sacrificial	1.9 app.	

Sources: U.S. Bureau of Mines Minerals Yearbook 1969
Campbell, Metals and Materials, Jan. 1972

Table C6 - U.S. Consumption of Primary Magnesium by end use category (Metric tons x 10^3)

Category	End Use	44	45	46	47	48	49	50	51	52	53	54	55	56
Structural Products	Castings	95.4	25.0	1.2	1.0	2.0	3.0	3.6	10.7	16.7	16.2	11.0	9.4	8.5
	Sheet	1.4	1.4	1.8	0.6	1.1	2.0	3.1	4.5	4.7	4.9	2.8	5.8	5.0
	Extrusions & Forgings	4.7	2.4	2.5	1.6	3.4	3.2	3.2	4.4	2.5	4.3	2.3	4.0	6.1
Sub Total Structural Products		101.5	28.7	5.5	3.5	5.5	8.2	9.8	19.6	23.8	25.4	16.0	19.2	19.6
Distributional Sacrificial and Other	Reducing Agent	-	-	-	-	-	-	0.1	0.5	1.2	2.5	5.8	7.3	12.1
	Aluminium Alloys	8.0	5.1	2.2	1.8	2.0	1.6	3.4	5.4	7.8	9.4	7.3	10.1	12.1
	Other Alloys	-	-	-	.03	.04	.03	0.2	0.4	0.9	0.4	0.1	0.3	0.1
	Scavenger & deoxid.	0.2	0.2	0.3	0.4	0.4	0.4	0.4	1.2	1.1	0.3	0.1	0.6	0.8
	Chemical	0.2	0.2	0.1	0.2	0.4	0.2	0.3	0.4	0.5	0.3	0.1	0.1	0.1
	Cathodic Protection	0	0	0	0.1	0.3	0.2	1.8	2.1	1.9	2.3	5.0	3.6	2.8
	Other	12.5	5.7	3.5	2.7	3.3	2.6	6.6	11.0	14.6	17.1	19.5	0.9	1.2
Sub Total Distributional and Sacrificial		20.7	11.2	6.0	5.3	6.4	5.0	12.8	21.1	28.0	32.2	37.8	22.9	29.1
TOTAL		122.2	39.9	11.6	8.8	11.9	13.2	22.6	40.7	51.9	57.6	53.9	42.1	48.7

Source: U.S. Bureau of Mines, Minerals Yearbooks

Table C6 (cont.) - U.S. Consumption of Primary Magnesium by end use category (Metric tons x 10^3)

Category	End Use	57	58	59	60	61	62	63	64	65	66	67	68	69
Structural Products	Castings	7.5	7.4	6.8	4.4	3.8	7.3	9.3	7.0	8.5	8.7	11.1	10.7	9.5
	Sheet	4.5	2.7	5.6	3.7	4.0	5.8	5.1	4.5	4.5	5.5	w	w	w
	Extrusions & Forgings	4.6	2.5	4.5	3.2	4.3	6.0	3.3	4.3	5.4	6.4	9.5	10.2	11.9
Sub Total Structural Products		16.6	13.6	16.9	11.3	12.2	19.1	17.7	15.7	18.4	20.6	21.1	20.8	21.4
Distributional Sacrificial and Other	Reducing Agent	18.8	5.4	2.9	6.3	7.2	2.6	2.8	3.4	7.7	7.7	6.1	5.6	6.7
	Aluminium Alloys	10.2	9.8	13.4	11.4	17.9	16.7	19.8	18.9	23.8	28.0	28.3	31.3	33.9
	Other Alloys	0.5	0.4	0.8	0.4	0.03	0.1	0.1	0.1	0.1	1.9	2.2	w	w
	Scavenger & Deoxid.	0.8	0.6	0.3	0.7	0.3	1.0	0.1	0.1	0.2	0.2	w	w	w
	Chemical	0.3	0.1	0.3	0.3	0.3	0.4	0.4	2.4	3.5	4.2	4.7	w	w
	Cathodic Protection	2.7	1.8	2.7	3.0	2.2	1.8	2.7	4.5	4.2	4.2	4.4	5.2	5.5
	Other	0.4	0.3	0.4	0.4	0.3	0.4	1.6	2.0	3.3	8.3	15.5	15.4	18.7
Sub Total Distributional and Sacrificial		23.7	18.5	20.8	22.4	28.3	23.0	27.4	31.3	42.7	44.4	61.2	57.5	64.8
TOTAL		40.4	32.1	37.7	33.7	40.4	42.1	45.1	47.0	61.2	65.0	82.3	88.4	86.2

Source: U.S. Bureau of Mines, Minerals Yearbook

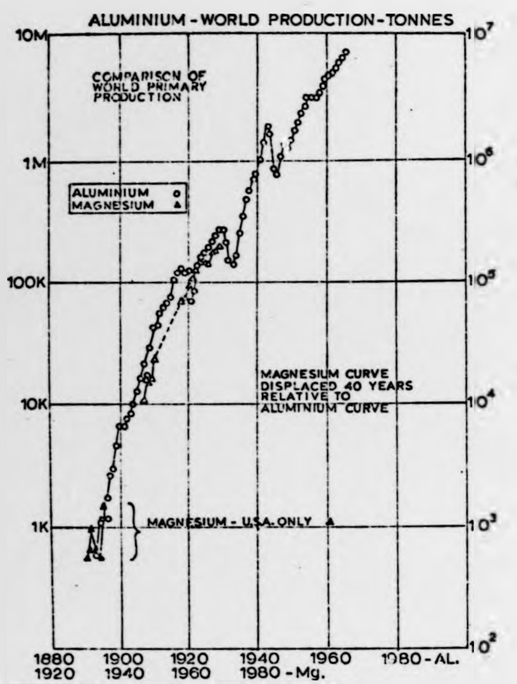
w = withheld

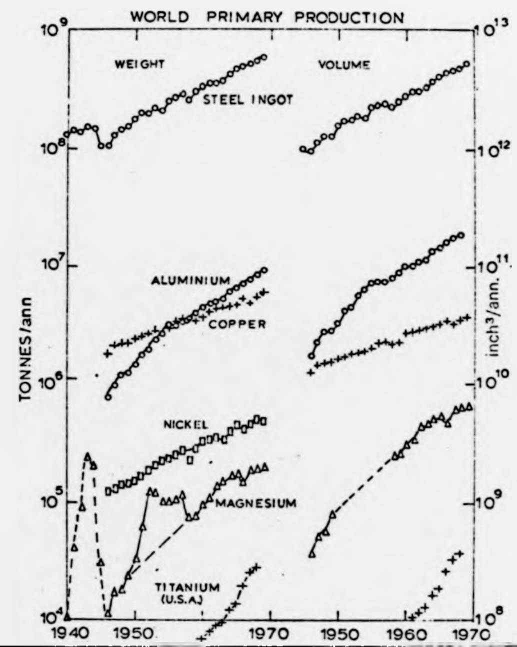
Table C7: Percentage of primary magnesium used in structural products by end use U.S. Market

Product use	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1968
Aircraft and Missiles	56.7	58.9	58.8	52.3	52.0	50.0	50.0	48.5	32.0	30.0	41.6
Consumer products	10.5	9.9	10.7	8.1	12.5	13.5	13.8	14.3	17.0	18.0	
Electrical and Electronic	3.5	2.8	3.6	5.4	8.0	7.9	8.0	9.0	15.0	15.0	10.4
Machinery and Tools	16.5	12.2	14.9	13.8	12.5	13.0	12.5	11.2	16.0	17.0	24.7
Materials Handling Equipment	4.8	6.1	4.7	5.6	5.0	5.5	5.8	6.3	6.0	6.0	10.4
Highway Vehicles	3.4	6.6	4.2	7.7	4.5	6.0	6.5	6.5	10.0	10.0	13.0
Graphic Arts	2.3	2.2	1.9	2.1	1.5	1.8	2.0	2.0	2.0	2.0	-
Miscellaneous	2.3	1.3	1.2	5.0	4.0	2.3	1.4	2.2	2.0	2.0	-
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.1
Total in Tons (metric x 10^3)	16.0	19.2	19.6	16.6	13.6	16.9	11.3	12.1	19.1	17.7	

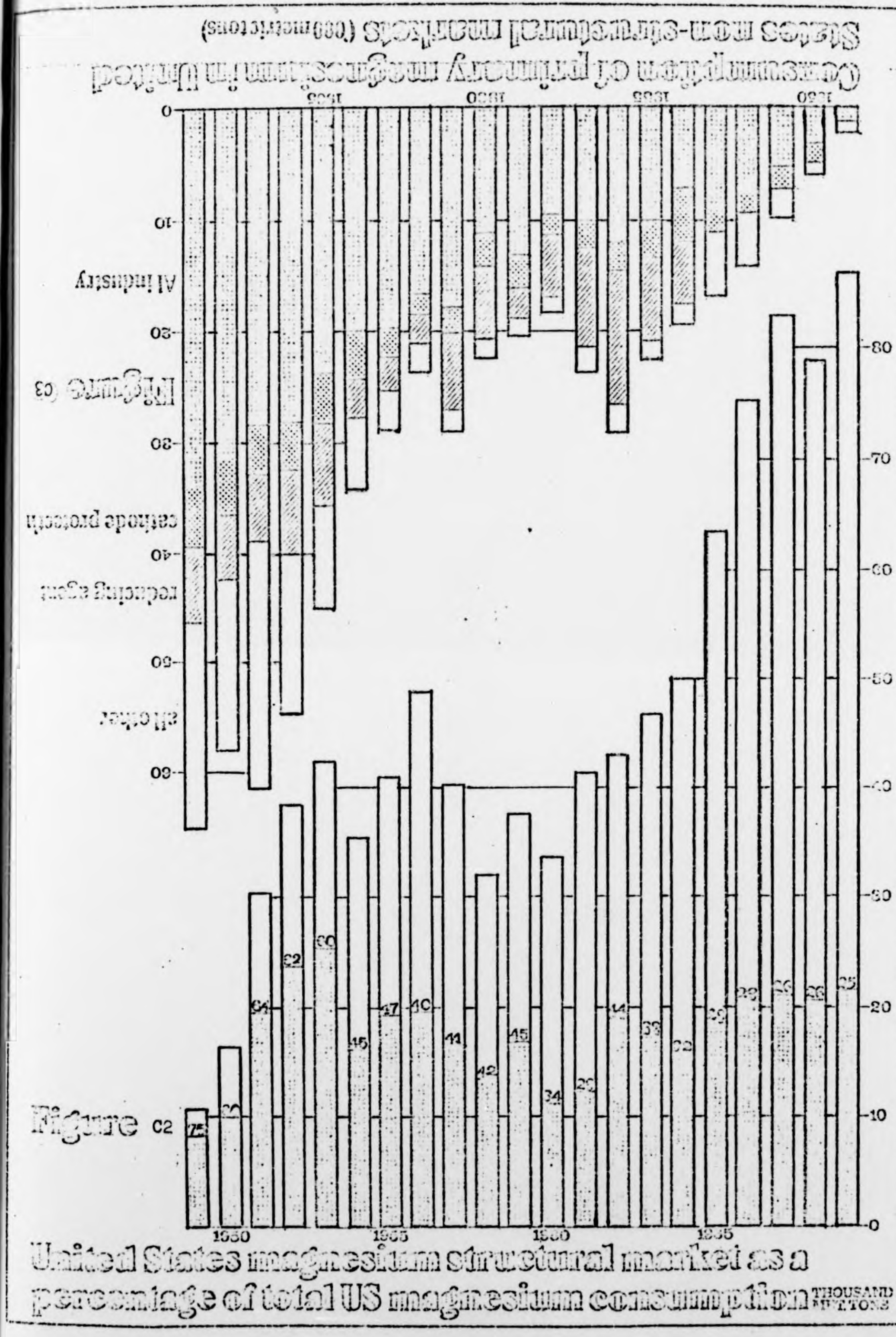
Source: Figures prepared by Dow Chemical for U.S. Bureau of Mines. 1968 figures from Paone J., Magnesium, in Mineral Facts and Problems, U.S. Bureau of Mines. Categories are not strictly comparable with rest of table.

FIGURE C1: COMPARATIVE GROWTH OF MAGNESIUM PRODUCTION



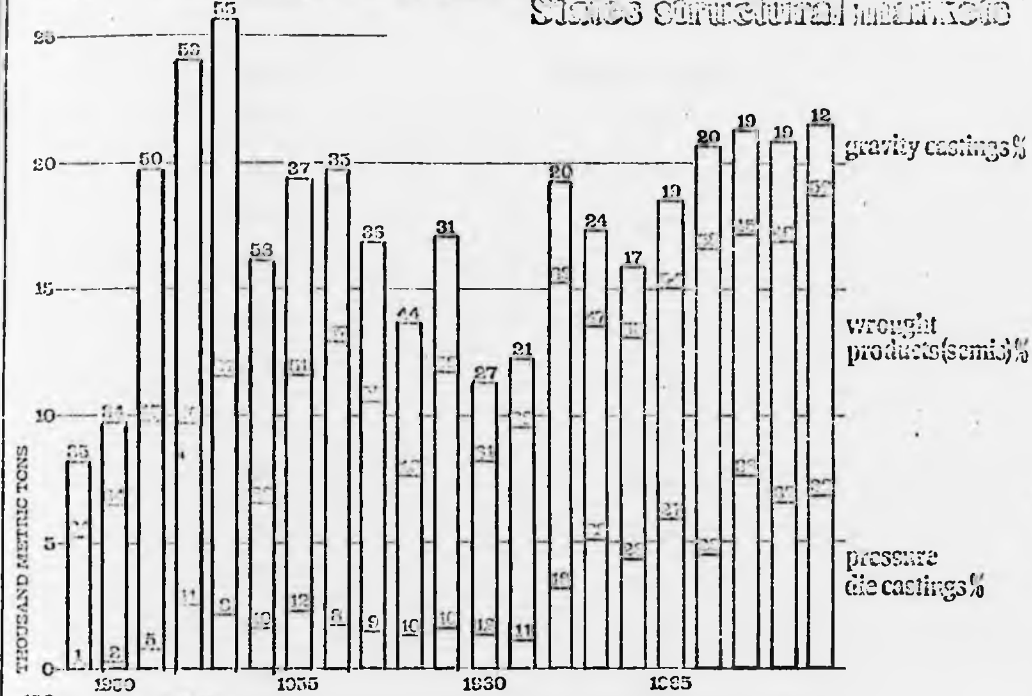


Source: BNFMRA



Source: Strickland, J.R. (1971), op.cit.

Fig c4 Consumption of primary magnesium in United States structural markets



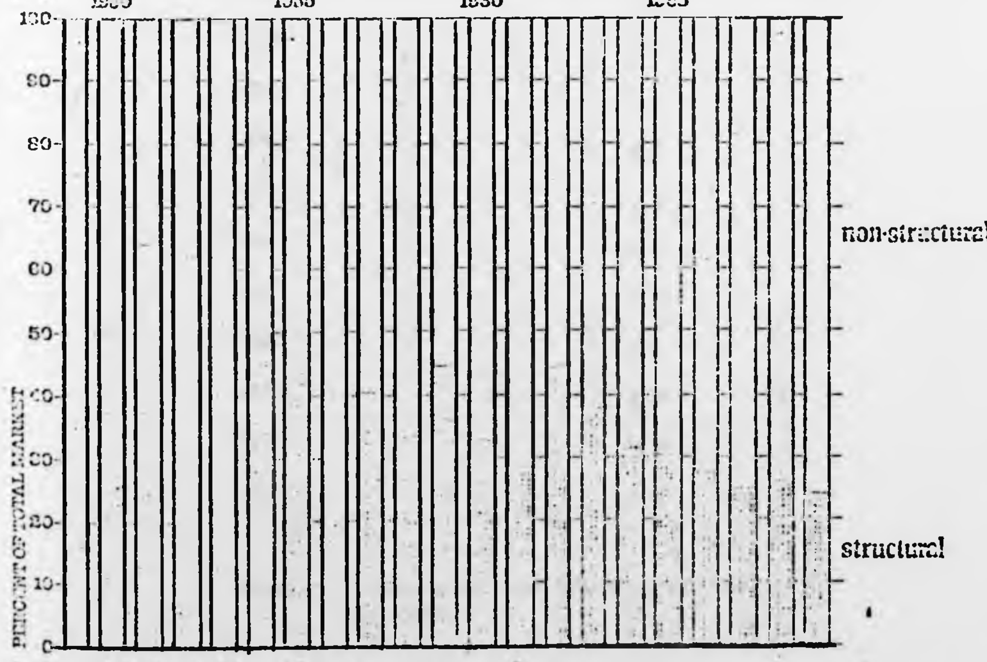


Fig c5 Distribution of US primary Mg consumption between structural and non-structural markets

Source: Strickland, J.R. (1971), op.cit.

Table C8 - Estimated U.K. Production of Dolomite

Year	Million Tonnes
1950	1.44
1951	1.47
1952	1.59
1953	1.99
1954	2.12
1955	2.16
1956	2.31
1957	2.74
1958	2.64
1959	2.9
1960	3.2
1961	2.9
1962	3.0
1963	2.0
1964	3.8
1965	3.9
1966	4.8
1967	4.8
1968	5.0
1969	5.8
1970	5.8
1971	6.1

Source: I.G.S. comm. and Statistical Summ. of Min. Ind.

Table C9 U.K. Imports of Dolomite (in long tons)

	1963	1964	1965	1966	1967	1968	1969	1970	1971
Total Commonwealth and Irish	5	17	20	10					
Norway	8,466	10,374	10,722	13,030				4,839	5,474
France	-	-	1,359	-				-	-
Spain	1,740)	1,862)	1,865)	6,391)				16,228	17,536
West Germany	)	)	)	)				493	632
Other Foreign	)	)	)	)					
Total Foreign	10,207	12,237	13,968	19,621					
Total	10,313	12,258	13,988	19,631	21,111	22,998	22,985	21,854	24,172

Source: Customs & Excise, I.G.S. Summary.

Table C10 - UK Imports of Magnesite/Magnesia (in Tonnes x 10^3)

Magnesite	1963	1964	1965	1966	1967	1968	1969	1970	1971
Dead Burnt	17.1	57.3	93.5	78.5	32.5	45.6	87.2	78.4	76 7
Magnesia								23.6	24.6

Source : I G S Comm.

Table C 11 - UK Exports of Magnesite/Magnesia (in Tonnes x 10^3)

Magnesite	1963	1964	1965	1966	1967	1968	1969	1970	1971
Dead Burnt								4.1	2.7
Magnesia								20.5	28.5

Source : I G S Comm.

TABLE C12 - U.K. PRODUCTION AND DELIVERIES OF REFRACTORY BRICKS AND SHAPES (Thousand Tonnes)

	Clay (including hollowware)	Silica (including siliceous)	High Alumina (including insulating)	Magnesite	Chrome/Mag	Mag/Chrome	Chrome	Dolomite	Total Basic	Grand Total (including cements etc. N.A.)
Production										
1957	1170.7	353.8	41.9	45.5	124.7	12.7	3.7	N.A	N.A	
1958	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	1824
1959	907.1	231.5	43.1	38.0	115.3	11.4	2.6	N.A	N.A	1688
1960	1054.4	263.5	53.9	53.4	180.4	28.2	2.5	8.5	264.5	2065
1961	1045.7	216.7	69.2	53.6	153.2	42.2	2.8	9.6	261.4	1875
1962	911.7	152.0	69.3	41.0	111.4	22.3	1.0	13.6	189.3	1567
1963	793.6	131.2	65.4	44.0	106.2	37.7	1.5	21.4	210.8	1555
1964	917.7	144.9	89.4	62.1	117.8	49.7	1.4	44.1	275.1	1764
1965	912.3	127.5	102.1	74.5	113.3	51.5	1.0	41.0	281.3	1732
1966	821.8	93.5	106.0	58.5	85.9	50.8	0.8	36.9	228.9	1520
1967	760.0	68.9	103.8	62.3	79.7	43.0	1.1	N.A	N.A	1402
1968	749.1	66.2	109.2	73.1	82.1	64.6	0.8	N.A	N.A	1436 (est)
1969	818.3	80.1	131.0	81.2	92.6	68.7	1.4	N.A.	N.A	1508
1970	808.7	81.2	124.8	78.2	105.1	73.5	1.1	N.A	N.A	1622
1971	670.7	72.8	152.8	72.4	74.4	74.6	1.1	N.A	N.A	
Deliveries										
1957	1121.6	349.0	41.8	45.7	123.6	12.4	3.7	N.A	N.A (179.4 est)	
1959	904.9	228.1	43.0	38.8	120.5	11.7	2.5	N.A	N.A (181.9 est)	
1960	1069.8	268.4	55.5	54.5	183.6	27.4	2.7	8.2	276.3	
1961	992.6	212.1	66.3	49.8	141.0	40.0	2.6	9.8	243.2	
1962	859.1	147.5	65.0	37.9	106.4	22.7	1.2	13.5	181.8	
1963	824.6	135.5	65.8	46.0	113.2	37.2	1.4	20.2	218.0	
1964	920.3	141.8	86.2	62.8	122.2	47.9	1.1	43.6	277.8	
1965	915.4	129.2	99.6	68.8	112.0	50.2	1.3	42.6	274.8	
1966	803.8	93.1	105.1	79.6	83.3	47.4	0.9	35.8	246.5	
1967	746.3	67.7	100.5	62.2	80.4	42.9	1.0	N.A	N.A	
1968	752.0	68.0	109.8	76.0	88.1	59.3	0.8	N.A	N.A	
1969	799.2	79.5	129.6	77.9	97.9	74.8	1.4	30.4	282.3	
1970	792.5	84.5	125.8	79.4	104.3	74.3	1.0	22.3	281.5	
1971	604.4	69.1	142.6	66.1	66.6	68.1	1.1	44.3	246.1	

Source: NFCI data in Industrial Minerals (1972), October, except "dolomite": estimates from Interplan Report (op.cit.) and "grand totals", from Richardson, H.M (1970), J.Brit.Ceram.Soc. 7, No 1. 1970 total from Grimshaw R.W. Ref Jour(1973) March

TABLE C13 - UK IMPORTS OF FINISHED REFRACTORY BRICKS (Thousand Tonnes)

		1966	1967	1968	1969	1970	1971
(i)	Fireclay total	7.5 (0.9)	6.7 (0.9)	5.8 (0.7)	9.8 (1.2)	15.8 (2.0)	9.0 (1.3)
	France	4.7	5.3	4.5	6.3	7.0	6.1
	West Germany	1.5	-	-	1.9	0.8	0.4
	USA	0.9	0.5	0.7	0.9	1.2	1.9
	Netherlands	-	-	-	-	6.6	0.1
(ii)	Magnesite and Chrome-mag total	24.0 (17.5)	17.9 (14.6)	20.2 (13.4)	29.6 (18.4)	28.4 (15.9)	35.4 (23.8)
	Austria	20.0	14.8	16.3	22.8	18.9	23.4
	West Germany	3.3	2.3	3.2	3.4	4.2	5.5
	Yugoslavia	-	-	-	-	2.0	1.0
	Canada	-	-	-	0.8	2.9	3.0
(iii)	Other Total	2.6	2.4	2.5	2.4	3.6	5.1
	West Germany	0.8	1.1	0.6	0.9	2.0	2.0
	USA	0.5	0.4	0.7	0.4	0.6	1.3
	Austria	0.5	-	-	-	-	0.3
	France	0.3	0.2	-	0.4	0.3	0.3
	Belgium	-	0.2	0.1	-	-	0.1
BRICKS: TOTAL		34.1	27.0	28.5	41.8	47.8	49.5

Source: Industrial Minerals (1972), October. Figures in brackets refer to percentage of domestic production

TABLE C14 - UK EXPORTS OF FINISHED REFRACTORY BRICKS (Thousand Tonnes)

	1966	1967	1968	1969	1970	1971
Refractory Bricks Total*	112.1	119.0	135.0	145.5	131.5	160.3
Australia	10.6	6.2	13.9	8.3	7.0	12.0
Canada	8.7	9.1	8.7	8.6	7.7	9.0
Ireland	6.0	5.5	7.1	8.5	8.1	7.2
Netherlands	17.7	17.5	19.5	22.8	19.8	18.6
Sweden	13.4	13.8	12.8	21.5	18.8	20.5
Spain	4.6	7.7	2.2	3.0	2.4	3.8
Belgium	4.3	5.4	7.0	6.1	8.8	6.4
Finland	3.7	4.8	4.7	7.9	6.8	6.1
West Germany	2.6	1.9	1.8	7.7	7.8	3.2
Norway	2.0	9.1	2.0	3.9	-	2.3
France	2.1	1.9	3.3	2.9	-	1.0

Source: Industrial Minerals (1972), October. *Includes non basic products as well as basic

TABLE C15 - The UK's Major Customers for Finished Refractory Bricks

Exports by country and category for January - June 1972 (metric tons)

	Magnesite and Mg/Cr bricks	High alumina, etc, bricks excl. fire-clay and heat insul.
Finland	2	580
Sweden	1,271	5,103
Norway	-	345
Denmark	35	848
W. Germany	122	2,662
Netherlands	2,683	2,975
Belgium	297	1,438
France	52	454
Italy	345	943
Greece	58	881
Spain	648	562
Ireland	171	2,206
S. Africa	319	2,303
Nigeria	1,024	539
India	1,825	4,522
Malaysia	315	475
Australia	2,302	1,174
N. Zealand	182	1,104
Canada	195	972
USA	275	1,060
Argentina	-	264
Total	14,626	42,247

Source: Annual Statement of Trade (1972)

APPENDIX D

Projections of demand for aggregates, 1971 - 2011

The purpose of this Appendix is to provide some basic, 'order of magnitude' estimates of the long term demand for aggregates: including sand and gravel, limestone, igneous rocks, and sandstone as classified in the census of production. As indicated in Chapter 3 the demand for aggregates is determined largely by the raw material requirements of the private and public sectors of the construction industry. As a first approximation, which must only be treated as a broad indication of trends, the demand for bulk materials is projected here as a function of the level of population.

For the U.K. as a whole the data on production of aggregates is satisfactory only as far back as 1940. As Table D1 indicates production of aggregates in recent years has far outstripped population growth. However the average increment in annual consumption/capita over the 30 year period (1942 - 1971) was 0.140 tonnes. If, as in the Somerset County Council report,[1] a 20 year average is preferred as a basis for projection the increment is somewhat lower at 0.137 tonnes (1952 - 1971), and for the 10 year period (1962 - 1971) the figure is 0.176 tonnes. For each calculated increment average, Table D2 extrapolates demand over the 40 year period to 2011 using the official natural population projections of the Department of the Environment.[2]

For Scotland statistics of the production of aggregates are only available as a continuous series for 1960 onwards.[3] Table D3 charts the available data and an annual incremental factor of

0.240 tonnes emerges. Applying this factor to, this time, two separate sets of population projections, the first one of which is a 'natural increase' (DoE) projection, the other being 'oil-influenced' (Strathclyde University[4]), two tentative sets of figures for demand for aggregates emerges (Table D4). The data series for these projections is much more limited than the U.K. section and does not really justify such long term extrapolations. It is worth even so noting the higher 10 year (62 - 71) factor of 0.240 tonnes for Scotland, than over the equivalent period for the whole U.K. (0.176 tonnes).

Regional breakdown of statistics of the production of aggregates in Scotland are not available and hence a regional factor cannot be computed. There are historical reasons, however, for suggesting that such a factor for the Highlands would be below the national average (low population density, less industrialisation etc.). For the purposes of 'order of magnitude' projections however it may be plausible to assume that future regional increments in demand will be much closer, or even in excess of the national average. On this basis therefore, and with similar reservations, the Scottish factor is used also for the Highlands projection - again using the two population series available (Table D4).

<u>Notes</u>

1. Somerset County Council, (1971) Quarrying in Somerset, Taunton
2. ibid
3. Scottish Abstract of Statistics. Annual. H.M.S.O.
4. Scott. Coun. Dev. Ind. (1973) A future for Scotland.

Table D1

U.K. Production of Aggregates, and Population 1940 - 1971

Year	Production tonnes x 10^6	Population x 10^6	Per Capita Cons. Tonnes	Annual Increment Tonnes +	Annual Increment Tonnes −	Average Increments
1940	67.23	48.226	1.39			
1941	65.23	48.216	1.35		0.04	
1942	69.79	48.400	1.44	0.90		
1943	65.18	48.789	1.34		0.10	
1944	63.52	49.016	1.30		0.04	
1945	43.49	49.182	0.88		0.42	
1946	51.49	49.217	1.17	0.29		
1947	62.59	49.511	1.26	0.09		
1948	70.09	50.080	1.40	0.14		
1949	75.40	50.381	1.50	0.10		
1950	80.80	50.616	1.60	0.10		
1951	88.40	50.288	1.76	0.16		
1952	96.50	50.431	1.91	0.15		
1953	101.40	50.593	2.00	0.09		30 yr:
1954	103.10	50.765	2.03	0.03		0.140 tonnes
1955	111.10	50.946	2.18	0.15		
1956	115.20	51.184	2.25	0.07		
1957	113.80	51.430	2.21		0.04	
1958	115.60	51.652	2.24	0.03		
1959	126.30	51.957	2.43	0.19		20 yr:
1960	136.90	52.373	2.61	0.18		0.137 tonnes
1961	148.10	52.807	2.80	0.19		
1962	151.90	53.314	2.85	0.05		
1963	159.20	53.637	2.97	0.12		
1964	193.00	53.998	3.57	0.60		
1965	195.20	54.361	3.59	0.02		
1966	208.70	54.654	3.82	0.23		10 yr:
1967	231.30	54.979	4.21	0.39		0.176 tonnes
1968	238.70	55.283	4.32	0.11		
1969	236.60	55.531	4.26		0.06	
1970	242.80	55.411	4.38	0.12		
1971	248.50	55.515	4.48	0.10		

Table D2

U.K. Population Projections and Estimated demand for Aggregates 1971 - 2011

Year	Population millions	30 year factor tonnes	20 year factor tonnes	10 year factor tonnes	Estimated Demand 30 year factor	Demand 20 year factor	Demand 10 year factor
Base Year 1971	55.525		4.48			248.5	
1981	57.263	5.88	5.85	6.29	336.7	335.0	360.2
1991	59.768	7.28	7.22	8.10	428.1	424.5	484.2
2001	62.400	8.68	8.59	9.91	541.6	536.0	618.4
2011	65.560	10.08	9.96	11.72	660.8	653.0	768.3

Table D3

Scottish Production of Aggregates, and Population, 1960 - 1972

Year	Production Aggregates	Population	Consumption/ Capita	Annual Increment		Average
	metric tons x 10^6	millions	tonnes	+ tonnes	- tonnes	10 year period
1960	12.99	5.178	2.51			
1961	14.57	5.184	2.81	0.30		
1962	14.63	5.197	2.81	0		
1963	15.83	5.205	3.04	0.23		
1964	19.25	5.206	3.70	0.66		
1965	19.25	5.204	3.70	0		
1966	20.05	5.191	3.86	0.16		0.240 tonnes (1961–1971)
1967	23.86	5.187	4.60	0.74		
1968	24.84	5.188	4.79	0.19		
1969	25.04	5.195	4.82	0.03		
1970	25.95	5.199	4.61		0.21	
1971	25.98	5.228	4.97	0.36		
1972	23.39					

Table D4

Scottish and Highlands Population projections and estimated demand for aggregates 1971 - 2011

Year	Population SCOTLAND	Population SCOTLAND	Population HIGHLANDS	Population HIGHLANDS	Factor	Estimated Aggregate Demand SCOTLAND	Estimated Aggregate Demand SCOTLAND	Estimated Aggregate Demand HIGHLANDS	Estimated Aggregate Demand HIGHLANDS
	OFFICIAL	STRATHCLYDE	OFFICIAL	STRATHCLYDE		OFFICIAL	STRATHCLYDE	OFFICIAL	STRATHCLYDE
	millions	millions	millions	millions	tonnes		millions of metric tons		
Base Year 1971	5.23		0.28		4.97	25.98		1.41	
1981	5.24		0.29		7.37	35.58		2.12	
Mid 80's		5.48		0.32	8.57		49.95		2.73
1991	5.41		0.31		9.77	52.89		3.02	
End Cent.		5.94		0.38	12.17		72.29		4.63
2001	5.59		N.A.		12.17	68.02		N.A.	
2011	5.83		N.A.		14.57	84.91		N.A.	

APPENDIX E

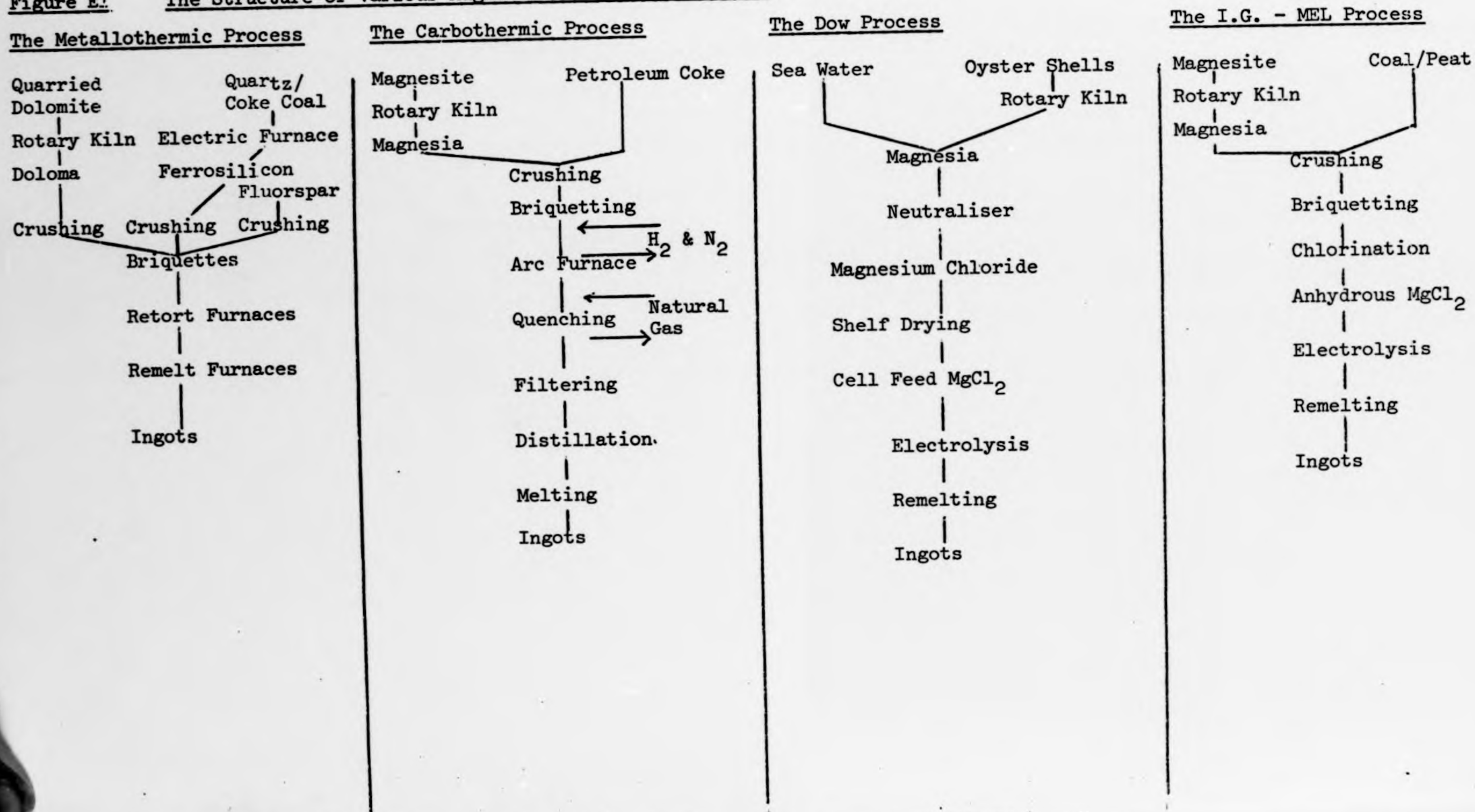
An evaluation of alternative methods of magnesium metal production

1. Introduction

This appendix attempts, in brief, a technological-economic analysis of magnesium production methods. It is not of course the product of first hand experience in the field but relies on an excellent series of papers produced over a number of years by the U.S. Bureau of Mines.[1] The objective here is to indicate potential room for manoeuvre, dependent on market characteristics, available where alternative technologies suited to different scales of operation can still be seriously evaluated. It is an increasing source of regret in other basic process industries that alternative scale technologies have suffered in the drive towards maximum economies of scale regardless of the cyclical nature of market demand.

Magnesium is a difficult metal to separate from its various compounds to the extent that extractive processes tend to be energy intensive. It is clear therefore, that since "ores" tend to contain relatively low proportions of the metal, naturally concentrated ores such as brines and bitterns, will possess considerable initial advantages. Two qualitatively different reduction methods are available: electrolysis and direct (thermal) reduction. As explained in the text electrolytic processes invariably use magnesium chloride as a feedstock, whereas thermal reduction begins with magnesium oxide. It is in the preparation of the primary reductants that a much greater variety of alternatives is encountered. Nevertheless as Table E1 indicates

Figure E1 The Structure of Various Magnesium Production Methods



the relative economic importance of these preliminary stages of the production process is not crucial. Figure E1 provides some basic information on the structure of alternative production processes. All cost figures in this appendix:

> are based on hypothetical plants designed to produce 22,000 tonnes of magnesium per year. Fixed capital costs are updated to 1968. Estimated annual operating costs assume a 350 day operating year, linear depreciation over a 20-year period, a cost of 5 mills per kilowatt-hour for electricity, 25 cents per million BTU for natural gas, and an average operating labour cost of $3.25 per hour.

No attempt has been made to further update costs, or transpose them to a U.K. situation, as the overall aim is to indicate the relative economic significance of alternative methods.

2. Basic Description of alternative methods

2: 1. Thermic reduction

Materials which have been used as reductants in thermal production processes for magnesium include aluminium, calcium carbide, aluminium silicon alloys and carbon. High temperatures are required. For example in the following reactions.

$$3MgO + 2Al \rightleftharpoons 3Mg + Al_2O_3, \quad MgO + C \rightleftharpoons MgO + Co,$$
$$2MgO + Si \rightleftharpoons 2Mg + (SiO_2)^{2-}$$

standard free energies are zero at approximately 1550°C, 1850°C and 2300°C respectively, resulting in a vapour pressure of metallic magnesium equal to 1 atmosphere. But in practice lower temperatures must be used since vessels to contain the reactions at such high temperatures are not readily available.

The success of the reactions depend on maintaining a sufficient but small pressure differential between the magnesium vapour and the non volatile reaction components. This can only be achieved by either evacuating the vessel or sweeping the reactants with inert gases.

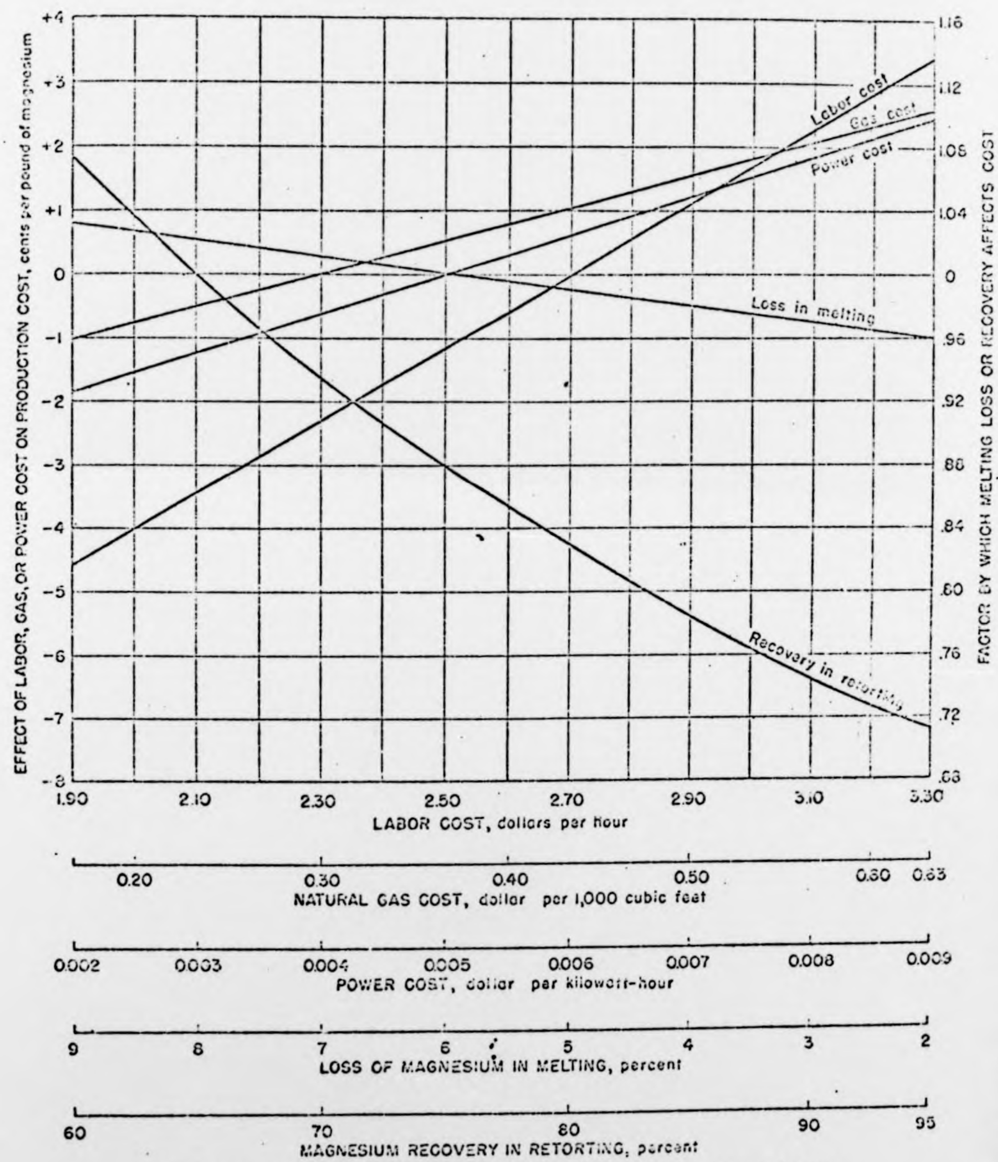
There are further problems involved in the use of carbon as a reductant and the U.S. Bureau of Mines set such methods apart under the designation "carbothermic methods". The critical problem is that if the gases remain in contact between 1850°C and 450°C the reverse reaction consumes the metallic magnesium. The method of "quenching" adopted is critical to the success of this technique.

Raw materials for both types of thermic reduction are generally either dolomite or magnesite, or sea water magnesia for economic rather than technical reasons. A typical metallothermic process proceeds as follows:

1. Calcined dolomite and 75 - 80% Ferrosilicon in a ratio of 5:1 are ground and mixed; about 1% of fluorspar is added; the mixture is briquetted.
2. The briquettes are charged into tubular retorts that are heated and evacuated. The fluorspar acts as a catalyst and magnesium condenses at one end of the retort which is water cooled. The process takes up to nine hours per batch. Magnesium of 99.8% purity results from the process.

Ferrosilicon is the generally preferred reductant since 5 parts of calcium are needed to liberate 3 parts of magnesium and similar stoichiometric considerations disfavour the use of aluminium and its alloys. As a whole the Pidgeon process consumes (very approximately) 9.9-11.0 kwhr/kg of magnesium produced. The retorting operation accounts for over 50% of

FIGURE E2: EFFECT OF VARYING CONDITIONS ON COST OF PRODUCING MAGNESIUM: METALLOTHERMIC METHOD



NOTE: Apply effect of labor, gas, or power cost (left ordinate) before applying factors for melting loss or recovery (right ordinate)

Source: Dean, K.C., et. al. (1965), op.cit.

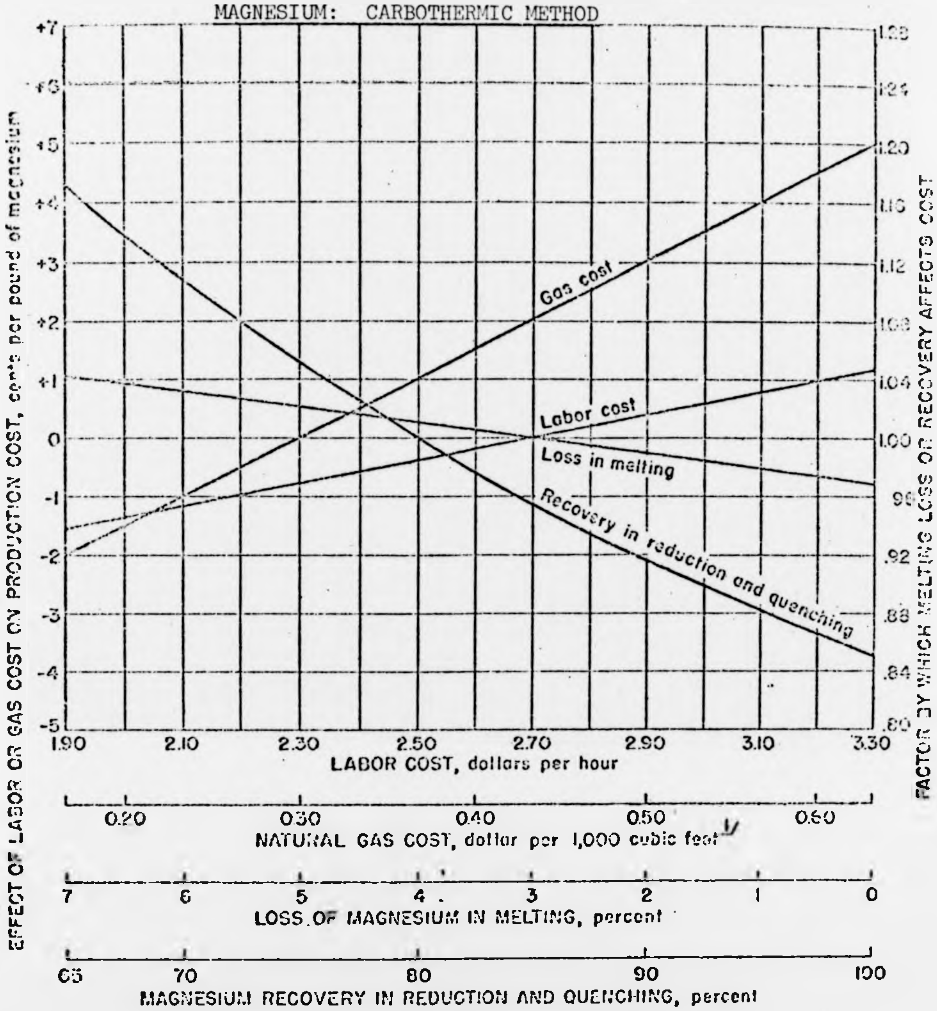
the total cost of the metallothermic operation (see Table E2) so clearly any improvements in the method should be concentrated in this area. There are a number of possibilities:

1. Larger retorts: these were used during the war and may yield present day economic advantages.
2. More effective discharging methods: a continuous process was developed in Germany but has not been seriously evaluated.
3. Better briquetting leading to improved reaction efficiency and shorter reaction times.
4. More efficient melting processes.

Figure E2 summarises estimates of the effects of changes in various factors of production on overall production costs by the metallothermic route using dolomite and ferrosilicon. An overall cost summary is to be found in Table E3.

The carbothermic process has never enjoyed a great deal of popularity. The potentially explosive combination of finely divided magnesium and carbon monoxide at high temperatures may be a significant factor, although the use of petroleum coke as a reductant presents additional hazards. The structure of the carbothermic process is similar to the metallothermic method up to the retorting stage. Briquettes of in this case magnesia and coke (2.8:1) are dropped into an arc furnace. The furnace operates at 150-170 volts at a temperature of 1,950 - 2050°C. The reduction products are cooled and diluted by mixing with natural gas almost immediately after leaving the high temperature reaction zone in the arc furnace. The gas containing magnesium dust is eventually passed to water cooled heat exchangers and filters where the dust is removed. The filters must subsequently

FIGURE E3: EFFECT OF VARYING CONDITIONS ON COST OF PRODUCING MAGNESIUM: CARBOTHERMIC METHOD



1/ Cost of natural gas returned to gas company is assumed to be constant.

NOTE: Apply effect of labor or gas cost (left ordinate) before applying factors for melting loss or recovery (right ordinate).

Source: Elkins, D.A., et. al. (1967), op.cit.

be heated in retort furnaces to recover the magnesium. In spite of the extra complexity of the operations recoveries are, at least hypothetically, rather higher on average (see Figure E3) than for the metallothermic process. This may be due to the larger batch sizes and fewer furnaces. Overall production costs are also apparently lower (see Table E3).

The major problems with direct reduction processes are:

1. Necessity for very pure raw materials to avoid cumulative contamination in retorts/furnaces.
2. Their labour intensity, through batch type operations.
3. Losses of magnesium during reduction and subsequent melting.

2:2 Electrolytic Methods of Magnesium Production

The chemical basis of magnesium technology as discussed in the text (Chapter Three) indicates that the most feasible route to the metal involves electrolysis of the chloride. A number of methods are in use and these differ mainly in their ability to use cell feeds at different states of dehydration. Whilst it is technically easy to produce moderately concentrated $MgCl_2$, the production of anhydrous $MgCl_2$ is expensive and technically more complex. And so reduction processes using partially dehydrated $MgCl_2$ have a prior cost advantage. But since increasing H_2O content reduces melt conductivity, electrolysis of completely anhydrous $MgCl_2$ is cheaper.

Preliminary Processing

The traditional starting material for electrolytic magnesium production was sea water containing 0.13% Mg b/w. More recently the natural potential of brines with up to 1% Mg has been seriously evaluated and has been shown to possess potential economic advantages. In the sea water process (see Figure E1) either calcined dolomite or lime (oyster shells) are reacted with sea water to precipitate highly insoluble magnesia ($Mg(OH)_2$). This is filtered, separated concentrated and reacted with hydrochloric acid. Evaporation to concentrate the magnesium chloride in the solution is the next step resulting in the crystallisation and removal of any remaining sodium chloride and calcium sulphate. Further evaporation eventually results in solid granular magnesium chloride, designated as "cell feed". In the brine based process natural brines (0.7% Mg av) are first concentrated naturally in solar evaporation ponds (7.5% Mg). Sodium and potassium salts are largely precipitated out at this stage. The effluent from the final solar pond contains 26.00% Magnesium chloride (7.5% Mg). Remaining unwanted salts are removed by precipitation and spray drying results in a cell feed containing 91.6% $MgCl_2$ (23% Mg). Total costs summaries for hypothetical plants producing various intermediate products are to be found in the text (Figure 3) and as unit costs in Table E1.

3 Individual Reduction Processes

3.1. The Dow Process

In this method the $MgCl_2.1.7H_2O$ cell feed is introduced into externally heated rectangular steel pots, each holding about 10 tons of electrolyte (54% NaCl, 23% $CaCl_2$ and 22% $MgCl_2$). The pot serves as a cathode whilst cylindrical graphite anodes are lowered into the melt. When the feed enters the cell most of the water flashes off almost immediately. The small amount of water entering the bath is electrolysed. This action plus chlorination of magnesia in the feed gradually consumes the anodes. Molten magnesium (99.8%) rises to the top of the bath and is trapped under inverted troughs that guide the magnesium to metal storage wells. Chlorine liberated during electrolysis is reconverted to hydrochloric acid and recycled. Operating amperages range up to 115,000 amps and current consumption per kg. of magnesium is about 18 Kwhr (= 8 Kwhr/lb).

3. 2. The I.G. - M.E.L. process

This process utilises anhydrous $MgCl_2$ which has been prepared by reacting MgO (from magnesite or sea-water) with chlorine in a special chlorinating furnace. The internal resistance of the cell is greater than in the Dow process and no external heating is required. The cell consists of rectangular steel shells lined with refractory bricks. The anodes are large rectangular graphite shells suspended crosswise in the cell. Steel cathodes are placed between the anodes. Chlorine gas is withdrawn from the anode compartments whilst metal collects in the cathode departments. The cell metal is impure and is transferred to holding furnaces where entrained chlorides are separated from molten metal before cooling. Anode consumption is low, current consumption/kg of magnesium ranges up to 18 Kwhr and operating amperages of up to 100,000 amps are used.

Overall comparisons for the two reduction processes are to be found in Table E1.

3.3 Improvements

The potential for improvement in the electrolyte reduction processes is best considered in two parts: improvements in intermediate processes and improvements in final reduction.

(i) Improvements in intermediate processes

Production costs for the two traditional electrolytic processes (under the assumption cited above) are as follows:

I.G. - M.E.L. Process (refer to Table E1)

Magnesite $\xrightarrow{81.6}$ MgO $\xrightarrow{216.1}$ $MgCl_2$, anhydrous $\xrightarrow{346.1}$ Mg.IGF cells = 681.3 $/t

NaCl $\xrightarrow{37.5}$ Cl_2 make up (↑ to MgO → $MgCl_2$ step)

with 20% return, required price = 1091.3 dollars per tonne.

Dow Process (refer to Table E1)

Oyster shells + sea water $\xrightarrow{72.8}$ $MgOH_2$ $\xrightarrow{17.6}$ 35% $MgCl_2$ $\xrightarrow{39.7}$ $MgCl_2 1.5 H_2O$ $\xrightarrow{405.6}$

→ Mg. Dow Cell = 610.7 dollars/tonne

35% $MgCl_2$ ← HCl $\xleftarrow{75.0}$ + NaCl ← Cell Gas

with 20% return required price = 961.2 dollars per tonne.

Thus whilst the IG-MEL process is cheaper (346.1:405.6) at the reduction stage, intermediate stages make this route more expensive overall (335.2:205.1). An alternative intermediate route could involve the dehydration of carnellite rich brines ($MgCl_2.6H_2O$). In this process ammonium chloride and a chlorinated biphenyl compound are added to 35% $MgCl_2$ solution. As excess water is removed by evaporation the double sale NH_4Cl $MgCl_2.6H_2O$ is crystallised. This double salt has less tendency to hydrolyse than $MgCl_2$ $6H_2O$ and it is subsequently dehydrated and decomposed to yield a virtually anhydrous $MgCl_2$ cell feed. The intermediate cost structure is:

Great Salt Lake Brine → 35% $MgCl_2$ → $MgCl_2$ anhydrous

→ Mg. I.G. cells = 365.8 dollars per tonne

- 5.4 ↓

saleable chlorine

with 20% return required price = 684.2 dollars per tonne.

(iii) Improvements in electrolytic reduction

Over half the cost of magnesium production by electrolytic methods is attributable to the reduction process. Table E4 indicates in particular the importance of power and labour costs. Efforts to reduce power consumption have concentrated on the electrolyte employed. One of the major disadvantages of existing reduction methods was the difficulty encountered in preventing liberated magnesium, which floats to the surface of the cell (being less dense than the electrolyte), from recombining with liberated chlorine.

Recently Dow chemical patented a new type of cell which eliminates curtains and allows a narrow electrode gap (1"), whilst also permitting collection of metal at a submerged liquid cathode. This was made possible by exploiting the low density and high conductivity of electrolytes rich in LiCl. Operating voltages and power consumption are lower (9.9-11.0 kwhr/kg) and energy efficiency much higher than with conventional methods. Very low anode attack is experienced and high purity anode gas is obtainable. LiCl is highly deliquescent but the problem is now believed to have been surmounted with presumably highly favourable effects on production costs.

On the labour component it is believed that a semi continuous process is now operated by the National Lead Co. in which "both the cell feed and the product, magnesium metal, are continuously fed and withdrawn from the electrolytic cells into a collection cell. This process results in uniform operating conditions as well as lower labour requirements".[2]

4. Conclusions

The work of the U.S. Bureau of Mines in evaluating alternative methods of magnesium production yielded valuable comparative information between plants designed to produce 22,000 tonnes per year, with a working year of 350 days on a semi-continuous basis. It is difficult from this information alone to draw any firm conclusions on the potential economies of scale achievable, or desirable with individual methods. In general however the electrolyic process in any of its three main forms is the one which appears most amenable to large scale operation, and in fact it is only these methods that have ever been operated in excess of the hypothetical 22,000 tonne plants discussed here. Dow Chemicals Freeport magnesium plant produces over 120,000 tonnes of magnesium per annum, Norsk Hydro (I.G. - MEL) 45,000, and National Lead using the Great Salt Lake Brines also 45,000 tonnes (plus 80,000 tonnes of liquified chlorine).

Metallothermic processes when they have enjoyed high purity raw materials, appear to have operated optimally in the 12 - 24,000 t.p.a. range, but the possible economies of scale achievable through using larger retorts and continuous process techniques have not been fully evaluated. France and Italy have operated modified metallothermic processes for a number of years (the Magnétherm and Ravelli processes respectively), but in the absence of detailed technical and cost information no conclusions can be drawn at this stage concerning their cost competitiveness.

Notes

1. Elkins, D.A. et. al. (1967) op cit, Dean K.C. et. al. (1965) op cit. and Elians D.A. et al (1968) op cit. See Chapter three for detailed references.

2. Strickland, J.R. op cit.

Table E1 Unit Costs for magnesium production operations

Operation	Production costs		20% return on investment[1]	
	Dollars/ dry ton	Dollars/ Tonne Mg	Dollars/ Tonne Mg	
Dolomite → MgO CaO	11.1	55.1	26.5	INTERMEDIATE OPERATIONS
Oyster shells + seawater → $Mg(OH)_2$	28.0	72.8	61.7	
Dolomite + seawater → $Mg(OH)_2$	19.2	55.1	44.1	
$Mg(OH)_2$ → MgO	13.5	26.5	19.8	
Magnesite → MgO	44.3	81.6	33.1	
$Mg(OH)_2$ → 35% $MgCl_2$	4.4	17.6	8.8	
+ NaCl Dow Cell Gas → HCl, make up	21.9	75.0	70.5	
Great Salt Lake Brine → 35% $MgCl_2$	16.6	70.5	44.1	
35% $MgCl_2$ → $MgCl_2$ $1.5H_2O$	9.7	39.7	19.8	
MgO → $MgCl_2$, anhydrous	49.6	216.1	147.7	
NaCl → Cl_2, make up	77.2	37.5	46.3	
35% $MgCl_2$, anhydrous	16.1	68.3	44.1	
Metallothermic Reduction				
Small Batch		679.0	297.6	
Large Batch		504.9	246.9	
Carbothermic Reduction		399.0	227.1	
Electrolytic Reduction				
Dow Cell		405.6	189.6	
I.G.F. Cell		346.1	183.0	
Chlorine drying and liquefying	8.2	-119.1	11.0	

1 Before Taxes

2 See Supplementary Information Table E1A

Source: Elkins, D.A. et. al. (1968), op. cit. p.183

Table E1A (supplement) Costs for intermediate products and by products involved in magnesium metal production by various routes

Product	Raw Material	Product, dry tonnes per year (tonnes)	Cost, thousand dollars Fixed	Total Investment	Annual Operating
MgO CaO	Dolomite	108,600	2,650	2,970	1,200
$Mg(OH)_2$	Dolomite and sea water	61,700	4,680	4,920	1,180
$Mg(OH)_2$	Lime and sea water	57,300	6,440	6,850	1,610
MgO	$Mg(OH)_2$	41,300	2,030	2,180	560
MgO	Magnesite	40,700	3,190	3,710	1,800
$MgCl_2$, 35%	$Mg(OH)_2$	92,500	900	1,000	400
Make up HCl	NaCl + cell gas	75,300	7,220	7,720	1,650
$MgCl_2$, 35%	Great Salt Lake Brine	92,500	4,110	4,930	1,540
$MgCl_2$ $1.5H_2O$	$MgCl_2$ solution	85,400	1,930	2,130	860
Make-up Cl_2	NaCl	10,900	4,800	5,120	840
$MgCl_2$, anhydrous	$MgCl_2$ solution	92,500	4,410	4,780	1,490
Cl_2, liquid	Cl_2 gas	62,200	1,130	1,260	- 2,580

Source: Elkins, D. A. (1968) op. cit.

Table E2 Summary of Costs for Metallothermic Process*

Operation	Number of Operators	Capital Cost $M	Annual Operating Cost $M	% of Annual Operating Cost
Ferrosilicon Production	48.4	2.84	2.36	23.9
Ferrosilicon Crushing and Grinding	10.7	0.29	0.20	2.0
Dolomite crushing and sizing	4	0.49	0.10	1.0
Dolomite calcining	9.4	0.72	0.41	4.2
Dolomite grinding	8.5	0.20	0.17	1.7
Briquetting	18	0.54	0.37	3.8
Retorting	201	9.14	5.14	52.1
Melting	36	0.68	0.86	8.7
Dolomite	-	-	0.26	2.6
Plant facilities (10%)	-	1.49	-	-
Plant utilities (12%)	-	1.79	-	-
TOTAL FIXED CAPITAL COST	-	18.17	-	-
WORKING CAPITAL	-	2.55	-	-
TOTAL	336.0	20.72	9.87	100.0

Source: Dean K. C., et. al., (1965) op. cit. p.50

*1963 prices and wage rates, 12,000 ton plant, straight-line 20yr depreciation. The absolute cost figures are not directly comparable with Tables E1, but the relative importance of specific operations given here is probably still fairly representative of metallothermic operations.

Table E3 Overall Cost Summaries: Direct Reduction Processes

1. Metallothermic (see Table E1)

	Production Cost	20% return
Dolomite → CaO MgO	55.1	26.5
Ca O MgO $\xrightarrow{FeSi}$ Mg, metallothermic	679.0	297.6
TOTAL	734.1	324.1

Required Price: 1058.2 \$/tonne (833.3 with large batch method)

2. Carbothermic (see Table E1)

	Production Cost	20% return
Dolomite + Seawater $Mg(OH)_2$	55.1	44.1
$Mg(OH)_2$ → MgO	26.5	19.8
MgO → Mg, carbothermic	399.0	227.1
TOTAL	480.6	291.0

Required Price: 771.6 \$/tonne

Table E4 Factor costs per pound of magnesium produced in an Electrolytic Plant in 1962 and 1945-6 [1]

	Amount of Factor Needed/ TonneMg product	Cost of Factor 1962 $/tonne	%	Cost of Factor 1946 $/tonne	%
Electric Power	20.9 kwh	99.2		35.3	13.5
Lime	3.2 lbs	39.7		39.7	15.1
Chlorine	0.5 lb	41.9		19.8	7.6
Electrodes	0.1 lb	66.1		35.3	13.5
Natural Gas	0.057 MCuf	24.3		8.8	3.4
Labour		99.2		50.7	19.3
Sub Total		370.4		189.6	72.4
Other Costs[2]		110.2		72.8	27.7
Total		480.6		262.4	100.1

[1] Not strictly comparable with other text examples

[2] Including: supervision, payroll overhead, operating supplies, taxes, insurance, depreciation

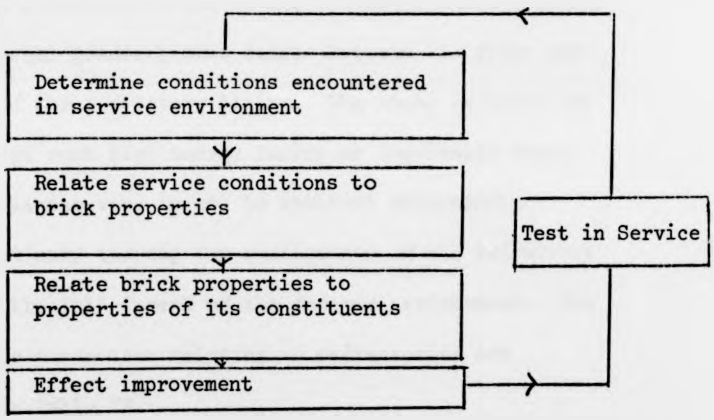
Source: Charles River Associates, op. cit. p.70 (adapted)

APPENDIX F

The technical basis of refractory selection

In the text, an abstract model of the technological economics of refractories demand was developed (Chapter four). Having identified the circumstances in which innovation can, in theory, be most successfully undertaken, this appendix develops a generally applicable basis for refractory selection, concentrating on the various technical parameters.

The following schema is suggested as a means of identifying areas of possible improvement in refractory performance:



The schema is designed to generate feedback and is capable of iteration until a desired technical or economic optimum has been achieved. In practice of course the smooth flow of information and improvement implied by the schema is rarely achieved: in particular controversy over diagnostic parameters, usually related to laboratory tests intended to indicate in-service performance, has provided an enormous technical literature and there is no pretence of omniscience as a consequence in the present study.

The above schema is used in the following sections to indicate how suitable refractories are developed for use in the LD-basic oxygen steelmaking process. The choice is deliberate: the literature is comprehensive, the process will account for the bulk of crude steel output in the U.K. for many years to come, and process is presently a major consumer of dolomite refractory blocks, which may assist in the identification of opportunities for mineral resource development as discussed in Chapter Five.

Service Conditions

A first reference to the LD service environment concerns the high thermal gradient that exists between the front and rear faces of the refractory lining. The steel industry has come to accept such high energy losses as inevitable where substantial lining wear is not to restrict steelmaking ability. But only the top few centimetres of the refractory lining bear the full impact of the furnace environment. The major furnace parameters relating to refractories are summarised in Table F1.

Relation of Furnace parameters to Refractory brick properties

It may appear quite a simple matter to outline the various physical, chemical and mechanical constraints experienced by the refractory lining of the BOS convertor and match these with the reproducible properties of a chosen product. Until very recently this was generally attempted by outlining standard test procedures which cumulatively could give a reasonable prediction of service performance. One major problem with this

Table F1

Parameters of steelmaking relevant to refractories design

Parameter	Remarks
Temperature	Two aspects especially relevant: temperature maxima and thermal reversals. Temperatures up to 3000°C at oxygen/bath interface, elsewhere gradient from 1200-1600°C. Major thermal reversal every twenty minutes i.e. at beginning and end of refining period.
Atmosphere	Speed of reaction results in a highly reducing atmosphere in the vessel where CO/CO_2 ratio away from the oxygen/bath interface ranges between 7:1 and 15:1
Slag Attack	Three stages of the refining process: (i) The first 5-7 minutes: removal of silica and manganese resulting in an acidic slag (ii) The middle 10 minutes: essentially decarburisation; depending on rate of oxidation iron oxide may be formed in the slag (iii) The last 3-5 minutes: removal of remaining manganese and phosphorus
Abrasion: Physical Impact	The thermochemistry of the BOS prevents scrap additions totalling more than 30% of the weight of the charge. Even so the effect of 90 tonnes of old scrap plus the molten iron charge falling onto the lining for heights of about 30 feet will be to engender severe mechanical stresses. The only published information on such pressures suggests that 6-10,000 p.s.i. could develop

approach concerns the ability to recreate a furnace environment in the laboratory. For furnace conditions only test one face of the brick, depending on the efficiency of construction of the lining. The consequent differential thermal and mechanical stresses, and degree of chemical penetration are extremely difficult to reproduce under laboratory conditions.

Table F2 attempts to relate the properties of the furnace environment with the macroscopic properties of various refractory products. As can be seen, the inadequacies of experimental data in certain areas and the absence of theories of causation in others, renders accurate identification of areas of potential innovation a matter of some speculation. It would appear that what is required is a brick which fully realises the potential of its constituents in terms of refractoriness, strength at high temperatures, and textural properties hindering the ingress of agents of premature wear. Where the inherent properties of the bricks constituents cannot match the rigours of the furnace environment, the manufacturing process has to be designed to compensate for identifiable deficiencies: through plugging up holes in the brick with tar, reducing permeability through higher forming pressures, or through higher firing temperatures to promote direct (as opposed to ceramic) bonding.

Table F2

The relation of in service conditions to the macroscopic properties of various refractory products

In-service criterion	Relation to macroscopic brick properties
Temperature	The service temperature ranges of various types of refractory are illustrated in Fig F1. Dolomite, magnesite, chrome, zircon, benzilia and carbon all appear to meet the requirement of withstanding temperatures up to 1650°C
Thermal Reversals	The exact measure of likely success in withstanding the stresses engendered by thermal reversals has been the subject of considerable controversy. Modern tendencies are to define hot strength in terms of modulus of rupture at high temperatures, and creep values. Composite refractories particularly containing chrome are especially susceptible to spalling, probably due to differential thermal expansion
Atmosphere	Most basic refractories are stable in the reducing conditions encountered in BOS convertors. Where oxidising conditions arise, of course most bulk refractories are stable since they are oxides. Carbon and silicon carbide are exceptions
Slag Attack	The properties of a refractory which relate to slag attack are chemical composition, permeability and porosity (and by inference bulk density), and shrinkage. In theory it is possible to minimise the potential for slag attack through simply preventing the slag entering the microstructure of the brick. Success in this area, aside from chemical composition, is largely related to the manufacturing method

Table F2 (Continued)

In-service criterion	Relation to macroscopic brick properties
Physical Abrasion	As a general rule the resistance of the refractory to abrasion and impact will, in the furnace environment, be proportional to its hot strength as determined above. Unfortunately experimental data is lacking in this area but it appears that very few refractory products indeed have the ability to withstand impact pressures of 6-10,000 p.s.i. at temperatures in excess of 1,000°C

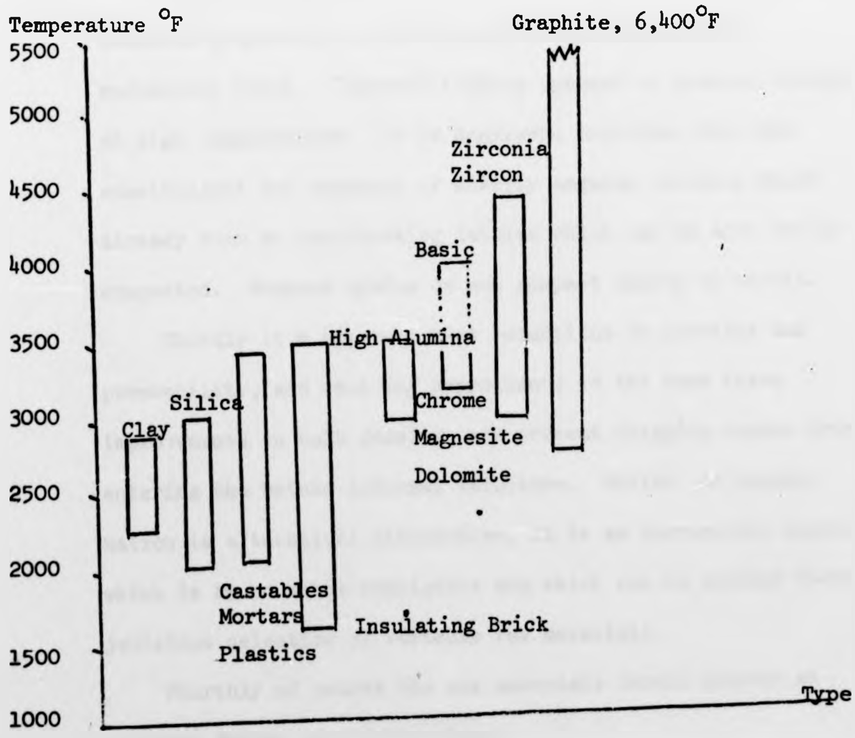


Figure F1: Service Temperature ranges of various refractories

Source: Burst J.C. and Sprechman, Chemical Engineering (1967), July.

Relating (macroscopic) brick properties to the (microscopic) properties of its constituents

At this stage it is feasible to isolate a few areas of improvement desirable in refractory products which can be exercised even at the raw materials stage. Firstly there is the evident advantage of a brick which behaves as a homogeneous physical and chemical system. Small amounts of impurities tend, through the different physico-chemical behaviour of the various mineralogical species, to produce undesirable mechanical stresses and strains in the brick which result in premature failure either through internal disintegration or through the ingress of agents of wear(slag) along fractures marking areas of differential mechanical behaviour. As a first approximation therefore all impurities are undesirable.

The second parameter traceable to raw materials is the textural properties of the mineral constituents of the refractory brick. "Direct"-bonding appears to promote strength at high temperatures. It is desirable therefore that the constituents are composed of sharply angular crystals which already form an interlocking lattice which can be more easily compacted. Rounded grains do not compact nearly so easily.

Thirdly it is apparent that reductions in porosity and permeability, and what may approximate to the same thing improvements in bulk density, can prevent slagging agents from entering the bricks internal structure. Whilst tar impregnation is a technical alternative, it is an incremental expense which is by no means negligible and which can be avoided given judicious selection of suitable raw materials.

Fourthly of course the raw materials should possess an adequate degree of refractoriness.

The effect of improvements: reassessment of factors of importance

This review has presented a highly abstracted method of achieving improvements in refractories performance. Most of the remarks will perhaps seem little more than common sense, but it has to be stressed that half the problem is the identification of which factors are of determining significance in refractory performance: factors which were simply stated at each stage of this analysis. In the real world of course the cycle is completed; improvements are effected; new products tested. Only then is it possible to reassess the value of the chosen monitors of performance, from whence the scheme of improvement begins again.

APPENDIX G

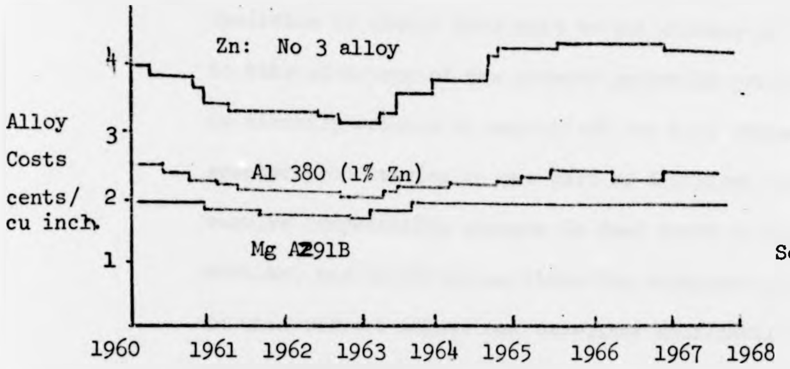
Die-casting: a note on the opportunity costs of change

The attractions of die-casting lie in the ability to produce large numbers of standard parts, within acceptable tolerance limits, with minimum metal loss. But capital costs are high, such that long continuous productions runs are desirable.
As was suggested in the text, end-use consumer sensitivity to prices of the various die-casting materials available, normally outweighs considerations of technical premium provided of course the part is capable of fulfilling its function satisfactorily. Accordingly, die-casting, has been suggested as a prominent area for expansion of magnesium demand, given improved price competitiveness.

The major commercial magnesium die casting alloy is AZ91B which contains 9% aluminium, 0.7% zinc and 0.13% manganese. Typical properties of AZ91B are as follows:[1]

Specific Gravity	1.81
Melting Point	$1105^{\circ}F$
Coefficient of thermal expansion in in/$^{\circ}F$	1.5×10^{-5}
Thermal conductivity in c.g.s. units	0.12
Tensile strength in p.s.i.	34,000
Yield strength in p.s.i.	23,000

Bearing in mind that in die casting application magnesium competes on a volume (per part) basis rather than cost per tonne basis, the following figure indicates magnesiums favourable position in recent years:



Source: Nelson, K.E. (1970), op.cit.

Figure G1: Comparison of Alloy Costs

Although simply on price grounds AZ91B appears competitive enough there are numerous other technical factors which have material economic consequences for the manufacturer contemplating a change to magnesium.

The method of die casting makes use of either a hot or cold chamber process. In the former case the molten metal from a hot reservoir is forced into the heated die by a piston or with compressed air. In the latter case the molten or pasty metal is baled into the machine from a separate crucible. The two methods are compared by Emley:[2]

"With cold chamber machines, maintenance costs are lower because moving parts are not continuously immersed in molten metal, pressures can be higher and metal temperature lower. Castings can generally be made sounder, though not necessarily stronger. Fatigue properties are generally better.

On the other hand with hot chamber machines productivity is higher, large thin walled castings can be made, scrap is less, metal losses are less, closing pressures and die wear are also less."

It is important to stress that the pros and cons of each method are determined with reference to the technical properties of the material actually being cast. Thus in anticipating a substitution of magnesium for aluminium casting it may be found desirable to change from cold to hot chamber process techniques to take advantage of the greater potential productivity which is directly related to magnesium's low heat content. But greater productivity in one part of the plant will probably require compensating changes in feed rates to the casting machine, and in machining times for roughcast products emerging. In this respect magnesiums excellent machinability has already been alluded to, but again investment in costly equipment, in this case, automated, high speed lathes, will be required to take full advantage of the production economies offered through technical advantages.

The conclusion therefore is that simple price comparisons between competing materials is a necessary but not sufficient indication of competetiveness in manufacturing applications. An integrated survey of all economies resulting from a particular technological innovation must be undertaken to yield an accurate reflection of the true costs involved in the opportunity for change.

Notes

1. Nelson, K.E. Imagine it die cast - in magnesium. Precision Metal (1970) May, 41-44. See also Precision Metal (1970) July, 59-61; and August. 40-41.
2. Emley, E.F. Magnesium Technology. Pergamon. 1966. p 426

APPENDIX H

The technical properties of dolomite as a concrete aggregate

This appendix sets out to identify a possible role for dolomite as a concrete aggregate. It relies heavily on the work of the Building Research Station and in particular the research carried out by Mr A.G. Edwards of that organisation. The empirical data is derived from the following two papers:

Edwards, A.G., Properties of concrete made with Scottish crushed rock aggregates. Building Research Station, Engineering Papers No. 42, November 1967

Edwards, A.G., Scottish Aggregates: rock constituents and suitability for concrete. B.R.S. (1970)

Concrete is essentially a composite mixture of a suitable aggregate bound in a matrix of cement (which is prepared by dead burning crushed limestone in a rotary kiln). The textural composition of the aggregate, and the mix of water:cement: aggregate are of considerable importance in producing a technically satisfactory product at an economically attractive cost. The chemistry of the setting process is also instrumental in determining the properties of the finished material but it is extremely complex and still incompletely understood.

The aggregate material usually preferred in concrete manufacture is sand and gravel since it provides a cheap means of achieving the desired grading of raw materials. Crushed rock aggregates are also used although in considerably smaller proportions because of the extra expense involved in crushing, sizing, grading and washing. In contrast to Scotland most of the gravel sources of the rest of the U.K. consist of either flint, quartzite or limestone. This is an issue of considerable importance since experience has shown that many concretes incorporating Scottish gravels show a tendency towards pronounced shrinkage - that is to say they expand when wetted and shrink when they dry out again causing shrinkage cracks in the finished structure. This was the starting point of the Building Research Stations investigation. Their results indicated that the aggregates producing the highest shrinkage value are the gravels of the Southern Uplands. These rocks contain a high proportion of derived greywacke pebbles which it is suggested are particularly susceptible to the shrinkage phenomenon by virtue of the high proportion of clay type/ grade material present. The lattice type structure of many clay minerals is particularly suitable for the absorption of water:glauconite, illite, montmorillonite and chlorite are common matrix constituents of many greywackes. At the other end of the scale quartzites and quartzitic sandstone were found to have very low shrinkage values. In summing up his investigation Edwards includes the following remarks:

"Before leaving the subject of shrinkage, there is one type which deserves special mention. I refer to limestone, which has been neglected by all sides of the construction industry in Scotland except the concrete brick makers who use it exclusively. The Laboratory has tested a wide range of limestones and marbles from all over the United Kingdom and abroad; some soft and absorptive, others hard and of low absorption; all produced concrete with a shrinkage below 0.04 percent, with the harder mountain limestones giving figures as low as 0.02 percent, and without exception the compressive strength of the concrete was much higher than average for a given mix design ...

(Limestone) is much more easily worked than most igneous rocks and generally breaks into a well shaped cubical particles. There are considerable reserves, not all of them shallow bedded, as reference to the IGS publication, 'The Limestones of Scotland', will show. In spite of this, there are only a handful of working quarries in Scotland who market aggregates suitable for the concrete industry."

Reference to Table H1 will show that limestones are indeed excellent concrete aggregates. Further, preliminary, research indicates that the Highlands dolomites included in the average figures cited performed at least as well as other comparable sources. It would appear that the traditional 'limestone prejudice' in the concrete industry is totally unjustified and that preference for local easily obtainable concreting gravel may lead to serious eventual structural deficiencies.

Type of Aggregate	Coarse Aggregate						Concrete - 1:2:4/0.6 (by wt.)								
	Aggregate Crushing Value	Aggregate Impact Value	Elongation Index	Flakiness Index	Specific Gravity	Water Absorption %	Drying Shrinkage %	Moisture Expansion %	Water Absorption %	28 day Compressive Strength (MN/m^2)		'E' Values (on $1m^2$)	Density at demould	Compacting Factor	Slump mm
										Air Cured	Water Cured				
Limestones including dolomites & marbles	22	19	53	25	2.71	0.51	0.028	0.023	4.9	32.0	38.0	30.0	2480	0.89	45
Granites	21	21	43	24	2.66	0.33	0.032	0.022	4.9	28.5	32.0	22.0	2445	0.87	05
Gabbros	16	11	44	22	2.96	0.27	0.035	0.026	4.6	28.0	33.0	29.0	2595	0.93	55
Dolerites	14	11	41	23	2.81	1.36	0.053	0.041	5.2	24.5	33.0	24.0	2520	0.88	20
Basalts	13	12	42	35	2.79	1.35	0.061	0.051	5.3	24.0	30.5	27.0	2490	0.88	40
Other Rocks	13	12	41	30	2.58	1.29	0.049	0.038	5.3	27.5	34.0	25.5	2380	0.87	30
Gravels	17	19	44	17	2.58	1.48	0.058	0.045	5.5	25.5	34.0	22.5	2400	0.87	30

Source: Edwards (1970), op cit.

Table H1 Average results of tests on different groups of crushed rock and gravel aggregates and concrete made with them