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THE CHATHAM RISE PHOSPHORITE RESOURCE, OFFSHORE NEW ZEALAND:
RISKS ASSOCIATED WITH DEVELOPMENT
AND IMPLICATIONS FOR POLICY

Presented in partial fulfilment
of the requirements for the Degree
of Master of Science
in the University of Canterbury
by
F.A. POYNTER

Centre for Resource Management
University of Canterbury
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The Chatham Rise phosphorite nodules have significant resource potential in terms of their distribution and concentration on the sea floor, and their end use as a phosphatic fertilizer. The most effective use of the nodules is as a direct application fertilizer which, at present, could assume a 10% share of the New Zealand market, expanding to at least 25% depending on its agronomic success.

Technology for recovering the nodules has been only recently developed and commercial deep ocean mining is unprecedented worldwide. The mine site, in depths of about 400 metres and 600 kilometres from the mainland, presents many unknowns. Two options for mining are proposed and examined:

1) the lease of a mining ship for operation 4-5 months of a year, and
2) the purchase of a mining vessel for year-round operation.

The first option appears to be cheaper overall at $45-70/tonne phosphorite delivered to a New Zealand port. A pronounced economies of scale effect tends to halve operating costs if production rate is doubled.

The net present value of the mining venture is subject to various constraints, the most significant of which is risk. There is risk associated with resource potential, mining technology, economics, and the legal and administrative framework governing operations. Risks are identified for each investor: Fletcher Challenge Ltd., West German interests, and New Zealand. It is determined that conflict exists among their various objectives for developing the phosphorite.

Mining will cause stress to the marine environment. The nodules provide substrate for many benthic organisms which in turn are food for some demersal fish and other species. It is difficult to determine how the environment will recover from mining or if effects will be contained within the mine area. Long term impacts such as the cumulative effect of large amounts of fine sediment dispersed over much of the Chatham Rise, are also difficult to predict. This and the destruction of the habitat of ling may have adverse consequences for the Chatham Rise fishery.

Risk is a significant consideration in novel, high technology developments such as the proposed Chatham Rise mining and as such, must be accounted for in policy. Policy must, therefore, be flexible and designed to cope with the unexpected. Recommendations are made for policy that is adaptive, continuously assessed as new information is acquired and operations proceed.
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INTRODUCTION TO STUDY

Phosphorite nodules, deposited during mid-late Miocene (15-5 million years ago), are widely distributed on the Chatham Rise, a submarine platform offshore New Zealand (figure 1.0). The nodules have received attention, both scientific and commercial, over the past 30 years and, recently, serious interest in mining the deposits has been expressed by a joint venture group of Fletcher Challenge Limited of New Zealand and Preussag and Saltzgitter of West Germany. The nodules have economic potential as a source of phosphate for New Zealand soils. At the point of writing, exploratory activity continues under a 'Mineral License' obtained in May, 1981.

Many New Zealanders are not aware of the phosphorite resource on the Chatham Rise and even the current commercial interest has not received much media attention. Perhaps this is because the nodules occur on the seabed at depths of about 400 metres and are located about 600 kilometres from mainland New Zealand. There is a tendency to easily ignore the potential effects of development since they do not really occur in anyone's backyard. Not only is this a false assumption but this type of attitude may permit development to proceed unchecked only to produce a hefty bill of economic, environmental and social costs later on.

The goal of this study, then, is to examine the implications of developing the Chatham Rise phosphorite nodules. As such it should help to determine the best use for the resource from a national perspective, taking both present and future generations into consideration. This study takes a broad-brush approach for a couple of reasons. Development is still in the exploration stage and intentions to mine the deposits has not yet been declared by the commercial interests. As well, the inherent competitiveness
Figure 1.0. Location of study area. Bathymetry is in metres.
(Adapted from BP Recorder, Dec. 1981, p.9.)
in mining means information is held very close to the chest so that
detailed examination of many aspects is simply not possible. It becomes
obvious that to be effective this type of study must be done at an
early stage so that a proposal may be altered and/or alternatives consid-
ered. This study is a forum to bring out the issues and determine their
relative significance to the public, project investigators, and interest
groups. Although no true solution may be found, the issues say a lot in
themselves.

The study is divided into three main parts. Part I provides the basis
for a discussion of resource use and examines the physical characteristic
of the phosphorite and its potential. The technology for recovering the
nodules is then examined and some particulars for a mining operation on
the Chatham Rise are discussed. Part II introduces the concept of risk
which is the framework adopted for examining the implications of
development. Ground rules for development are usually designed according
to the objectives of the investors; these objectives and risks to them
are identified. Risks to other resources not the target for development
are also examined. Part III brings the issues into the present
institutional framework in New Zealand by examining the policy governing
developments such as that proposed for the Chatham Rise. It concludes the
study with a recommendation of how risks or implications identified in
Part II may be incorporated into policy.
"The need to augment or maintain our mineral base [has now lead] to the oceans - earth's last mineral frontier." (Barney, 1980, p.vii)
CHAPTER ONE

THE CHATHAM RISE PHOSPHORITE RESOURCE

1.1 HISTORY OF EXPLORATION AND PRESENT INTEREST

Study of the geology of the Chatham Rise has proceeded in sporadic attempts since phosphorite nodules were first recovered from the Rise by Reed and Hornibrook in 1950. Their report, in 1952, provided a description of the sediments and topography relating the paleogeography of the Rise to the rest of New Zealand. Norris (1964), then of the New Zealand Oceanographic Institute (NZOI), was the first to attach economic value to some of the sediments - particularly the glauconite and "phosphate" nodules. He assembled a fairly detailed picture of the sediments and the geological history of the Rise, mostly from information obtained during two cruises by NZOI over the period 1960-63.

Interest in the Chatham Rise phosphorite resumed again in 1967 when Global Marine Inc. of California obtained a "prospecting warrant" for a large area covering the entire Rise from 175°W to 175°E (figure 1.1). In January, 1968, Global Marine Inc. conducted reconnaissance exploration to further define the commercial potential on the Chatham Rise. Samples were sent to the Department of Mineral Technology, University of Otago, and the New Zealand Fertilizer Manufacturers' Research Association (NZFMRA) for studies, financed by Global Marine, on the distribution and beneficiation of the phosphorites. The deposits were shown to be distributed in an east-west belt along the crest of the Rise in "significant" concentrations.

Beneficiation tests were concerned with processing the Chatham Rise phosphorite to single superphosphate and test results were only
Figure 1.1. Map of the Chathan Rise showing license areas formerly held by Global Marine Inc. (USA) and JBL Exploration (NZ) Ltd, and the area presently under license to Fletcher Challenge Ltd. (Source for Global Marine and JBL areas: Earth Scientists Pty. Ltd. Report, 1973. Source for Fletcher Challenge license area: GeoResearch Associates, 1981.)
marginally satisfactory. This may have been the reason why Global Marine did not renew its prospecting warrant and no further interest in the area has been expressed by them.

In 1973, after another gap in activity, JBL Exploration (NZ) Ltd., commissioned a study using the data compiled earlier by NZOI and Global Marine Inc. The report, by Earth Scientists Pty. Ltd., painted "a potentially very valuable" deposit and spurred JBL to obtain exploration rights over the area (figure 1.1). Their optimistic (turnaround) assessment of Global Marine's data seems to be related to research, ongoing at that time, into use of the Chatham Rise phosphorite as a direct application fertilizer. Additional surveys and feasibility studies were quickly proposed but failed to materialize as JBL Exploration declared bankruptcy later in 1973.

Activity resumed once again as NZOI began its own detailed investigation in 1975, conducting four cruises by 1978. This produced the most detailed picture to date - a 3-D distribution pattern of the deposits from photographs and sub-surface cores (Cullen, 1978a; Cullen and Singleton, 1977). This new information and the dwindling supply situation with New Zealand's traditional phosphate sources combined to make the Chatham Rise phosphorites an attractive prospect. In addition, Cullen (1978b) presented some detailed analyses of the associated uranium and glauconite with the suggestion that they may also be available in commercial quantities. The stage was set for resource exploitation.

With an eye toward the phosphorite resource, an "Agreement for Scientific and Technological Co-operation between West Germany and New Zealand" was signed in 1976. The first cruise, on the German vessel
R/V Valdivia was organized in 1978 and funded by the German government, through its Federal Ministry of Research and Technology. Representatives on board were from one of its departments, the West German Federal Institute for Geosciences and Natural Resources (BGR)* and from the New Zealand Department of Scientific and Industrial Research (DSIR), mainly scientists from NZOI. The results from this cruise encouraged Challenge Corp. Ltd., (now part of Fletcher Challenge) to apply for an "exploration license" over the Chatham Rise in 1980. A second, more intensive exploration cruise followed in 1981, using a larger German vessel, the R/V Sonne and concentrated on the area of the Rise between longitudes 179°E and 180°.

The cruise was again funded mostly by the German government and managed by its research arm, BGR. Fletcher Challenge Ltd. and the DSIR both contributed funds to the cruise and their representatives were on board. West German commercial interest was also represented on the Sonne with participants from Preussag A.G. and Saltzgitter A.G. present. These two industrial giants, together with Metallgesellschaft, form an exploration consortium, AMR*. This consortium is involved in other deep ocean mining projects in the equatorial Pacific (manganese nodules) and the Red Sea (metalliferous muds). It appears that in preliminary negotiations with Challenge Corp. Ltd., the full consortium was involved. By 1981, however, Metallgesellschaft had pulled out leaving Preussag and Saltzgitter as the main German interest.

Near the end of the Sonne cruise, in May 1981, Fletcher Challenge was granted a mineral license under the Continental Shelf Act 1964 for three

* BGR - "Bundesanstalt für Geowissenschaften und Rohstoffe"
* AMR - "Arbeitsgemeinschaft meerestechnisch gewinnbare Rohstoffe"
years with the right of renewal for a further three-year term. The license covered an area of 193,330 km², most of which was surrendered later that year, under the terms of the license. The present license covers an area approximately 70,389 km² (figure 1.1 and 1.2). Following this, Preussag and Saltzgitter initialled a "Heads of Agreement" with Fletcher Challenge to signal their mutual interest in the project and to conduct studies (on paper), of technological and economic feasibility. Costs of these studies have been shared as 75% Fletcher Challenge and 25% Preussag and Saltzgitter. The project is currently at this stage. It is anticipated that results of the feasibility studies will be assessed by the joint venture early in 1983 whereupon a decision to mine or not will be made. If the review is favourable, pilot test mining will be the next step.
Figure 1.2. Detailed area of the Chatham Rise presently held under mineral license by Fletcher Challenge Ltd. (Source: GeoResearch Associates, Wellington (1981).)
CHRONOLOGY OF EVENTS LEADING TO PROPOSED
CHATHAM RISE MINING PROJECT.

1873-76  First phosphorite nodules recovered during the HMS Challenger Expedition.

1950  Reed and Hornibrook, of the New Zealand Geological Survey, aboard the RRS Discovery II, recover sediment samples from the Chatham Rise.

1960-63  Two cruises to obtain geological information conducted by NZOI.

1968  Global Marine Inc. (USA) issued "prospecting warrant" and conduct exploration cruise. No further interest expressed.


1975-78  Four cruises to obtain information on deposits conducted by NZOI.

1976  Agreement of "Scientific and Technological Co-operation" signed between West Germany and New Zealand.

1978  Joint survey conducted, using R/V Valdivia and funded by the West German government. Co-operative between West German Federal Institute for Geosciences and Natural Resources (BGR) and NZOI.

May, 1980  Challenge Corp. Ltd., (now part of Fletcher Challenge Ltd.) applied for an "exploration license" over the Chatham Rise.

March 30-May 27, 1981  Joint exploration cruise using R/V Sonne. Representatives included BGR and NZOI but commercial interests play a major role (Preussag, Saltzgitter and Fletcher Challenge Ltd.). The German Government provided most of the funds.

May 21, 1981  "Mineral license" granted to Fletcher Challenge Ltd. under the Continental Shelf Act 1964. License has a three year term with renewal rights for a further three years.

October 1, 1981  Most of license area surrendered under terms of the Act. New license area is 70,389 km².

January-February, 1983  Results of economic and technologic feasibility studies to be received by commercial interests for a go/no go decision on mining.
1.2 RESOURCE DESCRIPTION

1.2.1 Marine Phosphorite Formation

Phosphorite is a sedimentary deposit comprised principally of phosphate minerals (Pettijohn, 1957). Most of those minerals are a variety of apatite, $\text{Ca}_5(\text{PO}_4)_3$, the most common of which are fluorapatite $\text{Ca}_5(\text{PO}_4)_3\text{F}^-$, chlorapatite $\text{Ca}_5(\text{PO}_4)_3\text{Cl}^-$ and hydroxapatite $\text{Ca}_5(\text{PO}_4)_3\text{OH}^-$. The most favourable conditions for the formation of phosphorite occur in relatively shallow water of less than 330 m depth (Bromley, 1967). It is generally held that phosphorite formation is associated with upwellings of cold phosphate-rich waters onto a shallow platform. This influx results in an environment of high biological productivity and eventually, the formation of organic rich sediments as the organisms die and sink to the bottom. The interstitial waters of the sediments become enriched as phosphate leaches from the organic remains (Blatt et al., 1977). From this stage, there exists considerable debate about the formation of phosphorites. Two main theories (which may not be mutually exclusive) have been proposed.

One theory is that primary deposition occurs as direct inorganic precipitation of calcium phosphate. This usually results in the formation of laminae or nodules of phosphorite. The second involves replacement or phosphatization of various forms of calcium carbonate ($\text{CaCO}_3$) such as limestone and chalk, converting it to carbonate fluorapatite (Cronan, 1980). The phosphatized pieces, or beds, may take the shape of the "host" or break into pieces of various size. The deposits become lithified and subject to various geological processes depending on their environment of deposition.
The Chatham Rise phosphorite deposits differ from most world examples in that they occur on an eastern continental margin rather than a western margin (figure 1.3). As most phosphorites, however, the deposits are located on a submarine shelf or plateau, such as the Chatham Rise, in low to mid latitude areas. The upwelling necessary for the formation of phosphorites on the Rise was probably caused by deep flowing currents being forced up over the shallow platform. Indeed, during the Tertiary, when the deposits were formed, sea level was lower than at present. This large, fairly shallow, "humpback" structure would have intercepted the cold, deep Antarctic current, forcing the flow over the Rise.

Figure 1.3. World wide distribution of sea floor phosphorites (from Kent, 1980, p.19).
Several modes and ages of phosphorite formation have been proposed for the Chatham Rise. The "erosional" theory first suggested in a general form by Reed and Hornibrook (1952) and since advanced by Cullen (1975) is supported here. This has been disputed by Pasho (1976) who has proposed a later age of phosphatization followed by uplift and subaerial erosion to form the nodules but subsequent dating and chemical analyses do not support this more elaborate method of phosphorite formation.

Cullen (1980) has determined that phosphorite formation occurred on the Chatham Rise in the Middle to Late Miocene - about 15-5 million years ago. He suggests that it is the result of replacement of older limestone (Lower Miocene) and chalk (Upper Oligocene) deposits. These sediments were then reworked, possibly due to changes in the flow of the Antarctic current or in sea level. The non-phosphatized limestone and chalk were winnowed away and the heavier phosphatized fragments were concentrated. The phosphorite, spanning 10 million years, remains as a lag deposit of nodules and fragments (figure 1.4).

1.2.2 Chatham Rise Deposit Description

Distribution:
The Chatham Rise is a large submarine plateau extending to the east from the Banks Peninsula of the South Island for 500 nautical miles (926 km) to a short distance beyond the Chatham Islands. Here, the broad plateau breaches the surface, dropping off fairly steeply beyond the islands. The general structure of the Rise is a function of repeated emergences and submergences over geological time with the most recent submergence following the last glacial period (with the subsequent rise in sea level).
Figure 1.4. Schematic of surficial stratigraphy of central Chatham Rise. (From Cullen, 1980, p.142.)
The platform has a fairly flat crest defined by the 500 m depth contour line, dipping steeply to the north to depths of 3000 m and more gently to the south. It is along the crest of the Chatham Rise that the phosphorite nodules are situated. They occur between longitudes 177°E and 177°W and latitudes 43°S and 44°S with their largest accumulations around the 180° meridian (Pasho, 1976). This general "belt" of occurrence measures about 480 km by 50 km wide and is situated in about 400 m of water.

Early reserve estimates by Global Marine Inc. placed phosphorite reserves on the Chatham Rise at approximately 135 million tons (Earth Scientists Pty. Ltd., 1973) but it is not definite to what area this number refers. During the Valdivia cruise, very detailed measurements taken within a 227 km² area produced a reserves estimate of 14.7 million tonnes. That figure was later extended to an area 10 nautical miles (18.5 km) wide on either side of the crest of the Chatham Rise, between longitudes 179°E and 180° and the total estimate proposed was 100 million tonnes (Cullen, 1979). Data from the recent Sonne cruise however, has whittled down this earlier estimate to 40 million tonnes "proven" in the mining area, 179°E to 180° and around latitude 43°30'S, an area measuring about 600 km². Although this is undoubtedly a conservative estimate, it will be used by the investors and, as such, will be used in this study. Mero (1965) has placed the ocean's 'economically' recoverable reserves of phosphorite at 30 billion tons. For comparison, world land reserves are presented in table 1.1.
Table 1.1. World reserves and resources of phosphate rock.
(From Higgins, in Syers and Gregg, 1981, p.52.)

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Concentration:
The concentration of the deposits along the Rise is defined in relative terms. The exposures of phosphorite nodules are described as "patchy" (Cullen, 1980) (plate 1) and the patches range in size from tens of kilometres across to just a few metres with patches sometimes occurring within patches. The patches, then, refer to all scales of concentration and are controlled by larger scale morphological features as well as
local relief patterns. Concentration is a difficult parameter to define because the nodules sit in a glauconitic sand/silt which varies in thickness from a few cm to about 150 cm (op.cit.). The nodules usually occur at the base of this sediment but are also found scattered throughout and on the sediment surface (plate 2). The nodule layer can therefore range from a few cm to 60 cm thick making them a highly variable target. This mixture of glauconitic sand and nodules is underlain by an older (Oligocene) semi-consolidated chalk or ooze "basement" (figure 1.4). A high resolution seismic device, the Huntec "boomer" used in the Sonne cruise allowed much of the immediate (up to 30 cm) subsurface to be delineated and also further highlighted areas of concentration within the mining area. Although the crest of the Rise is only gently undulating with slopes of less than 5°, the phosphorite appears to be concentrated in more rugged, hummocky areas with slopes approaching 10-15° and undulations 1-15 metres high (R. Falconer, pers.comm.).

From detailed measurements within an area of large scale concentration around the 180° meridian, Cullen (1978) has determined an average concentration of ±65 kg/m².

Size:
The description of the phosphorite deposits as nodules may be misleading in the implied similarity with manganese nodules - deposits of much different origin, composition and size. The large, bulbous manganese nodules average about 15-20 cm in diameter whereas the phosphorite nodules are much smaller. It may be argued that they are not nodules in the strict sense but fragments of phosphatized and partially phosphatized limestone and hence they are irregular shaped pieces, more like pebbles (plate 3). Their size is quite variable, ranging from a few mm to a couple of hundred mm across but it is thought the average lies somewhere between 20 and 40 mm (Cullen, 1980).
Plate 1: Bottom photo showing distribution of phosphorite nodules on sea floor. Base of photo approximately 1 metre. (All photos courtesy of D.J. Cullen, New Zealand Oceanographic Institute, Wellington.)

Plate 2: Core sample showing nodules lying on the surface and scattered throughout the underlying sediment. (NZOI photo.)
Plate 3: Cross-section of phosphorite nodule, a slightly larger than average size sample. Note the irregular shape and zonation from dark margin to paler centre. (NZOI photo.)

Plate 4: Bottom photo of nodules showing some bottom organisms such as large crinoids (C). Smaller cidarid echinoids are also present in the photo but not plainly visible.
Colour and Texture:

Most of the nodules are olive black to olive grey in colour, which is attributed to a thin veneer of glauconite, an iron magnesium silicate, that appears to coat most of the nodules. Some of the fragments have pitted and grooved exteriors or extensive fracturing attesting to the various organic and physio-chemical processes active in their submarine environment subsequent to their formation.

In cross-section there is a colour gradation from the dark exterior of the nodule to a lighter yellow-brown to grey-green centre (plate 3). This is a feature of the type of formation i.e. replacement or phosphatization of the original limestone. Replacement by carbonate fluorapatite is more intense at the exterior and decreases in intensity toward the interior (Pascho, 1976; Cullen, 1980) hence the colour zonation. As a result, phosphate content differs according to the size of the nodule.

Composition:

Cullen (op.cit.) has found that the larger (>64 mm) fragments, since they are often only partially replaced, generally have low $P_{2}O_{5}$ values - about 17-18%, (7.5% P). The smaller (<6 mm) particles have concentrations up to 24% $P_{2}O_{5}$ (10.5% P). The chemical analyses for eight samples are presented in table 1.2 and suggest an average $P_{2}O_{5}$ concentration of 21-22% (9.5-10% P). This average value has been determined in several independent studies including the first by Reed and Hornibrook in 1952.

Although the nodules contain many chemical compounds as well as major and trace elements, the important constituents other than phosphate are glauconite and uranium. Glauconite is a very common mineral in the sediments of the Chatham Rise. It appears to be a secondary mineral
derived from pre-existing rocks and occurs as a major constituent both in the sediment and within the nodules themselves. It occurs as dark green sand-size grains and as replacement and infillings of various shell fragments and skeletal material. It is also present as a thin dark veneer surrounding the nodules as a coating (Cullen, 1967) or perhaps as a rim replacement (Pasho, 1976) (plate 3). Norris (1964) has suggested the Chatham Rise glauconite as an excellent source of agricultural potash.

The presence of uranium in the Chatham Rise sediments was first investigated by Kolodny and Kaplan (1970). Marine phosphorites have long been recognized as an important source of uranium and the Chatham Rise deposits show much potential. The uranium content of the nodules is extremely variable but they generally contain between 150 and 250 ppm $\text{U}_3\text{O}_8$ with extremes of 512 ppm and 11 ppm also recorded (Cullen, 1978) (table 1.3).

A size/concentration relationship is suggested by Cullen with maximum uranium values present in the smaller (10-30 mm) nodules but more analyses are required to substantiate this correlation. At any rate, average values of between 150 and 250 ppm uranium are concentrations higher than that considered economic in most land deposits. The uranium may be extracted as a by-product of certain types of fertilizer processing. This aspect will be discussed in the following section.
Table 1.2. Chemical analysis of Chatham Rise phosphorites: major elements and compounds. (From Cullen, 1980, p.145.)

<table>
<thead>
<tr>
<th></th>
<th>Station H955 (Sample 1)</th>
<th></th>
<th>Station H955 (Sample 2)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>P₂O₅</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
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<tr>
<td></td>
<td>23.8</td>
<td>23.0</td>
<td>23.0</td>
<td>21.3</td>
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<tr>
<td>CO₂</td>
<td>5.4</td>
<td>9.2</td>
<td>10.9</td>
<td>14.5</td>
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<tr>
<td>H₂O⁺</td>
<td>3.5</td>
<td>3.2</td>
<td>3.1</td>
<td>2.4</td>
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<tr>
<td>H₂O⁻</td>
<td>0.44</td>
<td>0.33</td>
<td>0.32</td>
<td>0.37</td>
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<tr>
<td>SiO₂</td>
<td>11.2</td>
<td>7.4</td>
<td>4.5</td>
<td>4.0</td>
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<tr>
<td>Al₂O₃</td>
<td>1.0</td>
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<tr>
<td>FeO</td>
<td>0.49</td>
<td>0.32</td>
<td>0.23</td>
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<tr>
<td>Fe₂O₃</td>
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<tr>
<td>TiO₂</td>
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<td>0.02</td>
<td>0.01</td>
<td>0.04</td>
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<tr>
<td>MnO</td>
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<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>CaO</td>
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<td>44.0</td>
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<tr>
<td>MgO</td>
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<td>1.0</td>
<td>0.86</td>
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<tr>
<td>K₂O</td>
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<td>1.1</td>
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<td>0.59</td>
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<td>Na₂O</td>
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<td>0.88</td>
<td>0.89</td>
<td>0.81</td>
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<tr>
<td>SO₃</td>
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<td>1.7</td>
<td>1.6</td>
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<td>F</td>
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<td>2.9</td>
<td>2.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Cl</td>
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<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>

Columns 1,5: particles less than 6.5 mm
Columns 2,6: particles 6.5-13.0 mm
Columns 3,7: particles 13.0-26.0 mm
Columns 4,8: particles 26.0-52.0 mm
Table 1.3. Chemical analysis of Chatham Rise phosphorites: Trace element composition. (From Cullen, 1980, p.145.)

<table>
<thead>
<tr>
<th>Element</th>
<th>N877</th>
<th>N879(1)</th>
<th>N879(2)</th>
<th>N879(3)</th>
</tr>
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<tbody>
<tr>
<td>U</td>
<td>58</td>
<td>100</td>
<td>92</td>
<td>170</td>
</tr>
<tr>
<td>Th</td>
<td>2.7</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Pb</td>
<td>23</td>
<td>35</td>
<td>53</td>
<td>38</td>
</tr>
<tr>
<td>Hf</td>
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<td>&lt;2.0</td>
<td>&lt;2.0</td>
<td>&lt;2.0</td>
</tr>
<tr>
<td>Yb</td>
<td>&lt;1.0</td>
<td>3.5</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Er</td>
<td>&lt;0.6</td>
<td>3.7</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Ho</td>
<td>&lt;0.3</td>
<td>1.4</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td>Dy</td>
<td>&lt;0.7</td>
<td>4.8</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Tb</td>
<td>&lt;0.3</td>
<td>1.2</td>
<td>0.44</td>
<td>0.44</td>
</tr>
<tr>
<td>Gd</td>
<td>&lt;1.0</td>
<td>9.0</td>
<td>3.8</td>
<td>3.2</td>
</tr>
<tr>
<td>Eu</td>
<td>&lt;0.5</td>
<td>1.0</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Sm</td>
<td>&lt;1.0</td>
<td>8.2</td>
<td>3.6</td>
<td>3.9</td>
</tr>
<tr>
<td>Nd</td>
<td>11</td>
<td>18</td>
<td>7.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Pr</td>
<td>3.2</td>
<td>4.7</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Ce</td>
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<td>15</td>
</tr>
<tr>
<td>Ba</td>
<td>200</td>
<td>120</td>
<td>230</td>
<td>120</td>
</tr>
<tr>
<td>Cs</td>
<td>3.2</td>
<td>4.3</td>
<td>2.1</td>
<td>0.93</td>
</tr>
<tr>
<td>I</td>
<td>&gt;200</td>
<td>&gt;200</td>
<td>&gt;200</td>
<td>30</td>
</tr>
<tr>
<td>Nb</td>
<td>2.9</td>
<td>1.4</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Zr</td>
<td>160</td>
<td>48</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td>Y</td>
<td>35</td>
<td>84</td>
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<td>37</td>
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<tr>
<td>Sr</td>
<td>700</td>
<td>&gt;1000</td>
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<td>1000</td>
</tr>
<tr>
<td>Rb</td>
<td>60</td>
<td>&gt;100</td>
<td>40</td>
<td>14</td>
</tr>
</tbody>
</table>

(1) 1.16-6.35 mm size range
(2) 6.35-16.64 mm size range
(3) 16.64-64.0 mm size range
As earlier outlined, the type of phosphatization in the Chatham Rise deposits has been the replacement of calcium carbonate by carbonate-fluorapatite (the mineral francolite). This high degree of substitution of carbonate and fluorine ions in the apatite (Ca₃(PO₄)₂) lattice defines the Chatham Rise Phosphorite (CRP) as a very reactive phosphate. The presence of carbonate renders the compound unstable and it is more susceptible to solution in the soil than non-reactive rocks. Nevertheless, reactive types which are applied directly have a slower rate of release than non-reactive rocks which are processed into water-soluble fertilizers such as superphosphate (Gregg and Syers, 1982).

Figure 1.5. Phosphate fertilizer routes from phosphate rock. (From UN Fertilizer Manual, (1969) in Sheldon and Burnett, 1979, p.372.)
There are several options for processing phosphate rocks as illustrated in figure 1.5. Some of these will be discussed in the following paragraphs.

A) Direct Application Fertilizer:

Their solubility in the soil means reactive rocks can effectively be directly applied (all phosphate rocks could be directly applied but non-reactive rocks are not effective). Minor processing is necessary and the rock is generally wetted, granulated and dried before application. Their residual effect, slowly releasing phosphate over time, depends on the size of the granule and the amount applied, although the exact correlation is still being researched (Rajan and Saunders, 1982).

Aside from this condition of being finely ground, reactive rocks appear to be restricted to use on acid soils, those with pH <5.8.

As soil becomes less acidic and calcium levels rise, the reactive rocks become less soluble (op.cit.). The slow release/residual effect of reactive rocks also limits their use to areas where the P levels are already sufficiently high. The time lag in phosphate release (from 2 to 5 months) means they cannot produce the rapid effect necessary for improving or developing pastures. For this reason, they are more suitable to maintenance situations (Rajan and Saunders, 1982; Gregg and Syers, 1982).

Depending on the degree of substitution within the apatite structure, reactive phosphates can vary in reactivity. In 1977, a research program began at Massey University, Palmerston North to test CRP (9% P) against single superphosphate (10% P) and reactive rock from Sechura, Peru (13-14% P). As Gregg and Syers (1982) report, the field trials, conducted over three years in various locations demonstrated CRP to compare favourably with super. The first year of equal applications
showed no difference between yields. In the second year, twice the amount of CRP (70 kg P/ha) against super (35 kg P/ha) was applied and in the third year the same amount of super but no additional CRP was applied. The results at the end of the third year, clearly showed higher yields for CRP, demonstrating its beneficial residual effect. One implication of this residual effect is the option of applying it in good climatic conditions such as wet/warm weather for results in dry/colder weather. Trials comparing CRP with Sechura reactive rock are still in progress but preliminary results show CRP as demonstrating better residual effects (op.cit.) although the Sechura rock obviously is of higher quality. Although these results are promising, larger and more comprehensive trials are necessary to further establish the effectiveness of CRP. A five year program has just been instigated under Dr Bert Quin of the Ministry of Agriculture and Fisheries (MAF) to co-ordinate additional field trials in various areas of the country.

One additional point should be made about the use of reactive rocks. None of the types tested so far have had sulphur added - an element that limits productivity in New Zealand soils almost as much as phosphate. This means that reactive rocks will be limited to use on high sulphur soils or else sulphur will have to be added to the granulated rock. Practical methods of adding elemental sulphur to reactive rocks to make a manageable "biosuper" for aerial application are still being researched (finely ground sulphur is very explosive). There appears to be some progress with work on a "sulphur-anhydrite pellet" which can be added safely to granulated reactive rocks (Rothbaum et al., 1980 in Mauger, 1982). When these difficulties are resolved, it will allow reactive rocks to be used for a much wider range of conditions.
B) Processing to Single Superphosphate:

Single superphosphate ("super") is produced from ground phosphate rock by reaction with sulphuric acid. The major product is monocalcium phosphate which is completely water soluble (Quin, 1982). Traditionally, the phosphate has been non-reactive, high quality rock from sources within Oceania with recent imports from Florida. Superphosphate is the most widely used fertilizer in New Zealand.

The Chatham Rise rock could be made into a single superphosphate but it would have a low P content since CRP has a 9-10% P while the present rock phosphate used to manufacture super is of higher quality (16-17%). Processing CRP into superphosphate does not take advantage of the beneficial properties of reactive rocks and the super produced does not hold any special use.

C) CRP/Super Blend:

Another option for CRP is to granulate it and blend it with single superphosphate, resulting in a homogenous mix. Apparently, trials in North Carolina have been very successful using two blends of 25% and 45% reactive with super (Mauger, 1982). The blend would have the advantage of higher P content than either of the ingredients alone.

As well, Rajan and Saunders (1982) suggest that a blend could overcome the problem with reactives of having a time lag of 2-5 months before they produce a response. Mixing the two types would also allow sulphur to be incorporated with the reactive, insomuch as it is present in the super. This resultant reduction in sulphur could be a problem but many New Zealand soils have an oversupply anyway (B. Quin, pers. comm.).

D) Processing to Triple Superphosphate (TSP):

Triple superphosphate contains twice the P content of single
superphosphate, bringing it to 20% P. TSP is manufactured by the "wet process" as for super by reacting the phosphate rock with sulphuric acid to convert the calcium phosphate of the rock to phosphoric acid and calcium sulphate. The phosphoric acid is then mixed with additional rock phosphate, converting tri-calcium phosphate to mono-calcium phosphate, resulting in triple superphosphate. Trials carried out at New Zealand Fertilizer Manufacturers' Research Association (NZFMRA) have processed CRP into a top-grade TSP, separating out uranium in the process (D.J. Higgins, pers.comm.).

E) By-product Options:
As detailed in an earlier section, uranium is present in the Chatham Rise nodules at an average 200 ppm (0.02%), which by most standards constitutes commercial quantities. Indeed, marine phosphorites are considered an important world source of uranium (Finch et al., 1973; in Cullen, 1978b).

Uranium can be extracted as a by-product of fertilizer manufacture but this is confined to processes that produce phosphoric acid as an intermediate. Reaction of sulphuric acid with the phosphate rock releases the associated uranium which appears in the phosphoric acid produced (Derry, 1981). Recovery of uranium from phosphoric acid on a commercial basis occurs in the U.S.A. and part of Europe. At prices of around US$100/kg U,* it is an attractive bonus to fertilizer manufacturers.

If CRP is to be simply crushed and pelletized before application, it obviously will not be practical (not necessarily impossible) to extract the uranium. Recovery via processing to triple super and single super phosphate would be possible.

* Recent trends (during 1982) have shown a decline in most mineral prices and uranium market prices are now in the neighbourhood of US$50/kg.
F) Preferred Option:

It is difficult to select a preferred end use for the Chatham Rise nodules. Within New Zealand there are varied opinions as to the processing routes possible, let alone the wisest choice. This study proposes use of CRP as a direct application fertilizer and as second choice, blending CRP with single superphosphate. Although Fletcher Challenge has not announced its intentions for the phosphorite, it appears to favour the direct application option.

This option is supported by the following factors:

1) Preliminary trial results show CRP, applied directly, to have a good residual effect and to realize higher yields than equal amounts of super.

2) Its slow release (residual effect) means that it can be applied once every three years rather than proportionately every year for three years. This offers the consumer reduced application costs over that period and the option to absorb the initial expenditure in a good income year.

3) The lower cost of processing the CRP as a direct application fertilizer should mean a lower cost to the consumer. An overall cost comparison between super and CRP by Gregg and Syers (1982) is shown in Table 1.4. These figures, however, do not include the addition of sulphur which, if mixed with the CRP, could raise the costs.

4) A direct application fertilizer provides the consumer with an alternative which allows more flexibility and may be more
suitable for his/her particular situation.

Table 1.4. Cost comparison: CRP and Super (From Gregg and Syers, 1982, p.86.)

<table>
<thead>
<tr>
<th>Trial Data Assumptions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Ex works price of CRP = ex works price of superphosphate.</td>
</tr>
<tr>
<td>(2) An annual application of &lt;35 kgP, as superphosphate over three years would have given a lower yield than 70 kgP applied only once as CRP.</td>
</tr>
<tr>
<td>(3) Elemental sulphur applied in year 1 would supply adequate S over a three year period.</td>
</tr>
</tbody>
</table>

Case situation - 500 hectares, 143 km from nearest works.

(a) Superphosphate per year
- 412 kg - $121 tonne⁻¹ (35 kgP) 49.85
- Application $22 tonne⁻¹ 9.06
- Freight 2.88

\[
61.79 \times 3 = 185.37
\]

(b) CRP + Elemental S
- 745 kg CRP (70 kgP) 86.42
- 90 kg Elemental S 16.38
- Application (835 kg) 18.37
- Mixing 1.00
- Freight 5.85

\[
128.02 = 128.02
\]

Using (b), saving = 57.35

Total savings over 3 years = $28,675

Some disadvantages of this option include:

1) It is confined to acid soils (pH <5.8) and to maintenance (rather than improving) conditions. The dissolution of reactive rocks is affected by rainfall, rendering them unsuitable for low rainfall areas (op.cit.). At this stage no estimates of suitable farming
areas for CRP have been made. The acidic constraint apparently only exempts about 25% of New Zealand (B. Quin, pers.comm.). Areas which have been regularly topdressed and would require only a maintenance fertilizer also include a large proportion of this country. If no sulphur is added to CRP, its use will be further limited to areas regularly topdressed with soils of high S retention (Gregg and Syers, 1982). Obviously, it is difficult to define the market for CRP at this early stage. However, an intuitive figure from Dr Bert Quin, based on preliminary field trials is 25% of the total market. This would be an eventual status however and he suggests an "introductory" market share of about 10% until its success is established.

2) There is a lag effect on response of CRP of 2-5 months.

3) The mechanical style processing for CRP will not allow uranium, a profitable by-product otherwise, to be extracted.

The other attractive option for CRP is to blend it with super. Because of the features noted earlier for such a mixture, it will be suitable for more varying conditions and hence comprise a larger share of the market. CRP may be used for both options.

In whatever form, phosphate is a necessary ingredient to New Zealand soils since they are naturally deficient in that element (National Research Advisory Council, 1978). As yet no substitutes for phosphatic fertilizer have been developed. Supply of phosphate has not been a problem though since healthy stocks exist on land. But as for some other minerals, development interests have lead from traditional land sources into the oceans. The next chapter examines the technology for retrieving such deposits from the sea floor.
CHAPTER TWO
DEEP OCEAN MINING

2.1 HISTORY OF DEVELOPMENTS IN DEEP OCEAN MINING

Submarine nodules were first recovered from the sea floor during the *HMS Challenger* Expedition, 1873-1876. Manganese nodules were dredged from the Atlantic, Pacific and Indian oceans and phosphorites were retrieved off the coast of South Africa (Murray and Renard, 1891). Although phosphorites have since been discovered in several submarine locations it has been the increasing interest in widespread manganese nodules that has led to the present state of the art of deep ocean mining.

After their initial discovery, study of submarine nodules continued sporadically until the 1960s. It was the work of a research student at Berkeley that sparked the interest of the mining community. He examined the technologic and economic feasibility of mining and processing manganese nodules for their manganese, nickel, copper and cobalt metals (Mero, 1960; 1965; 1977). His results demonstrated the potential value of the nodule resource and attracted the attention of various nations, notably the United States, West Germany, France, Japan and Canada.

Since then, extensive investigation has occurred in a manganese nodule belt, known as the Clarion-Clipperton fracture zone, just north of the Equator in the Pacific and to a lesser degree in the South Pacific and Indian oceans. Pilot mining was conducted in 1970 by Deepsea Ventures Inc. on the Blake Plateau off eastern United States; in 1972 by the Hughes Glomar Explorer in the Pacific (Goldsby, 1977); and, in 1979 by
the Deepsea Miner II, again in the Pacific (Cronan, 1980). Industry sources once maintained that commercial mining would commence before 1980 but changes in market forces have delayed its incipience. More recently, delays can be attributed to a breakdown in International Law of the Sea negotiations concerning regulations governing deep ocean mining outside any one country's jurisdiction.

Work on recovering submarine phosphorites has not proceeded with the same inspiration or drama. This is a result of the large reserves of phosphorite on land which keep the value of the mineral low and means the prize from ocean mining is not nearly as glamorous as for manganese nodules. There were two attempts to establish commercial phosphorite mining offshore California in the early 1960s. The operations, one by a subsidiary of Union Oil Co., and the other, a joint effort by Lockheed Aircraft Corp. and International Minerals and Chemical Corp. (IMC) were both aborted (Tronsden and Mead, 1977). Both deposits were intended for export and apparently neither venture proved as profitable as envisaged, which may be related to the presence of large land deposits in the United States. There does appear to be renewed interest in these California deposits for possible development near the end of this century (op.cit.).

Other developments in deep ocean mining involve metalliferous sediments - deposits with high concentrations of iron, manganese, zinc and copper. These sediments are associated with submarine volcanic activity and are situated over much of the sea floor but the greatest concentrations found to date have been in the Red Sea (Cronan, 1980). The deposits occur in pockets, or "deeps" and in some locations, are still forming, giving them very high economic potential. Detailed exploration and mining feasibility studies using the R/V Valdivia (one of the German
vessels used on the Chatham Rise), have resulted in delineating large reserves. In 1979, Preussag of West Germany (also involved with the Chatham Rise project) successfully tested their mining technology in the "Atlantis II" deep of the Red Sea and pilot trials are continuing. (New Scientist, 19 February, 1981; Mining Magazine, August, 1981).

Indications are that a commercial operation has been approved but the starting date has not been disclosed. Although such a mining system would be technically different from nodule mining, a commercial operation could certainly supply much information on logistics and operational aspects that would be applicable to other operations.

As previously mentioned, several nations have stakes in the race to develop and test suitable mining systems. The competitiveness of this situation should not be underestimated. In the case of the manganese nodules and metalliferous sediments in particular, the prize is a large one and the sophisticated technology required means there is much prestige involved. An expensive race is on among the countries and/or consortia who can develop the most successful mining methods. The participants in this "high tech" game are listed in table 2.1.
<table>
<thead>
<tr>
<th>Consortia involved in International Deep Ocean Mining</th>
<th>Interest</th>
</tr>
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<tbody>
<tr>
<td>1. Kennecott Copper Corp.</td>
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</tr>
<tr>
<td>Noranda (Canada)</td>
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</tr>
<tr>
<td>Consolidated Gold Fields (United Kingdom)</td>
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</tr>
<tr>
<td>Rio Tinto Zinc (United Kingdom)</td>
<td>10%</td>
</tr>
<tr>
<td>British Petroleum (United Kingdom)</td>
<td>10%</td>
</tr>
<tr>
<td>Mitsubishi (Japan)</td>
<td>10%</td>
</tr>
<tr>
<td>2. Ocean Mining Associates (OMA)</td>
<td></td>
</tr>
<tr>
<td>Essex Minerals Company (a US corporation owned by US Steel Corp.)</td>
<td>33 1/3%</td>
</tr>
<tr>
<td>Union Seas, Inc. (a US corporation owned by Union Minieres, S.A., of Belgium)</td>
<td>33 1/3%</td>
</tr>
<tr>
<td>Sun Ocean Ventures, Inc. (a US corporation owned by Sun Co., Inc.)</td>
<td>33 1/3%</td>
</tr>
<tr>
<td>Deepsea Ventures, Inc. (a US corporation and service contractor to Ocean Mining Associates)</td>
<td></td>
</tr>
<tr>
<td>3. Ocean Minerals Company (OMC)</td>
<td>NA</td>
</tr>
<tr>
<td>Lockheed Missiles and Space Company, Inc. (subsidiary of Lockheed Aircraft Company, USA)</td>
<td></td>
</tr>
<tr>
<td>Amoco Minerals Company (subsidiary of Standard Oil of Indiana, USA)</td>
<td></td>
</tr>
<tr>
<td>Hilliton International Metals, B.V. (subsidiary of Royal Dutch Shell, Netherlands)</td>
<td></td>
</tr>
<tr>
<td>Papendrecht (subsidiary of Bos Kalis Westminster Dredging, Netherlands)</td>
<td></td>
</tr>
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<td>4. Ocean Management, Inc. (OMI)</td>
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</tr>
<tr>
<td>INCO, Ltd. (Canada)</td>
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<td>SEenco, Inc. (USA)</td>
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<td>AMR Group (West Germany)</td>
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<td>Metallgesellschaft A.G.</td>
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<td>Salzgitter A.G.</td>
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<tr>
<td>Rheinische Braunkohlenwerke A.G.</td>
<td></td>
</tr>
<tr>
<td>DONCO Group (23 Japanese companies led by Sumitomo)</td>
<td>25%</td>
</tr>
<tr>
<td>5. CLB Consortium (to be disbanded after mining system test)</td>
<td>NA</td>
</tr>
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NA = Not available.

Table modified from list included in Congressional testimony by
Dr. Wayne Dubs, Kennecott Copper Corp.
2.2 TECHNOLOGY DESCRIPTION

2.2.1 Design Options

Recovering sand and gravel or placer deposits in nearshore areas has resulted in the development of many types of dredge. The design must be altered considerably, however, when the mining target is in much deeper water, from 300-5000 metres.

There are two main features of deep ocean deposits which demand more complex methods of retrieval (Cronan, 1980). One, greater depths mean the material must be lifted through a much longer water column, thereby subjecting the system to physical and mechanical forces quite different from shallow water operations. Much more energy is required. Second, most nodule deposits are relatively thin, surficial (more or less) layers rather than bedload or seams. Therefore a collecting device must skim the surface taking in as many nodules, and as little else, as possible. It must also be capable of covering a large areal distance to compensate for the meagre pickings at each site.

The design particulars to adjust for these differences depend on the type of system used. The techniques developed thus far range from simple adaptations of conventional techniques to the very complex. Many of the details, as well as more recent innovations are not available - a direct result of the competitiveness that surrounds the industry. Two basic methods are commonly discussed in the literature and will be presented here (figure 2.1). The second method will then be described in greater detail as it, or some variation on the basic design, is envisaged for mining on the Chatham Rise (R.J. Bentley, pers.comm.).
A) Mechanical Systems:

The most popular mechanical system promoted is the Continuous Line Bucket (CLB) dredge (figure 2.1(a)). As illustrated, the principle is fairly basic: a huge loop of cable circulates from the ships to the sea floor where the buckets scoop up the deposits, carry them back to one ship where they are unloaded and, then, the buckets return to the dredge line (via the other ship to avoid entanglement).

Although the system is not very complex, certain aspects need careful attention such as bucket design and capacity, and cable strength. This method has been tested however, and has shown high potential for nodule recovery at 3755 m (Mesuda et al., 1971).

Of all the methods proposed, the CLB system entails the lowest costs and the lowest energy requirements. Some authors (Gauthier and Marvaldi, 1975 in Cronan, 1980) see it as a viable option in areas where the hydraulic system would not attain a sufficient rate of production without expanding the collecting device beyond optimal size. In addition, the independent parts of the CLB means that any sediment clogging could be attended to without grand scale interruption as would occur with the hydraulic system. Although this latter merit would apply to the Chatham Rise case, it is doubtful that the production rate used on the Chatham Rise will be high enough to warrant the use of buckets.

One of the major criticisms of the CLB system is that the buckets would not be as fine-tuned to the deposits as the collecting vehicle of the hydraulic system, (Livesay et al., 1978). In areas of small nodules and patchy distribution, such as the Chatham Rise, nodule pick-up using buckets may not be very efficient. Spillage of fine sediment out of the buckets as they travel back to the ship is also a disadvantage as compared with the fully enclosed pipe lift system.
Figure 2.1. Representation of the two main methods currently proposed for deep ocean mining:
A) Continuous line bucket system using two ships
B) Hydraulic dredging system
b) Hydraulic Systems:

The hydraulic system is comprised of a nodule collecting device at the sea bottom, attached to a pipe for lifting the nodules, and a mining ship at the surface (figure 2.1(b)). There are two variations of this system currently proposed: one system uses submerged pumps to lift the nodules (hydraulic suction dredging) and the other uses compressed air.

The second method, the air lift system is more elaborate. It operates by introducing compressed air into the main pipe, creating a density contrast between the fluid in the pipe and the sea water. The resultant force causes an upward flow of fluid eventually carrying nodules to the surface (Smale-Adams and Jackson, 1978).

This system has the highest energy demand of all the methods proposed and typically the highest costs. Apparently, the important advantage of the airlift system over the cheaper hydraulic suction system is that there is just one large pump involved in the former and hence, no moving parts i.e. attached pumps, below the water surface. However, for mining operations at intermediate depths (300-1000 metres) such as on the Chatham Rise, this advantage would be downplayed since multistage pumping stations would probably not be required. In addition, Livesay et al., (1978) express concern over the unexplored behaviour of 3-phase slurries (air/water/solids) and suggest some questionable aspects of the air-lift system.

For these reasons, some of which are inherent "faults" in general design or else inappropriate or unnecessary features for the Chatham Rise environment, hydraulic suction dredging appears to be the most suitable technology for the Chatham Rise and will be considered in greater detail in the following section. Indications from Fletcher Challenge Ltd., also
suggest that it is likely to be the chosen mining system. It also appears to be the preferred technology for manganese nodule mining, endorsed by such prominent researchers in the field as Mero, 1977; Livesey et al., 1978; Cronan, 1980; and Welling et al., 1980.

2.2.2 Hydraulic Suction Dredging

This method involves a collecting vehicle at the sea bottom and a pipe and pump system to contain and lift the nodules. At the surface is a mining ship to control operations, store the nodules, and possibly transport them to port. Alternatively, a barge would deliver the nodules to shore. The general design of these features will now be discussed and where possible, they have been tailored to the Chatham Rise case.

A) Collecting Vehicle:

The collecting vehicle or "miner" must satisfy several functional requirements (Livesey et al., 1977; Cronan, 1980) (figure 2.2). It must be large enough to collect the determined amount of nodules yet not so big that it loses its maneuverability. The aperture must be optimized to take in more nodules than associated sediment and be capable of a rough sorting process. As much of the non-target as possible must be discarded before the costly trip to the surface. The collecting vehicle should therefore be designed and constructed for high efficiency and optimization of these parameters.

The size suggested for the collector to be used on the Chatham Rise is 8 m (length) by 10 m (width). The aperture will span most of that width but the size of the aperture itself is difficult to predict. For the Chatham Rise, the nodules are generally very small (average 20-40 mm) but some samples reach 150 mm. The preliminary indications of an inverse relationship between size and P concentration (Cullen, 1980) suggests that
Figure 2.2. Three suggested designs for a collecting vehicle:
1) sled-type miner (Welling et al., 1980), 2) Lockheed
design with arm for nodule screening (New Scientist,
19 March, 1981, p. 737), 3) vacuum-cleaner type (op. cit.).
the smaller size range may be most desirable. For efficiency sake, however, the collector may be designed to gather as many nodules as possible — whatever the size. Allowing large nodules to enter may also permit undesirable pieces such as glacial erratics and boulders present on the crest of the Rise. Dredging such pieces will contribute to the wear and damage of the collector as well as it being expensive to lift to the surface pieces which have no economic value.

At the other extreme will be design specifications to cope with the fine sediment that overlies, underlies and is scattered throughout the nodule layers. These sediments — unconsolidated glauconitic sand/mud and semi-consolidated chalk/ooze will be easily picked up with the nodules. The sandy/muddy layer can range from a few cm to 150 cm thick with the nodules scattered throughout but predominantly at the base. Apparently, the miner will dig into this sediment to a depth of 500 mm (50 cm) so fine material will most certainly enter the dredge head. Aside from being costly to transport to the surface since they detract lift space from the nodules, they may cause a problem by clogging the aperture or other parts of the collector. To contend with the accompanying material — both coarse and fine factions, the collector must be capable of a rough sorting process — perhaps by weight, to expel the unwanted sediment.

Crushing the nodules in the collector before the trip to the surface is another design option. This seems particularly important if nodules are greater than 60 mm but since the Chatham Rise nodules are much smaller, crushing is probably not warranted. Generally, the best design for the collector seems to be the simplest so that potential trouble can be avoided.

Many of the patented designs have sensors and controls mounted on the
collecting vehicle (Welling et al., 1980). A television camera allows for more accurate navigation and observations of the sea floor. Seismic devices, such as a side-scanning sonar would also be useful in mapping the topography in the mining area. A cable from the ship to the collector provides links for the television and sonar as well as transmit power for its "inhouse" functions of picking up and sorting the deposits. The collector, then, is controlled directly from the mining ship. Some proposals have been made for self-propelling, programmable vehicles for mining but, apparently, tests by Lockheed using such a device have not been successful. The simpler, towed vehicle appears to be the favoured design. It is suggested that the miner will travel at a speed of one knot, allowing it to cover about 1.8 km of sea floor per hour.

B) Pipe and Pump System:
As originally described for these purposes by Mero (1960), the hydraulic suction dredging system involves a submerged centrifugal pump(s) placed along the dredge pipe. The number of pumps would depend on the water depth of the particular operation. The intermediate depths of the Chatham Rise mining area (about 400 m) suggests that only one submerged pumping station will be required -- as opposed to the more elaborate requirements of the deeper manganese nodule mining operations. By having the dredge pumps submerged, the barometric limitations of centrifugal pumps are overcome and the seawater/nodule mixture can be lifted, with good control and continuous flow, to the surface. Besides its function as a conduit for the nodule slurry, the pipe must also provide the power and communication links from the ship to the collecting device.

As shown in figure 2.3(a), Mero favours a dredge system supported by floats rather than suspended directly from the ship as illustrated in (b). One main float tank would house the centrifugal pump and another
Figure 2.2 Two proposals for ocean mining systems: A) Mero (1960) design (from Mero, 1964, p.262), B) Welling et al. (1980) design.
float would sit at the surface as a stabilizer to keep the dredge afloat. This detached system would prevent surface waves from affecting the dredge pipe (Mero, 1965; 1977).

The proposal of a hydraulic dredging system by Welling et al., (1980) is slightly different from that suggested by Mero. The former specify that the pipe extend directly from the ship with a flexible linkage situated at the end, just above the sea floor, connecting the lift system to the collecting vehicle (figure 2.3(b)). As illustrated, the large apparatus at the end of the pipe string is the "buffer". This device serves the same purpose as Mero's "main float tank" in that it houses the hydraulic power unit and the electrical apparatus. The buffer, however, can also supply temporary storage for the nodules as they are transferred from the collecting vehicle. The buffer then feeds the slurry into the pipe and it is lifted to the mining ship.

The strong point of the Welling et al. design is the directly suspended pipe. It is more accessible for repairs and maintenance and, as well, this design can be accommodated by a retro-fitted drillship. Although Mero's design would prevent a lot of surface wave interference, the flexible linkage of the Welling design could probably serve the same purpose.

Although the power requirements of the hydraulic lift using submerged pumps is less than the air-lift option, the energy demand is still much higher than for conventional dredging. Mero (1964) maintains that power for the dredge motor can be taken from the main propulsion motors of the ship. Since during dredging very little propulsion is required, there should be sufficient power available. If not, an auxiliary generator(s) would have to be installed. Mero uses the conversion that for 75%
efficiency, 0.778 hp per foot of depth is required. For the Chatham Rise operation, 1250' x 0.778 hp equals about a 1000 hp system or about 746 KJ/sec. An average drillship used for oil exploration and/or production has this capability although this requirement does seem conspicuously low.

Another estimate of the power requirements for hydraulic "hoisting" is provided by Tinsley (1979) and appears slightly more realistic. He relates the horsepower needed to the rate of production arriving at a ratio of hp:TPD of .86 (and a higher ratio of .91 for deeper depths). Although the depths are much greater than for the Chatham Rise operation, using the lower ratio (.86) this places the power requirement at 1720 hp. Considering this and the low figure of about 1000 hp using Mero's method, a likely estimate of power requirement is probably 1500 hp.

C) Mining Ship:

There are several options for a ship suitable for deep ocean mining and these can be modified from those used for more conventional functions. Some authors (Livesay et al., 1978) suggest using petroleum drillships. The pre-pilot mining tests in 1978 by Preussag on the metalliferous muds of the Red Sea were conducted using an oil exploration drillship (Mining Magazine, 19 August, 1981). Storage of the deposits prior to off-loading onto a barge or other carrier may present a space problem but not an engineering impossibility. These vessels offer several features such as dynamic positioning* for precise positioning and navigation of the collecting device. This feature could minimize mining in barren areas.

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* dynamic positioning as described by Welling, 1980, p.142: "A sonar transducer on the ship hull obtains distance from transponders several miles apart. The information is fed into a computer which then commands the ship's propulsion and thruster systems, allowing the ship to navigate accurately within a few feet of a prescribed course."
and maximize coverage of areas of high nodule density. The relationship between economic return and accurate navigational capabilities is obvious. A drillship would also come readily equipped to handle pipe storage and use.

The Deepsea Miner II used in pilot mining trials during 1979 is a 20,000 tonne converted ore carrier. This is another option for a mining ship. The information from Fletcher Challenge Ltd. is that a ship may be available for the Chatham Rise operation that is capable of many functions. This multi-purpose ship could be used for petroleum exploration in the deep waters of continental margins; to mine the metalliferous muds in the Red Sea area; and to extract nodules from the sea floor.

Whatever design and size is decided, the ship must obviously be weather-hardy and able to remain at sea for long periods. Crew and supplies could be transported to the ship using smaller supply vessels or helicopters or else, the ship could return to port at regular intervals for these purposes.

D) Ocean Transport:

Ironically, designing a system to extract minerals from great depths can appear quite simple when one examines the problems associated with transferring the dredged material to another vessel at sea. Preventing collision under the sometimes severe and always unpredictable Pacific over the Chatham Rise will be a major task. The fact that the two vessels must come very close to ease the transfer of material demonstrates the value of the dynamic positioning system discussed earlier. The receiver, probably a barge, would be more difficult to control. This seemingly straight-forward aspect of the operation may well be the most dangerous. This problem is frequently discussed in literature concerning
manganese nodule mining. In the Pacific region particularly the large
distances to the nearest port (2000-3000 km) makes the barge system
about the only option.

For some of the California offshore operations, pipelines to shore have
been suggested for deposits about 40 km offshore. Barges are also
suggested for these and more distant deposits, but scarcity of barges
for purchase and hire is noted (Tronsden and Mead, 1977). The number
of barges and tugs required depends upon the production rate of any
operation.

For the Chatham Rise mining, the two viable options appear to be use of
barges as discussed above, or use of the mining vessel for transport to
port. This second option entails the ship leaving the mining location
every three or four weeks to make the 24 hour, about 600 km, trip to port.
There it would unload the nodules, undergo maintenance and take on
supplies and new crew, all of which may require a week.

E) Offloading:
Several technologies for offloading are available. For the nodules off-
shore California, Tronsden and Mead (1977) consider two basic options:
One uses dredge pumps to move the nodule slurry from the ship or barge
to port and then along pipelines to the processing plant - situated near
the port. The other option uses buckets to move material onto hoppers
and eventually conveyers which take it to the plant. It has not been
disclosed which method will be used in the Chatham Rise case but since
the first option, using dredge pumps, comes with industry recommendations,
it is likely to be the preferred option.
This concludes a description of methods for retrieving minerals from the sea floor. It is interesting to note the surge of technological development in the past decade and the current state of the art of ocean mining. Of the methods discussed, it is suggested that hydraulic suction dredging will be used on the Chatham Rise and its technical features and requirements have been elucidated. The next chapter attempts to define some of the operating and economic considerations specific to a mining operation on the Chatham Rise.
CHAPTER THREE

CHATHAM RISE MINING OPERATION

3.1 INTRODUCTION

The intention of this section is to elucidate some of the operating particulars of a mining operation on the Chatham Rise. In conventional mining, many of these factors are garnered from previous experience and indeed, when dealing with land deposits and/or a proven technology, calculation of the mining particulars is relatively straightforward. However, when one enters the realm of deep ocean mining, all the rules change. The absence of a commercial mining precedent; the curious environment of the deposits; the novelty of the technology; and, the inherent competition, combine to make it difficult to obtain information. Paradoxically, the inordinate investment and risks involved in deep ocean mining places much importance on those very estimates and details that are difficult to produce.

This basic limitation is magnified here because this is an independent study conducted outside the aegis of commercial investors, making information even more difficult to obtain. Another limitation stems from the timing of this research in that the Chatham Rise mining project itself is still evolving. Plans and details of the operation change, and reserve estimates are very transient data. In an effort to ameliorate the situation, this study has made liberal use of international, published literature on various aspects of deep ocean mining as well as maintaining contact with Fletcher Challenge and relevant government departments.

One conventional rule that remains intact is that mineral deposits vary considerably from place to place. Extrapolation of technical data from
the literature and the design of operating considerations must recognize the characteristics of a particular site and deposit. As well, economic considerations must account for relevant market forces. As a preface to examining mining particulars a description of the characteristics of the Chatham Rise mining site follows.
1.2 SITE CONSIDERATIONS

1.2.1 Topography

The crest of the Chatham Rise is outlined by the 500 m contour line but the license area itself is located in about 400 m of water. The crest is slightly convex and Norris (1964) suggests the Rise is a broad, anticlinal structure. The Rise contains several saddles, banks and channels but the discussion here will be confined to the crest of the Rise - the license area (see figure 1.2). The sea bottom here is undulating but never achieves greater than 150 m of relief, generally with slopes of around 5°, over its broad expanse. Therefore, no distinct or obstructive features are present within the area. On a more local scale, however, high resolution seismic data recently obtained during the Sonne cruise indicates a rough, hummocky terrain in the areas of phosphorite concentration. In this region, slopes approaching 10-15° occur and, relative to the gentle relief elsewhere on the crest, constitutes a rugged terrain. The collecting vehicle will have to be tailored for this type of sea bottom.

1.2.2 Currents

The size and relief of the Chatham Rise allow it to exert strong control over water movements in the area. This is apparently responsible for the lucrative fishing in the area and, indeed, the precipitation of phosphate at an earlier geological time and probably at present (Norris, 1964). A summary of existing information on the physical oceanography of the Chatham Rise area, prepared by Heath (1981), indicates some features which could directly affect a mining operation.

The Rise influences and is itself affected by the paths of several currents around the east coast of New Zealand, but just two main currents flow over the Rise (figure 3.1). The East Cape current from the north and the
Figure 3.1. Ocean circulation patterns in the south-western Pacific. The dashed line represents the 1000 m isobath. (From Heath, 1981, p.4.)
Southland Current from the south, intercept the submarine ridge and flow east parallel, along the crest of the Rise. Heath reports (from only two existing direct current measurements) that the mean speed (mean of two different depth measurements) is estimated at 0.15 m/sec. Current speed will be an important consideration in the design of the dredging pipes and determining the speed of the ship and the collecting device during dredging. They will also affect the dispersal of sediment placed in suspension by the mining. Temporal variability in the circulation patterns, already demonstrated for the Chatham Rise environment will be another important variable to consider. Obviously these aspects must be more closely investigated before mining commences. Apparently, several current measurements were made by Fletcher Challenge during the 1981 Sonne cruise but they are not yet available.

3.2.3 Weather

General information on weather patterns in the Chatham Rise area comes mostly from ship reports. Predominant wind directions on the Rise are northerly in the summer when anticyclones occur northeast of the Chatham Islands, and southwesterlies prevail in winter when anticyclones are centred east of the South Island (Browne, 1975). Estimates of wind velocity which are calculated from estimates of wave height, are biased by the small number of ship reports and the discrepancies between ships. Average wave heights on the Rise are apparently associated with winds from the northwest through the west to southwest. The heaviest swells are also from the west or southwest, originating in the southern ocean (I. Miller, pers.comm.).

Typically, the weather pattern, such as the incidence of anticyclones, is highly unpredictable. Winds of gale force may occur at any time and from any direction. In their report for JRL Exploration (NZ) Ltd., Earth
Scientists Pty Ltd., (1973) state that "very rough" and "high sea" states average only seven days a year on the Rise with a sea state of "rough" for 28% of the year. They conclude that weather would not be a limiting factor in a mining operation although it is not clear what parameters are accounted for in such descriptives as "rough" and "very rough". It is the contention here that the weather on the Chatham Rise will play havoc with a mining operation - as it does for many marine operations. Downtime as a result of the weather should therefore be accounted for in operating considerations.

As a final comment on the weather the Chatham Rise is situated near the northern limit for drifting Antarctic ice. However, it is doubtful that ice pans will be of sufficient frequency and size to constitute a major threat.
3.3 OPERATING CONSIDERATIONS

3.3.1 Rate of Production

An important factor in determining the production rate of a mineral deposit is quality. Quality embraces such features as nodule composition, concentration, and distribution on the sea floor. Ultimately, these features determine mining feasibility and the possible end use of the product.

The product potential of the Chatham Rise phosphorite has been examined in a previous chapter (1(3)) and several processing options described. For the purposes of this study, it is assumed that direct application fertilizer will be the preferred use. The production rate will be determined by examining the market for direct application fertilizer in New Zealand and in a later section, the operating and capital costs.

New Zealand presently imports about 1.2 million tonnes per year of rock phosphate (New Zealand Department of Statistics), mostly high quality material (16% P) from Nauru, and Christmas Island. Virtually all of this is converted to single superphosphate (9% P) which, in 1981, accounted for approximately 2.0 million tonnes. Dr Bert Quin, MAF, has suggested that direct application Chatham Rise phosphorite (CRP) could initially assume 10% of this market, gradually increasing to about 25% of the total fertilizer market. Since CRP has approximately the same concentration of phosphate as superphosphate (9% P), a 10% share amounts to about 200,000 tonnes per year. If sulphur is added to the CRP before application, the P content would decrease to about 7% and more of the phosphate nodules would have to be extracted to compensate. A production rate of 200,000 tonnes per year agrees with estimates received from Fletcher Challenge Ltd (R. Bentley, pers. comm.). All of these figures are naturally subject to change once operations commence depending upon how well CRP is
received by consumers and upon the costs of mining.

Debris (sandy muds, ooze, glacial erratics) will also be taken up by the collecting device. Although some sorting will occur in the device at the sea bottom, it is generally assumed that about one third of the total solids dredged will be debris (Tronsden and Mead, 1977). Therefore, to produce 200,000 tonnes per year of phosphate, 300,000 tonnes of material will need to be mined.

3.3.2 Proposals for mining

The type of mining operation proposed for the Chatham Rise has not yet been disclosed. Two options are proposed here and briefly described below.

1) Chartering a vessel equipped for deep ocean mining. It is envisaged that peripatetic ships capable of mining and petroleum drilling at large depths will become available in the future. Downtime, due to weather and technologic difficulties, will probably remove about four days from each working month. If the mining vessel is used to transport the nodules from the mine site to port, this would involve an additional seven days.

Assuming a 20 day month and a mining rate of 2000 tonnes P per day (a rate which has already been proven in tests), 200,000 tonnes could be extracted in five months. In time, this period could be shortened by increasing the daily production rate.

2) A second option is to purchase a mining ship or to retrofit an existing drill ship or ore carrier. The operation would be year-round with about 250 working days per year. Using the same daily production rate, of
2000 tonnes, yearly production of phosphate would be about 500,000 tonnes. Although this is much more than desired, it does not seem worthwhile to operate at a much smaller daily rate* or to only use such a large capital investment (the ship) for a short part of the year. If this option is chosen, the phosphorite oversupply (about 300,000 tonnes) will have to be stockpiled.

3.3.3 Reserves
As detailed in Chapter One, section 1.2.2, several reserve estimates have been proposed - all referring to different size mine sites. In this study proven reserves of 40 million tonnes for the "preferred mining area", 179°E to 180° and around latitude 43°30' will be used.

3.3.4 Mining Area
A mine site is defined as the area containing nodules with a sufficient grade and abundance to sustain a commercial mining operation (Archer, 1979). The boundaries of the mine site will change with economic circumstances.

The area to be covered within the mine site to meet production requirements is dependent upon the density of deposits. Density is variable among the Chatham Rise nodules but an average value suggested by Cullen (1978) is ±65 kg/m². Fletcher Challenge Ltd., has adopted a more conservative estimate of 50 kg/m². Using this lower density estimate, one square kilometre will yield 50,000 tonnes. To meet yearly production requirements of 200,000 tonnes, the mine site will measure (theoretically)

* Although there are obvious differences in the product and site, for comparison, daily production rates for other deep ocean mining operations are proposed as 20,000 tonnes per day for manganese nodule mining (Cronan, 1980) and 30,000 tonnes per day for the phosphorites offshore California (Tronsdon and Mead, 1977).
4 km$^2$. Incorporating the width of the aperture of the collecting vehicle (10 m) into line dimensions, this area translates into 400 km by 10 m per year. The rental option, based on 100 days mining activity means that 4 km by 10 m will be mined each day. These estimates will increase substantially however, due to the inherent inefficiency of mining systems.

3.3.5 Recovery Efficiency

There are several types of efficiency to consider in determining overall recovery efficiency (Pasho, 1979). Within the mine site there are areas with obstacles, steep slopes or other features that make mining impractical, leaving about 75-80% theoretically available for mining. From this amount of nodules available, only a certain percentage will be recovered by the collecting vehicle. This is termed "dredge efficiency" and ranges from about 40% to 70%. In addition "sweep efficiency" defines that part of the mineable area actually swept by the collector, estimated at between 40% to 75%. These broad ranges reflect the experimental stage of operations estimates and the differences among the various systems proposed. As well, the minimum values can be expected to improve as mining proceeds (Archer, 1979).

Combining these factors, early "first generation" systems may only have about 25% overall efficiency. This suggests that initially at least, the Chatham Rise operation may have to cover 16 km by 10 m each day or 16 km$^2$ each year.

3.3.6 Resource Life

Theoretically, the life of a resource is the amount of time allowed for its complete exhaustion. At a production rate of 200,000 tonnes per year, a stock of 40 million proven tonnes will last for 200 years. However this number does not reflect the real situation for a couple of reasons: one,
estimates of production rate and proven reserves will probably both increase as mining continues; and, two, not all of the resource is recoverable. Because of the relatively low efficiencies of "first generation" mining, there is a potential loss of recoverable resource (Pasho, 1979), thereby decreasing resource life. At an average recovery rate, i.e. average between first generation and later improved efficiencies of 45% (Archer, 1979), recoverable reserves drop to 18 million tonnes. Using the same production rate (200,000 tonnes per year), resource life is now reduced to 90 years. This is a more realistic figure but it must be remembered that the rate of production may increase substantially depending on demand.

3.3.7 Mine Life

Many factors, mostly economic, determine the duration of a mining operation. One important factor is related to the financing schedule of the investors so that mine life covers the debt pay-back period and provides an ensuing surplus period. As well, the duration should allow for an attractive rate of return. Archer (1979) contends that a mine life of 15-20 years is sufficient to meet these requirements.
It is important to attempt a cost estimation exercise in this study to more clearly understand the scale and nature of the investment involved in a deep ocean mining project.

The costs of both mining proposals are examined. A price range for rental of a mining ship has been supplied by Fletcher Challenge Ltd., but no cost per tonne estimates for a yearly operation were available. Since this is an important parameter in option two and useful as a comparison for option one, ball-park figures have been obtained from available literature on manganese nodule mining in the Pacific, phosphorite mining offshore California, and earlier estimates for the Chatham Rise deposits.

There are inherent limitations involved with this approach. Firstly, there are pitfalls in extrapolation of data tailored for other operations because of site differences. Secondly, there is much uncertainty associated with cost projections, with inaccuracies of ±30% (Tinsley, 1979). Finally, cost estimations, like all other projections for deep ocean mining, suffer from the absence of a commercial operation to substantiate or base any figures. All cost estimates are therefore very much subject to change. Cost estimates from selected studies are shown in table 3.1 and represent the range for a year round operation such as suggested in option two. Some specific assumptions in these estimates are noted below:

(a) The total costs estimates presented here include the costs of extraction, transport to the nearest port and offloading. Some of the references cited do not specify the items incorporated in
their estimates of total cost while others produce details, making it difficult to directly compare estimates. Where possible, attempts have been made to present estimates of fixed capital only, such items as R & D and working capital are not included. As well, some workers adjust their estimates to account for risk although this is not always possible to ascertain.

(b) Where possible, all estimates have been converted for dry (metric) tonnes of phosphorite recovered. It is unfortunate that the literature is sprinkled with such variable terminology as wet or dry nodules, total dredged material or total phosphate, and metric and imperial units. The choice is often not specified.

(c) Most operations differ in their production rates, a factor that significantly affects operation costs. The most frequent rate used is one million dry tonnes per year. Adjustment will be made to tailor this to the Chatham Rise case.

(d) Emphasis is placed on operating costs rather than capital costs. The latter are extremely variable depending on the technology, the type of vessel used, and the mine site. The broad range of capital costs cited in the literature is presented but not discussed.

(e) Costs quoted are direct costs only. They are not adjusted for any environment or social considerations that may be imposed upon the operators.
(f) A general inflation correction is used to bring all estimates to New Zealand (1981) dollars. While this is necessary for comparison purposes, increases due to inflation may be partly offset by decreases caused by advances in technology.

The cost of the leased ship operation (option 1) are estimated to range from $45 to $75 per tonne. This is based on a production rate of 200,000 tonnes, (or 2000 tonnes per day) and a suggested rental charge for a mining vessel of from $60,000 to $100,000 per day (Richard Bentley, pers. comm.). Although only 100 working days are required at a rate of 2000 tonnes per day, about 150 days will be needed in total, to account for offloading trips to port and back and some downtime.

3.4.1 Summary of Costs

Although the costs presented in table 3.1 have all been corrected for inflation, the estimates from recent works are noticeably larger than earlier estimates. This probably reflects increases in energy and materials over the past 8-10 years. In addition, the technology proposed for the Chatham Rise is more elaborate than that assumed in the Global Marine and JBL studies of the early '70s and therefore the costs will invariably be higher.

The technology proposed to mine the California phosphorites (Tronsden and Mead, 1977) is similar to that proposed for the Chatham Rise but conditions such as water depth, proximity to shore and weather will be more severe for the Chatham Rise case. The estimate of $40/tonne, then, may be too low.

The last two estimates in table 3.1 refer to manganese nodule mining, although they have been slightly adjusted for the Chatham Rise conditions.
However, the larger scale and more complex operating conditions involved in these ventures suggests that the maximum estimate of $70/tonne, especially, is too high.

Weighing these factors, a probable estimate of operating cost for option 2 is about $50/tonne. It is important to note that capital costs have not been included. According to some of the estimates presented in table 3.1, they will add substantially to total cost.

In comparison, the cost of renting a mining ship, option 1, estimated at $45-70/tonne, reflects the total cost, i.e. a capital charge is built into the operating cost. On the basis of these costs, the rental option appears to be cheaper.
Table 3.1. Costs of deep ocean mining and transport to port - option 2

<table>
<thead>
<tr>
<th>Reference</th>
<th>Operating Cost A $/dry metric tonne</th>
<th>Operating Cost B Corrected for inflation $/tonne</th>
<th>Operating Cost C Corrected for lower production rate $/tonne</th>
<th>Capital Costs D $ x 106</th>
</tr>
</thead>
</table>

1. Assumptions and conditions of the cost estimates as discussed in these references are presented in Appendix A.

2. The process used for inflation correction is presented in Appendix B.

3. As indicated in Appendix A, most of these estimates are for a 1 million dry tonne or ton production rate. For application to an operation with a rate of one half that (500,000 tonnes) as suggested in mining option 2 operating costs are doubled. This reflects a pronounced economy-of-scale effect, as advanced by the authors referenced.
PART II - RISK DETERMINATION

"Risk is the one factor about which others can tell you the least." (Megill, 1971, p.90)
Introduction to Part II

A proposal to use a nation's resources must be appraised by government to determine returns to the nation, or net social benefit (NSB). To make an intelligent choice, the benefits and costs must be displayed and compared with alternative development proposals. This is traditionally done by comparing their respective net present values (NPV), net social benefits which are discounted over the life of the project.

\[
\text{Max } \text{NPV} = \text{Max} \sum_{0}^{T} \frac{B_t(x) - C_t(x) - E_t(x)}{(1+r)^t}
\]

s.t. \sum_{0}^{T} x_t \leq x^*

where \( B_t \) - dollar value of benefits incurred in time \( t \)

\( C_t \) - dollar value of costs incurred in time \( t \)

\( E_t \) - dollar value of net externalities in time \( t \)

\( r \) - chosen discount rate

\( x \) - resource output

\( T \) - life of the project

\( x^* \) - resource potential

To evaluate the proposed mining of the Chatham Rise phosphorite in this light, one must first be aware of the existing situation. Rock phosphate is the second most costly import to New Zealand, topped only by petroleum. Imports over the past eight years are presented in table 4.0 with the latest cost estimate for 1981 close to $52 million c.d.v. (current value in the country), or about $80 million c.i.f. (cost to the country). The quantity of phosphate imported has increased quite steadily up to 1979 and dropped off slightly in the past two years - a trend which probably reflects rising cost to the consumer, as shown in the four-fold
Table 4.0. Value and Quantity of imported natural Calcium Phosphate from 1974-1981.
(Source, New Zealand Official Yearbooks.)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>QUANTITY (thousand tonnes)</td>
<td>948</td>
<td>1,210</td>
<td>936</td>
<td>1,050</td>
<td>1,137</td>
<td>1,349</td>
<td>1,209</td>
<td>1,025</td>
</tr>
<tr>
<td>VALUE (c.d.v. A) (thousand $)</td>
<td>$11,574</td>
<td>$33,714</td>
<td>$37,724</td>
<td>$39,541</td>
<td>$39,983</td>
<td>$45,509</td>
<td>$47,572</td>
<td>$51,834</td>
</tr>
<tr>
<td>VALUE (c.i.f. B) (thousand $)</td>
<td>$18,726</td>
<td>$44,676</td>
<td>$51,052</td>
<td>$61,277</td>
<td>$61,986</td>
<td>$69,351</td>
<td>$68,150</td>
<td>$80,447</td>
</tr>
<tr>
<td>$/tonne (c.d.v.)</td>
<td>$12</td>
<td>$28</td>
<td>$40</td>
<td>$38</td>
<td>$35</td>
<td>$34</td>
<td>$39</td>
<td>$51</td>
</tr>
<tr>
<td>$/tonne (c.i.f.)</td>
<td>$20</td>
<td>$37</td>
<td>$55</td>
<td>$58</td>
<td>$55</td>
<td>$51</td>
<td>$56</td>
<td>$78</td>
</tr>
</tbody>
</table>

NOTES:  
A) c.d.v. = current domestic value  
B) c.i.f. = cost including insurance and freight
increase in $/tonne over the past eight years. Virtually all imported rock phosphate is converted to single superphosphate ("super").

Traditionally, New Zealand's supply has been obtained from within Oceania - Nauru, Christmas Island and Ocean Island. However, deposits on Ocean Island have been exhausted and reserves from Nauru and Christmas Island are estimated to last for another fifteen and eight years, respectively (Cullen, 1979; Bentley, 1981). New Zealand will therefore have to look much further afield to sources in North Africa and eastern U.S.A. to meet its requirements. Indeed, it has already done so; imports from Florida began in 1979.

Ever increasing freight rates means supplies, especially from these distant sources, will come at a higher cost. Many of these sources are also lower quality than ones inside Oceania. The quality of "super" manufactured in this country has been steadily declining (Quin, 1981) and it appears that this trend will continue. As well, increases in application costs and reduction in government subsidy have contributed to an overall increase in the cost of super to the consumer of 190% between 1978 and 1980 (Rajan, 1981).

In Part I of this study the merits of reactive phosphate rock, such as the Chatham Rise phosphorite (CRP), were examined and it is suggested as a viable alternative to super in some situations. Having determined the agronomic potential of CRP, the next question is what are the costs and benefits associated with development of the phosphorite resource. The net present value of such a development is subject to various constraints which can be represented by the following equation:
All aspects of an investment decision are contingent upon the basic potential of the resource: its distribution on the sea floor, composition, concentration, size and location. For deep ocean mining the sophisticated and novel technology takes a prominent position in influencing the costs and benefits of a project. As well, in this case it introduces a foreign (West German) interest into the development. The technologic requirements are reflected in the economics as is the location of the deposit under 400 metres of seawater and 600 kilometres from shore. Administrative and legal considerations set the framework for the operation. But the remaining variable, risk, is proposed here as the most significant in assessing an investment like deep ocean mining. It has strong influence on collating and weighing the costs and benefits of a project to arrive at an investment decision.

The Risk Assessment Approach

The term "risk" has become well used in recent years, particularly in economic and environmental studies. One result of this popularity is confusion over its meaning and indeed, many definitions exist. O'Riordan (1979a) and Whyte and Burton (1980) adhere to the preferred dictionary definition of "risk" as a hazardous outcome and/or the probability of its occurrence. Others, Holling (1978a) for example, refer to this same concept as "uncertainty". Economists generally differentiate between risk and uncertainty, defining "risk" as the situation where a given probability can be assigned to an event and "uncertainty" as the situation where this cannot be done (Krutilla and Fisher, 1975; Peterson and Smith, 1982). A very loose definition from exploration economics proposes "risk" as an opportunity for loss (Megill, 1971).
All of these definitions concur with the concept of risk as used in this study, but the definition suggested by Rowe (1979) is probably the most appropriate: "Risk is the potential for the realization of unwanted consequences from impending events". In deference to some of the definitions cited above it is a measurable potential or probability. The term "uncertainty" is also used in this study and generally refers to unmeasurable probability of adverse events.

Risk assessment describes the total process of risk analysis (Goodman and Rowe, 1979) (Figure 4.0). Basically the process has two main components: risk determination, which involves identification of the risks and examination of the consequences; and, risk evaluation, where the risks are weighed against social and economic gains and the trade-offs and conflicts examined. In this study, emphasis is placed on the first component, risk determination. Risk evaluation will be addressed briefly in the final part of study as a criterion in the formulation of development policy.

Figure 4.0. The components of Risk Assessment.
The Chatham Rise phosphorite project is presently in the exploration stage. If risk management is to become an integral part of a development policy, identification of potential adverse events is essential at this early stage. The consequences of these risks must be understood so they can be effectively managed. Deep ocean mining lends itself to risk assessment by virtue of its large scale, its novel technology, the lack of previous experience and, an unpredictable marine environment. For the Chatham Rise project, these factors and the early stage of planning means that risks are difficult to measure. There are few quantifiable estimates available and the absence of comparative base levels renders many numbers meaningless. Therefore, there is no attempt to place economic values on risk for incorporation into a formal analysis. Many researchers dismiss a risk assessment approach if there is such a shortage of figures. Paradoxically, it is the frontier nature of such projects that creates the climate of risk and the need for those risks to be assessed. It follows then that by concentrating on identifying and understanding the risks involved in the mining operation, more questions will be raised than answered.

In this study, the audience or recipients of the risk are specified beyond the collective "man and the environment". Risk is determined for particular sectors involved in the Chatham Rise project and different types of risk are identified such as legal, economic, technologic, environmental and social. Perception of risk varies depending on the type of risk involved and one's stance. In each case, the author has attempted to represent the perceptions of the concerned sector, where possible canvassed for first-hand opinions.

The following two chapters in this section begin the process of assessment by identifying risks and their consequences. Chapter Four, Investment
Risk, discusses the many kinds of risk involved for each investor. The nature of risks to the marine environment, including implications for the Chatham Rise fishery, are examined in Chapter Five.
CHAPTER FOUR

INVESTMENT RISK

4.1 INVESTOR'S OBJECTIVES

The parties involved in the Chatham Rise project, the New Zealand government, Fletcher Challenge Ltd., and the German interests, have their investment directed toward different objectives.

The objectives of the New Zealand government are proposed as: one, to satisfy, in part, demand for phosphatic fertilizer; two, to secure an indigenous supply of phosphate to meet that demand; and three, to provide an alternative fertilizer to consumers. It is proposed that Fletcher Challenge Ltd. has three objectives: profit, manufacturing interests, and prestige. Finally, German interest in the project is assumed to be as a test for their mining technology and also for prestige.

According to the Continental Shelf Act 1964 and the Territorial Sea and Exclusive Economic Zone Act 1977, the mineral resources of the Chatham Rise belong to New Zealand. The New Zealand public hold the property rights and hence constitute a major interest in any development project.

The reasons for New Zealand's involvement, as proposed here, are part and parcel of its overall goal to maximize social and economic welfare. This is generally defined as maximizing the present value of net social benefits (Herfindahl and Kneese, 1974), as discussed in the introduction to Part II. Such a mandate implies that the government must ensure optimum development and consumption of its resources; the optimum will depend on the specific circumstances. In this study, the emphasis is on the optimum pattern of development rather than consumption (directly)
but the latter is implicit since development must account for the needs of present and future generations. The phosphorite resource, from the New Zealand viewpoint, must be developed in a way that achieves the objectives of partly satisfying demand and obtaining a secure supply while maximizing consumer satisfaction over time. The development pattern must also concur with other objectives inherent in such a broad goal of maximizing social welfare such as minimizing social and environmental costs. This aspect will be examined in later chapters.

Fletcher Challenge Ltd is the New Zealand commercial interest in the mining project. The company was formed in January, 1981 by a merger of three major New Zealand companies: Challenge Corporation Ltd., Fletcher Holdings Ltd., and Tasman Pulp and Paper Co. Ltd. Fletcher Challenge Ltd. is the largest publicly listed company in New Zealand. Profit for the period 1980-81 (financial year) for the three combined was estimated at $80.7 million and has just edged over $90 million for the year 1981-82.

Profit in the Chatham Rise project will be determined by the economic efficiency of mining and marketing and is a straightforward objective. The other objectives proposed for Fletcher Challenge may require some explanation. There are very few sectors of the New Zealand economy that do not involve Fletcher Challenge with the notable exception of fertilizer manufacture. Although a reactive fertilizer would only allow them a small share of the market, it is a foot in the door of a very stable industry. The third objective of prestige relates more to mining than marketing aspects. Deep ocean mining brings with it a sense of sophistication not usually attributed to conventional mining operations. It is "big-time" for even the largest company in New Zealand. Fletcher Challenge's involvement will certainly serve as valuable advertisement.
INTERNATIONALLY AND COULD PAVE THE WAY FOR MORE JOINT VENTURE PROJECTS IN NEW ZEALAND OR MORE INVOLVEMENT OF FLETCHER CHALLENGE OVERSEAS.

The German interest in the Chatham Rise is represented by several sectors. Commercial interest is headed by Preussag and Saltzgitter A.G. These two, together with Metallgesellschaft, another large German company, form the industrial group AMR (see Chapter 1(1)), which is the prospecting and exploration arm of the German government (Derkemann et al., 1981). Although Metallgesellschaft did not enter the joint venture agreement made with Fletcher Challenge in November, 1981, Preussag and Saltzgitter still receive heavy support from the German government and apparently represent the national interest (op.cit.). The German government has also been directly involved in the project through the German Geological Survey (BGR). In fact both the Valdivia and Sonne cruises were under the auspices of a BGR/NZOI liaison, although commercial interests were present. The November 1981 joint venture feasibility study agreement was the first initiative by the industrial concerns (Fletcher Challenge, Preussag and Saltzgitter).

The reasons for German interest in mining on the Chatham Rise are not altogether obvious. Their objectives are proposed in light of the state of the art in deep ocean mining. Very few tests of mining equipment have occurred under actual sea conditions and, of course, none at a commercial scale. After appropriate pilot tests, the Chatham Rise venture could provide a valuable opportunity for the Germans. As previously outlined, Preussag and Saltzgitter form the major part of AMR which is, in turn, a member of OMI (Ocean Management Inc.) - an international consortium of corporations involved in deep ocean mining. OMI is one of the "big five" consortia (see table 2.1) involved in the race to mine the Pacific manganese nodules. AMR is also head of a project.
to mine the metalliferous mids of the Red Sea and therefore would have much interest in an opportunity to test their system.

An objective of prestige stems from this. The race to develop a working technology for deep ocean mining is a torrid one. Many countries, through either government or private interests, are involved and much international status will be awarded to the winner.

Because of their varied objectives then, the optimum course of action may be different for each investor. How does the proposed Chatham Rise mining stand up in terms of each objective; how do the costs and benefits weigh out? As discussed in the introduction to Part II, risk is a significant criterion in such a determination. The various types of risk involved for the three investors will now be examined, grouped according to the variables presented in an earlier equation.

\[
\text{RESOURCE POTENTIAL} + \text{STATE OF TECHNOLOGY} + \text{LEGAL and ECONOMICS + ADMINISTRATIVE CONSIDERATIONS} = \text{INVESTMENT DECISION}
\]
4.2 RISK ASSOCIATED WITH RESOURCE POTENTIAL

The characteristics of the phosphorite nodules govern their resource potential, both for mining and marketing. The potential for mining can be assessed using the following features: deposit characteristics, site characteristics, and relative location (Earney, 1980). Existing information on these characteristics was presented earlier and some problems elucidated, for example, handling the ooze and muddy sediment during mining. It can be argued that such problems do not come under the general rubric of risk because they are known. The greatest risk in assessing resource potential is the information not known or understood.

Collecting data from the sea floor is tricky. In situ values are difficult to obtain and to correlate with measures from cored samples. Deposits are, by no means, uniform and random sample measurements may not reflect the total resource value. Even with more geotechnical investigations, gaps are only narrowed, never closed. The very nature of mining means that these uncertainties are assimilated into decisions about the feasibility of an operation. Once mining commences and more information becomes available, these estimates invariably change and the uncertainty decreases.

The risk associated with this type of information may result in increasing operating costs for Fletcher Challenge which may inhibit profits. It is also a risk to the German interest in that technology design must be cognizant of parameters such as average nodule size, distribution and concentration, and the nature of the surrounding sediment. A smooth technologic operation depends on these factors being understood. For New Zealand, uncertainty over resource values is a risk to maximization of social welfare. The real "user cost" to the present generation
increases substantially, i.e. future generations lose out, if mining commences and, for example, the deposit proves to be less extensive than originally thought. The projected life of the resource is significant and therefore much weight is placed on the parameters or resource characteristics that define it.

The value or potential of the phosphorite resource as a fertilizer is still being tested. Field trials have shown Chatham Rise phosphorite (CRP) to be very effective, particularly as a maintenance fertilizer (Gregg and Syers, 1982). However, it must be recognized that the trials conducted so far have been of a variable nature. Only a few overseas trials on reactive rocks have been performed on grassland and here in New Zealand, although results with CRP have certainly been favourable, trials have not been co-ordinated or comprehensive.

A new program just started by Ministry of Agriculture and Fisheries (MAF) to investigate the potential of CRP will probably require five years for completion and assessment of field trial results (B. Quin, pers. comm.). Preliminary results obtained from disjointed trials will probably be used to make a decision before then and obviously there is a degree of risk involved in having to rely on such data. This does not apply to the German interests since they are, apparently, not interested in the mined product. However, it is a very real risk for Fletcher Challenge whose overall mining profit and to a lesser degree, its opportunity to expand into the fertilizer manufacturing industry, rest on the market success of CRP. For New Zealand, CRP offers farmers an alternative which may be more effective for their particular situation. It is helping to maximize consumer satisfaction and any risk to its success in the field is a risk to that objective.
4.3 TECHNOLOGIC RISK

The scale of deep ocean mining and the lack of experience with such operations worldwide, constitutes considerable technologic risk. Even after endless laboratory and pilot mining trials, only a full-scale operation will show up the faults and inadequacies of a particular design. It is not possible to subject equipment, even in simulation, to the cumulative action of, in this case, about 3000 tonnes of material daily. Stresses from seawater and nodule slurry will cause corrosion and erosion of materials; machinery life and maintenance requirements are still a large unknown.

The nature of the risk involved in deep ocean mining is demonstrated by the size and composition of the five existing mining consortia (see table 2.1). Members are from four of the richest, most industrialized countries: Japan, France, West Germany, and the United States. According to the joint venture agreement between the commercial interests in the Chatham Rise project, if mining gets the go-ahead, the technology will be developed by the Germans. This is in line with their industrial and technical prowess as well as their other deep ocean mining interests as members of the OMI consortium. In this case however, albeit a smaller operation, the Germans will be shouldering risks without the security of its partners in OMI (Japan, U.S.A. and Canada). So, of the three investors in the Chatham Rise project, technologic risk is probably greatest for the German interests since each of their objectives, as proposed here, is contingent upon the success of their mining system. Obviously though, the entire mining venture hinges on how effective the technology proves and therefore, the risk is also shared by Fletcher Challenge and New Zealand.
There is an additional risk of technology changing within the period established for the mine life of the Chatham Rise project as the global effort to mine the seabed increases. It is very likely that improvements will occur in recovery, economic and energy efficiencies of deep ocean mining systems. The Chatham Rise project may well be one of the first commercial enterprises and hence, subsequent improvements in design are inevitable. This may be an important consideration if the project is locked into using a West German design. There are large capital costs associated with changing technology in the middle of an operation that will probably make their original technology choice irreversible.
4.4 ECONOMIC RISK

Deep ocean mining is extremely capital intensive and the economic risks are proportionally high. This is especially significant for the commercial interests but is also relevant to the New Zealand goal of maximum social welfare. This is an extensive area for discussion and includes issues which reach beyond strictly economic risks to social concerns as well. This section is divided into risks associated with exploration, mining, and marketing.

4.4.1 Exploration Risk

Before any mining activity begins, substantial amounts are spent on research and development (R&D) and exploration. For minerals, as for petroleum, the success of production depends on a comprehensive exploration program. Naturally, this precursor is afforded a budget in proportion to the scale of the planned mining operation. In deep ocean mining, exploration programs are elaborate and costly but they are instrumental in reducing the risks during mining.

For the exploration phase of the Chatham Rise project, the German interests chartered both the Valdivia and the Sonne (both vessels are privately owned within Germany) and paid the bulk of the cruise costs. Their expenditure for the cruise costs is estimated to be at least $1.5 million (R. Bentley, pers. comm.). Fletcher Challenge has contributed $50,000 toward cruise financing (the Sonne cruise) and another $73,000 for additional testing and sampling equipment. The New Zealand government has matched the $50,000 as well as contributing the services of some of its agencies, in particular the Department of Scientific and Industrial Research (DSIR) through New Zealand Oceanographic Institute (NZOI) which has participated in the cruises and is presently helping to evaluate the collected data.
A feasibility study was instigated by the commercial interests in May, 1981 to examine the economic and technologic aspects of mining and delivery to a New Zealand port. Fletcher Challenge has assumed 75% of the costs of this study with the German partners contributing the remaining 25%. A decision about pilot scale testing of the mining system is expected to be made early in 1983. The feasibility study (a paper study only) is estimated to have cost Fletcher Challenge about $500,000 to date (mid-1982). They also pay a $30,000 (per annum) rental fee on their exploration license (40 cents per km²). Judging by Fletcher Challenge's expenditure, the German share of the feasibility study would be in the neighbourhood of $200,000, bringing their contribution thus far to about $1.7 million. Apparently much of this has been carried by the German government and not the commercial interests directly.

All of these costs are incurred before a decision is made to mine. It is an unfortunate aspect of resource input at the exploration stage that returns may never be realized. To this point about $650,000 in exploration costs have been "sunk" by Fletcher Challenge - an irreversible expenditure. Although the German contribution is much higher ($1.7 million), this expenditure and the knowledge gained can be spread among their other deep ocean mining interests, thereby reducing the risk.

It is worthwhile to note some of the economic risks that Fletcher Challenge (and the Germans to some degree) have not had to shoulder during the exploration phase. With few exceptions, companies engaged in mining activities spend much time and money discovering mineral deposits. Mackenzie (1981) points out that small mining companies may direct about 30% of their budget towards just finding the ore and often much money can be spent without delineating a prospect. Fletcher Challenge has not had to bear any discovery risk. Not only were the nodules discovered over a
century ago, but prior to their interest, much reconnaissance work had been carried out over the past 15 years by both government and private companies. So in some respects, Fletcher Challenge has inherited a project with much of the early risky work already completed.

4.4.2 Mining Risk

Commercial Interests: Since a decision about mining has not yet been made it is not known how costs and responsibility will be divided between Fletcher Challenge and the German interests for the actual operation. Considering the option of renting the mining ship (option 1) it appears the Germans would absorb the capital costs of the multipurpose vessel and Fletcher Challenge would pay chartering fees as part of their operating costs.

The 'costs' of CRP delivered to a New Zealand port were calculated in an earlier chapter and are presented again in table 4.1. Processing costs are estimated at $10/tonne which is less than the current cost ($15-20/tonne) because of the simpler processing route for CRP. The value of CRP is placed below the current value of super ($125/tonne approximately) because of its slightly lower P content. The result is a ball park figure of apparent profit to Fletcher Challenge from the mining venture. It is difficult to calculate actual profit - additional costs, such as lease rates and royalties or incentives such as writing off exploration costs may affect a company's taxable income considerably. Nevertheless, assuming a 50% tax rate these profit estimates are reduced to 8-23% for option 1 and 20% for option 2. The profit margin for option 2 will be squeezed even further once the capital costs of the mining ship (which are not involved in option 1) are taken into account and a more accurate estimate may be 15%. The popular figure for an "acceptable" return on investment for high risk ventures is generally quoted at 20%. 
Table 4.1. Apparent profit based on operating and processing costs of both mining proposals.

<table>
<thead>
<tr>
<th></th>
<th>OPTION 1</th>
<th>OPTION 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rental of Mining Ship (200,000 t/yr)</td>
<td>Purchased ship Year Round (500,000 t/yr)</td>
</tr>
<tr>
<td>Mining Cost</td>
<td>$55-80/tonne</td>
<td>$60/tonne</td>
</tr>
<tr>
<td>Annual Cost (Based</td>
<td>$11-16 million</td>
<td>$30 million</td>
</tr>
<tr>
<td>on Production Rate)</td>
<td>$100/tonne</td>
<td>$100/tonne</td>
</tr>
<tr>
<td>Value CRP ex works a</td>
<td>$20 million</td>
<td>$50 million</td>
</tr>
<tr>
<td>Yearly Value CRP</td>
<td>15-45%</td>
<td>40%</td>
</tr>
<tr>
<td>Yearly Profit (Before tax)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

a. CRP = 9% P; SSP(SUPER) = 10% P

This higher than usual return acts as an insurance against risk. Taking the best estimate for option 1 (23%) and 15% for option 2, the mining venture appears to be "marginal". It should be obvious that these numbers must be treated very loosely and should not give any illusion of precision. The purpose of this exercise is not to determine the economic feasibility of mining for Fletcher Challenge, indeed it would be foolhardy with such little data. Rather, numbers are used to understand the type of investment and the returns involved with developing the phosphorite. As posited in the introduction to Part II of this study, the principal factor influencing returns is risk. The following paragraphs examine the risks which may affect costs and revenues for the commercial investors.

There are various methods to account for risk in mineral investment decisions. Arrow and Fisher (1974) demonstrate that the effect of risk is to reduce present values or the net benefit stream. This could involve a number of procedures such as raising the discount rate as a risk premium; demanding shorter pay-back periods for the project; or, simply adjusting inputs by biasing estimates of costs, mineral values,
etc. (MacKenzie, 1981). For example, Fletcher Challenge is using a very conservative reserve estimate (40 million tonnes) in their analyses which could be interpreted as a security measure.

Whatever the method chosen to incorporate risk, the choices must be arranged so that the option where the chance for gain is higher and the risk of loss is lower becomes evident. MacKenzie (op.cit.) illustrates this by considering risk as the probability of the occurrence of possible values about an expected result (figure 4.1). This expected result would be some measure of investment benefit. For the Chatham Rise project, for example, this could be a 20% rate of return. The investor then has a picture of the alternatives that reflects the risks involved in each one. The option selected depends on the 'gambling' nature of the investor. Option 'j' has lower variance about the mean and entails less risk yet option 'i' may still be chosen if the investor feels there is a slight chance of scoring a very large return.

There are some obvious risks associated with the second option proposed for the Chatham Rise which is based on buying a ship and retrofitting it for deep ocean mining. Operations would proceed year round at a daily production rate of 2000 tonnes per day, resulting in a yearly production of about 500,000 tonnes of phosphorite (see Chapter 3, section 3.2.2). This amount of mined phosphorite presents a considerable marketing problem since it has been suggested that the market at present, will probably only accept less than half that amount of CRP per year. Until this market share increases then, about 300,000 tonnes will have to be stockpiled or else exported each year, although the latter is unlikely. This will result in an unhealthy balance of costs and revenues for Fletcher Challenge. On the other hand, it does not make good economic sense to have a mining ship, a large capital investment, sitting idle for half a year. It could
Figure 4.1. Risk as a probability distribution. (From MacKenzie, 1981, p.250.)
possibly be made available for charter but its specialty service is not likely to be in high demand and as well, the crew and technical staff necessary for such an operation seems outside the scope of Fletcher Challenge's interest in deep ocean mining.

Option 1 entails features that reduce some of these risks. By hiring the mining vessel there is no commitment to a long term mining operation; no large, initial capital outlay; nor the maintenance responsibility of a special purpose vessel. Mining its requirements during four months of a year confines operating costs and company "energy" to a much shorter period. The smaller production rate (200,000 tonnes per year) is more easily accepted on the domestic market, although it too would have to be stockpiled and released over a year period.

One apparent risk with this option is the rental arrangement. If the ship is designed as an all-purpose vessel, for example, for oil drilling, mining for metalliferous muds and nodule mining, its availability may become a problem. Problems with rig availability have plagued the oil industry for many years, especially for offshore operations. Nevertheless, option 1 seems to have the narrower distribution of potential results about an expected outcome, i.e. less risk.

One factor, in particular, is acknowledged as having a pronounced effect on costs and revenues of deep ocean mining and applies to both options: economies of scale. Trends indicate that operating costs are very sensitive to production rates and tend to double if the rate is halved (Mero, 1965; Kaufman, 1970; Tronsden and Mead, 1977; Tinsley, 1979). Suggested production rates for other manganese and phosphorite mining operations range from 1 million to 3 million tonnes, although rates obviously depend on the type of operation and the value of the product.
The proposed rate of production for the Chatham Rise operation is much smaller and it is based on what the market will accept. However the place for reactive fertilizer may expand or else there are other processing alternatives open to Fletcher Challenge, as outlined in an earlier section. For whatever reason it would significantly improve the economic efficiency of the mining operations if the production rate was increased.

Again, it is worthwhile to note some of the common mining risks that do not pertain to Fletcher Challenge. The first relates to the structure of the company. Since it is not only a mining company, the economic efficiency of the Chatham Rise operation is not a matter of survival as it is for many strictly-mining companies (MacKenzie, 1981). Naturally, a profitable return on investment is important to Fletcher Challenge, but it is a means of growth not a measure to ensure survival. As a large company with diverse interests, the risk of a capital intensive and highly technologic project can be spread among its other ventures. This "risk-sharing" is a common procedure in large corporations.

There is also very little risk to Fletcher Challenge of mining competition. If they do not act on the Chatham Rise project now, it is doubtful that another party will come into the picture, harvest the resources, and capture the profits. As the largest New Zealand company, it appears to be the most able to handle the high risks involved in a deep ocean mining project. Larger companies from overseas may prove more capable but it is doubtful that the resource would be open for development by a group with no New Zealand interest.

New Zealand Government: A national goal of maximizing social welfare involves an efficient and equitable allocation of resources over time.
This indicates the importance of understanding the life of a resource which depends on reserve estimates, recoverable reserves, and the mining rate as determined by the commercial interests. Using present recovery efficiencies of 40%, proven reserves of 40 million tonnes (mt) are reduced to 16 mt. It is anticipated that both reserve and recovery estimates will increase but how much this will affect the Chatham Rise project depends upon the timing of the project. If it proceeds within the next ten years, recovery efficiencies may not improve significantly since it is doubtful that other ventures world-wide will be in operation by then. Similar to the economies of scale argument, a higher production rate not only halves operating costs but also the resource life. At a rate of 500,000 tonnes per year, the phosphorite (at present reserves) would have a 28 year life; at twice that production rate the resource would last for only 14 years, and, at 200,000 tonnes per year, it would stretch out to 70 years.

Clearly, the life of a resource is a significant national consideration; optimum allocation must account for the demand of future generations. The present generation has a tacit responsibility to leave future generations alternatives and options for consumption.

From a national stance the mining operation can also be viewed as providing opportunities for employment. Already the exploration stage has involved the services of several government departments such as DSIR (particularly NZOI), MAF and CFE. Most of these have been technical positions but none have been newly created. Fletcher Challenge has commissioned various studies providing contract work for several (about five) New Zealand consulting groups. The mining stage will involve more direct and indirect employment and job creation, although the extent of this will depend on which mining option is chosen. For the rental option,
employment opportunities for New Zealanders may be very limited. Fletcher Challenge will be chartering a ship that will very likely come with its own technological and service crew. Representatives from industry and government will probably be present during mining but, again, these will not be newly created positions.

Option 2, the year round mining operation, will involve greater job opportunities. A crew size of 100-120 persons has been suggested for a 50,000 tonne mining ship (Cronan, 1980) but the Chatham Rise operation should be somewhat smaller and requirements are more likely to be 85-100 people. About half this number will be skilled and highly-skilled positions. Many of these may be reserved by Germany as part of its technological investment, leaving about 15-20 positions to be filled by Fletcher Challenge with perhaps a few government representatives. Some of these positions may attract skills from overseas and it is difficult to estimate the numbers of New Zealanders that may be involved. About 40-50 positions will require unskilled labour. Initially, at least, these will probably come from people with offshore drilling experience since many of the duties, the lifestyle, and routines are similar. This may serve to limit the number of New Zealanders hired in the early stages but as more become trained, the entire roster could eventually be filled by them. There will be limited work opportunities for women on the mining ship. Experience in other offshore operations suggests only a few positions will be available: as cleaning staff, kitchen help, and technical staff. It is unlikely that the female contingent would number more than seven.

The crew would probably operate as 30 day shifts so the number of positions is effectively doubled. This places the number of skilled positions available to New Zealanders at about 20 and unskilled at 80-100, if the
year round operation was selected.

In petroleum exploration and production most of the employment is generated in the supporting and related manufacturing activities (Siddayao, 1978) and this will probably be the case for deep ocean mining. As for direct employment, the year round mining operations (option 2) offers the most benefits to the supporting services. It is difficult at this stage to determine if processing of the phosphorite will offer increased employment opportunities. Some new positions will be created to process the phosphorite into a direct application fertilizer but it is difficult to gauge the net job creation because this may displace existing jobs in the fertilizer manufacture industry. The amount of displacement will depend on how much of the fertilizer market will be captured by a direct application CRP.

The manufacture of parts for the mining operation is not likely to become a bustling new industry for New Zealand. With the exception of small, universal parts and perhaps the collecting vehicle (R. Bentley, pers. comm.), most technological aspects will be taken care of by Germany.

However, the port selected as a base for the operations should benefit substantially. The mining ship (and barges and tugs, if used) will require maintenance and repairs, and pay dock fees. Services and supplies, such as food, will come from the region. The port would house the processing facilities, thereby increasing distribution and transport services. There would be an increase of people into the region both directly associated with the mining (to be ferried back and forth to the ship) and indirectly, through the service infrastructure. As yet, it has not been disclosed which port is pegged for this development if mining proceeds. While an east-coast South Island port seems a logical choice,
it must be noted that it is about the same distance to the North Island from the mine site.

4.4.3 Marketing Risk

Commercial Interests: For Fletcher Challenge Ltd., the phosphorite resource has value only if it can be extracted and marketed economically. Therefore, economic efficiency will only be determined after the phosphorite enters the market place.

At this very early stage of the project Fletcher Challenge has already taken steps to ensure that the mined material is "theirs". It has assumed 100% of the costs of market investigations and commissioned its own agricultural studies to diminish the risk of losing its hold on the phosphorite to the German partners, which could potentially threaten Fletcher Challenge's fertilizer manufacturing aims. However this appears unlikely, as suggested by the indifference of the Germans toward the phosphorite; they might just as well be potatoes. The result is that the Germans do not directly share any marketing risks.

There are three main market risks for the investor (Fletcher Challenge) and they all relate to the timing of the venture. The main concern is with product acceptance. Introducing a new material into a situation dominated for many years by one type of fertilizer will require clever public relations and the confidence of the farming community. The risk of rejection is somewhat reduced by the introduction of another direct application phosphate fertilizer from Sechura, Peru into North Island hill country in 1981 with apparent success (B. Quin, pers.comm.). The phosphorite was imported by Winstone's and Dalgety's, two large New Zealand manufacturers.
A second concern is the risk of commodity replacement. In this light the introduction of Sechura phosphate becomes a threat and in addition it is generally recognized as a higher quality fertilizer than CRP (Gregg and Syers, 1982; Rajan and Saunders, 1982). Rajan and Saunders indicate that reactive rocks from North Carolina, Israel and Jordan may also become available. Therefore the risk of import competition is very real, especially when dealing with such a small share of the market. Other types of fertilizer also threaten replacement. Worldwide, there is an increasing trend toward importing phosphoric acid for processing into triple superphosphate, an option that would reduce costs of raw material transport to New Zealand. This higher quality (18-20% P) fertilizer would certainly be in competition with direct application fertilizers for hill and high country areas.

This leads to a third consideration for marketing CRP - the importance of lower cost. A ceiling will have to be placed on the price of CRP, at least initially, to secure market acceptance. There is no world market price for phosphate as for most other minerals. Prices are negotiated through the New Zealand Phosphate Commission and vary according to the source and quality of the phosphate. As discussed earlier, prices have been steadily increasing due to rising freight rates (see table 4.0) and are expected to increase dramatically as traditional sources within Oceania are exhausted and New Zealand becomes dependent on more distant supplies. This suggests that the prospect of keeping CRP prices below the steadily increasing costs of imported rock phosphate should not be too daunting.

However, recent trends suggest that phosphate prices may not be as predictable as thought. It appears in the short term at least, i.e. to 1985, phosphate export prices in the United States will be decreasing from their 1980 levels (ECN Fertilizers Magazine, January 25, 1982). A supply glut
in the United States, due to various international economic and political factors has meant a projected reduction in price of $4-5 per ton (f.o.b.) for 1982 and continuing to at least 1985. Other major producers such as Morocco have followed suit and actually undercut the United States export price in 1981 (op.cit.). The cost to New Zealand will continue to increase of course, because of rising freight costs, but not as drastically as predicted by some. Bentley (1981), for example, has predicted that by 1990 prices would be in the neighbourhood of $250 per tonne (delivered), assuming a 3-5% increase in demand each year. A more realistic estimate in light of the recent price reductions is suggested here as $150 per tonne (delivered).

It should be obvious though that with such perturbations, even reversals, to price trends possible, there is substantial risk attached to a benefit stream of CRP calculated on dramatic price increases. With an added stipulation of CRP having to remain cheaper than imported material, the profit margin may well be trimmed. It is interesting to note that mining of the manganese nodules in the Pacific was scheduled to occur in the early 1980s but has not precipitated due, in part, to legal wrangling but mostly because of a depressed world market (price) for metals.

New Zealand: The national objectives for the Chatham Rise development centre around consumer satisfaction with the potential of a cheaper, more suitable fertilizer for certain conditions and the security of obtaining that supply from an indigenous source. CRP is not only an alternative fertilizer with respect to its physical properties but it also offers farmers an opportunity to spread costs more effectively. Direct application fertilizers have a residual effect and therefore need to be applied less frequently than super or any other non-reactive phosphate. Application costs, which have been steadily rising (especially for
aerial topdressing), could be reduced as CRP would probably only need to
be applied every third year instead of each year. The real saving is in
having the option to apply the fertilizer in a "good" year i.e. when
farm income levels are high so that costs are more easily absorbed.
Mauger (1982) contends that in good years farmers deliberately overtop-
dress with super, anyway. So this method of putting "phosphate in the
bank" with direct application fertilizer should be an attraction. As
well, to secure its place on the market, CRP will be, initially at least,
a cheaper option.

The unstable price situation does bring an element of risk into the
national picture. As discussed for Fletcher Challenge, price increases
for phosphate may not rise as dramatically as expected as the present
short-term decrease has emphatically shown. So there is a risk that
even with increasing freight rates added on, imported phosphate may end
up cheaper than phosphorite mined on the Chatham Rise, a situation that
will lower net social benefit. Naturally, the mining operation will be
scheduled with this in mind but the unpredictable nature of the inter-
national situation may still thwart careful planning. This may urge
the government to subsidize CRP by offering the investors a guaranteed
price, resulting in an inefficient allocation of resources.

Attending the national interest should also include examining sources
close to home other than the Chatham Rise. Aside from rising freight
rates, there is a security problem associated with the distant sources
mentioned earlier. Perturbations in the future supply situation are a
possibility. Although supplies of phosphate are well distributed worldwide,
about two-thirds of the total reserves are controlled by Arab and African
nations, suggesting a possible threat to supply security à la OPEC.
Potential sources close to home are in Australia and on the South Island
of New Zealand. Australia has approximately 3.1 billion tons identified reserves of rock phosphate, ranging from 8-14% P (Tronsden and Mead, 1977). These deposits are located in the Northern Territory, some 200 miles inland and as yet, prohibitive freight rates have delayed their development. It is anticipated that one of these deposits, "Duchess", will open up by 1990 but it is not known whether the phosphate (non-reactive) will be available for export. As well, some of the Australian phosphate has high iron and aluminium content or else high silicon content such as the Duchess deposits, which can cause processing difficulties (Sheldon and Burnett, 1979).

In New Zealand there has been renewed interest in the Clarendon deposits in South Otago. Low quality phosphate rock (average 4-5% P) was surface mined there during World War II (Williams, 1965) and there has been renewed interest in this deposit by Fletcher Challenge but no plans have been disclosed. There are several other pockets of phosphate rock around the South Island which have attracted some commercial interest although none of these represents supplies of significant size.

The point remains that if part of New Zealand's objective is to obtain a secure supply, there exist deposits close to home other than the Chatham Rise. However, none are reactive rock; the on-land New Zealand deposits are much lower quality and quantity; and, the Australia deposits have transport and manufacturing problems. Nevertheless, it must be remembered the CRP will only partly satisfy demand and will be a secure supply only for some consumers. It is by no means a national panacea for New Zealand's continued reliance on phosphate from overseas.

To the nation as a whole the development of the CRP will provide foreign exchange savings. The cost of phosphate imports in 1981 was about
$80 million (c.i.f.) (New Zealand Department of Statistics), which ranks phosphate as the second most costly import to New Zealand, topped only by petroleum. At the proposed mining rate of 200,000 tonnes per year (rental option), CRP would replace about 10% of the present imports (allowing for the lower P content of CRP). This would provide a foreign exchange savings of $8 million, for 1981 or about $21 million in 1990, using a projected cost of $155 per tonne and a 3% yearly increase in demand. Even a small share of the market can produce a large savings, and the market share of CRP may well increase. This savings could relieve some pressure from New Zealand's traditional agricultural exports and could be used to purchase goods from within the country. Whatever its use the result would be a more attractive balance of payments for the country.

A more direct benefit to the New Zealand government is through leases, taxes and royalties. A lease is paid on the current exploration license of 40 cents per square kilometre, providing annual revenue of about $30,000 from Fletcher Challenge. It is not known at this stage what arrangements will exist if mining ensues. A royalty similar to one placed on Maui gas may be employed and company profits from the Chatham Rise operation will be taxed.

4.4.4 Effect on Fertilizer Manufacturers

A discussion of the benefits to the nation must be complemented with an examination of social opportunity costs of developing the Chatham Rise phosphorite. Costs, or risks, to the marine environment will be discussed in the following chapter but it is appropriate here to address the issue of how CRP may affect the existing fertilizer industry.

First, a brief examination of the status quo. The demand for phosphate over the past eight years was presented earlier in table 4.0. Since
New Zealand soils are naturally deficient in phosphate; this demand pattern is not expected to change significantly in the foreseeable future and demand is generally thought to be inelastic. It is surprising, then, to discover that the use of phosphatic fertilizer has fluctuated greatly over the past 12 years. However, this is not a physical phenomenon and instead, appears to be related to farm income levels and the amount of government subsidies available toward manufacturing, transport and spreading costs (National Research Advisory Council, 1978).

An examination of government subsidies reveal that they have indeed fluctuated. A price subsidy of $5/tonne was introduced on all fertilizers (ex works) in July, 1970. It had climbed to $32/tonne by 1979 and then was drastically cut to $15/tonne in June, 1979, where it now remains (New Zealand Official Yearbook, 1981). Subsidies for fertilizer transport are presently about $7.50/tonne and about $0.88/tonne for spreading. Recent trends suggest that the government is moving away from input subsidies (Petrey, 1982). This and the purported rise in the price of imported rock phosphate will substantially affect the consumer in coming years.

The fertilizer market in New Zealand is presently shared among five manufacturing interests. With one exception these are farmer co-operatives with manufacturing plants at various North and South Island ports. The industry is very stable with attractive profits in the 15% range. The manufacturers, in equal share with the government, fund the New Zealand Fertilizer Manufacturers' Research Association (NZFMRA), the agency responsible for, among other things, research into alternative fertilizers.
There is considerable variation in topography, climate and soils throughout New Zealand and these different conditions place different demands on a fertilizer. This factor, coupled with the high cost of imported rock phosphate means that the use of super as the main source of fertilizer must be questioned (Mauger, 1982). Why then have alternatives or a range of fertilizers not been introduced? For the most part, the answer seems to lie with conflicts between interest groups over the type of fertilizer and manufacture and distribution details. As Mauger lightly scolds "... attitudinal differences between research, industry and government must be promptly resolved in the national interest."

As an example, it appears that fertilizer manufacturers have already questioned the encouraging results of research by Massey University and MAF on reactive rock (Gregg and Syers, 1982). As well, the companies who have already imported reactive rock on a trial basis (Dalgety's and Winstone's) apparently do not feel that their interests have received due support or protection from the research agency NZFMRA. It has become quite obvious to the author during the course of this study, that the Chatham Rise mining project is not a very popular subject among fertilizer manufacturers. This begs the question of what is the real threat, or risk, to the manufacturers of introducing reactive rock, specifically CRP to the New Zealand market? Is the perceived risk much greater than the real risk?

The overall impact will depend on the end use determined for CRP and as outlined in Chapter one, there are several options. If CRP is crushed and ground for use as a direct application fertilizer, it will probably assume about 10% of the market initially, with the potential of increasing its share to 25% (see Chapter 1(3)). This, of course, is the market for direct application fertilizer and sources other than the Chatham Rise,
such as Sechura, Peru, may also vie for a share. Nevertheless, it represents a potential loss of 25% to current manufacturers which translates into a reduction in profit and probably employment. It is difficult to estimate how many jobs will be lost and how many will be created in a new direct application industry. The net loss, however, will not be zero since plants which produce direct application fertilizer will require less staff because of the simpler processing route. It is premature to draw conclusions at this point but it would appear that the restrictive use and, hence, market share of direct application fertilizer will serve to minimize its impact on the rest of the industry.

The picture may change considerably if Fletcher Challenge decides to pursue any of the other processing options. The second most favourable option proposed in Chapter one is a blend of CRP and super: a blend which has already proven effective in trials in the United States. Such a blend would overcome many of the limitations of a direct application fertilizer and open up a much wider segment of the market, probably about 50%. This would be an attractive course to Fletcher Challenge for a couple of reasons. First, a larger share of the market would allow them to mine at a more economic (higher) rate. This should more than offset the higher processing costs of producing a blend. Second, it allows them to realize another of their objectives as proposed in this study: to pursue their manufacturing interests. Using CRP in a blend instead of, or better still, in conjunction with, producing a direct application fertilizer would not only gain them entry but award them a sizeable presence in fertilizer manufacture in New Zealand. It is suggested here that it is this presence that is perceived by present manufacturers as the greatest risk of the Chatham Rise development. Granted, industry is wary of the market effect of introducing direct application fertilizers but this alone does not seem to warrant the current state of apprehension.
This introduces issues which go beyond the intentions here. But it can be questioned whether such a threat, which is really market competition, constitutes a risk to the nation. In other words, is there a national risk associated with the commercial one? Is the increasing pervasiveness of Fletcher Challenge in all aspects of the New Zealand economy a threat to national interest, to a goal of maximum social welfare?
4.5 LEGAL AND ADMINISTRATIVE RISKS

The commercial interests in the mining project are subject to New Zealand laws and administrative arrangements. For both the German interests and Fletcher Challenge, the greatest risk from these arrangements is delays in the mining project. The procedure for issuing licenses and the terms built into an exploration or mining license can affect the timing and hike up costs for the investors. Enforcement of regulations (environmental, safety) during mining can interrupt the flow of the operation and hence, constitutes a risk to their objectives.

For example, the German concern lies with testing their technology and using that knowledge for their plans elsewhere; they will not be amenable to delays and interruptions. Undoubtedly, one of the more favourable aspects of New Zealand as a mining location is that, as yet, there are none of the legal conflicts over jurisdiction that plague most of the other deep ocean mining ventures.

This leads to a closer examination of the legitimacy of New Zealand's claim to the mineral resources of its surrounding ocean and the risks associated with its assertion of property rights over the Chatham Rise deposits.

4.5.1 Uncertainty in International Law

The major legal issue involved in mining the seabed concerns the extent of each country's marine jurisdiction and the regime for controlling claims beyond. One of the most publicized examples of the latter is the rich manganese nodule deposits in the equatorial Pacific. Since the Chatham Rise phosphorites lie within New Zealand's exclusive economic zone (EEZ), the property rights to the deposits are assumed to be very secure. This is not strictly the case, however. The limits of that national
jurisdiction over the resources of the seabed remain unresolved at the ongoing United Nations Third Conference on the Law of the Sea (UNCLOS III).

Property rights to marine resources are governed by the principles of International Law which are seeking definition at UNCLOS. Several provisions to secure those rights have received general acceptance at the third Conference since it opened in Caracas in 1974, and are contained in the Draft Treaty. Some States have asserted their claims unilaterally, based on these draft provisions, as New Zealand has done with the Continental Shelf Act 1964 and the Territorial Sea and Exclusive Economic Zone Act 1977. Uncertainty surrounds some of these claims because the principles of the Draft Treaty will not become entrenched into International Law until the convention is concluded. The Conference has sought to formulate all Law of the Sea issues simultaneously, as a "package deal".

"without agreement on all issues, agreement on any single item is empty, or temporary at best". (Auburn, 1977, p.446)

UNCLOS III is now in its eighth year and is being stalled by some very contentious issues such as the nature of mining operations in areas outside the jurisdiction of its member states. Uncertainty of New Zealand's property rights is not easily measured but will exist until the draft provisions gain acceptance. The following paragraphs examine the draft principles that affect New Zealand's claim to the resources of the Chatham Rise.

The first Law of the Sea Conference, convened in Geneva in 1958, resulted in the Continental Shelf Convention 1958. It is the first and only conference to reach conclusion and to meet with international approval.
The Continental Shelf doctrine gives coastal states the right to explore their own continental shelf and to exploit its resources. However, much uncertainty still exists over the formula for delineation of contiguous maritime boundaries and the rights of islands to claim a surrounding shelf area. These aspects are some of the important issues being debated at UNCLOS III.

A current draft provision of UNCLOS III is to recognize the shelf as the natural prolongation of the land to the outer edge of the continental margin, or to a distance of 200 nautical miles from the coastal mean high water mark (Draft Article 76, UNCLOS III). When the shelf extends beyond 200 miles, the maximum boundary is established at 350 miles from the base line or 100 miles seaward of the 2,500 metre isobath. Such claims would be subject to review by an International Boundary Commission and if exploitation occurred beyond 200 miles, a proportion of the derived revenues would be shared with other states. Extension of the continental shelf from the South Island of New Zealand to this maximum boundary would embrace the Chatham Rise deposits.

A second major issue is the right of islands to shelves of their own. Although existing law (Continental Shelf Convention 1958) recognizes the right of islands to have shelves, the debate now centres around the meaning of the term "island". In the Draft Treaty, an island is defined as a naturally formed area of land surrounded by water and above water at high tide. As well, islands must be able to sustain human habitation or economic life (Draft Article 121, UNCLOS III). By this definition, the Chatham Islands are entitled to their own continental shelf and it is upon this shelf that the phosphorite deposits are located. Therefore either of these provisions, Draft Article 76 or Draft Article 121, would secure New Zealand's property rights.
New Zealand's claim is also supported by a more recent concept introduced at UNCLOS III, the Exclusive Economic Zone (EEZ). The zone covers the area up to 200 nautical miles from the low water mark surrounding the coast, within which the coastal state would have sovereign rights to the exploration and exploitation of natural resources (Draft Articles 56 and 57, UNCLOS III).

As in the continental shelf debate, the main controversy has surrounded the rights of islands. There appears to be general acceptance of the definition of islands, presented earlier, as the type able to generate EEZ's. This provision would allow the Chatham Islands to generate an EEZ as advanced in the New Zealand Territorial Sea and Exclusive Economic Zone Act 1977. It is this zone that embraces the significant deposits of the Chatham Rise - between 179°E and 179°W (see figure 1.0).

It should be clear that these provisions, which have received general acceptance in principle, reinforce New Zealand's claim to the resources of the Chatham Rise. However, it is inherent in the "package-deal" approach of the convention that it may be some time before the convention is concluded and these draft provisions become International Law. Much of the opposition to these and other issues has come from the geographically disadvantaged states, for example landlocked countries, who stand to gain nothing from the resolution. They feel that the earlier declaration of the high seas as the "common heritage of mankind" is not being upheld by the legitimization of extended maritime claims. To reach a long overdue conclusion to UNCLOS III, compromise over some principles may be in order. So there is a risk, albeit small, that the draft articles discussed here may be revised. In the event of such an action, New Zealand is a very obvious target since its EEZ is one of the largest in the world due to its numerous surrounding islands and extensive coastline.
If UNCLOS III is concluded and these draft provisions ratified, New Zealand will have full property rights to the deposits of the Chatham Rise, recognized by International Law.

This concludes a discussion of risks involved in the Chatham Rise venture for each of the investors and how risk may affect the costs and benefits of a project. Referring back to the formula for maximizing net present value (p.73) there is yet another factor to be considered, externalities \( E_t(x) \). Externalities are effects that "escape" a project and are received or imposed on others (Sassone and Schaffer, 1978). Some positive externalities of the Chatham Rise project have already been identified, such as increased activity in the service industry in the port selected as an operations base. In the following chapter negative externalities, associated with the development, often termed social or environmental costs, are examined.
CHAPTER FIVE

RISK TO THE MARINE ENVIRONMENT

5.1 INTRODUCTION

The intention in this section is to examine how marine ecosystems may be affected by mining activity and to determine where the greatest risks lie. To such an end, it is necessary at the outset, to understand the condition of the existing environment. Data collected on the Chatham Rise during the Valdivia cruise (1978) and more particularly the Sonne cruise (1981), have provided the bulk of physical and biological information, specifically around the proposed mining area. Most of this information is on benthic species in particular, obtained from grab samples and videotapes of confined sections of the sea floor. This has been augmented by sparse data on plankton distribution and primary production obtained during earlier NZOI cruises, and information of fish stocks based predominantly on foreign and joint venture fishing vessel reports.

It is an unfortunate consequence of timing that information from the Sonne cruise has not yet been published. Under a secrecy agreement with the German parties, no data are to be released until the entire cruise results are published by the Germans early in 1983. However, conversations with various scientists and industry sources have provided some general information from both cruises which has helped to overcome the limitation to some extent.

Paradoxically, a second limitation stems from this. The biological information obtained on the Chatham Rise to date are systematic data on species types and very little is known about ecological relationships, how the
various species are distributed, and what controls the distribution. The paucity of this sort of information will hamper discussion on the impact or consequences of many of the effects described; such discussion could be a logical extension when ecological information is obtained. Indeed, it is hoped that by identifying areas of risk in this study, future investigators will have a more definitive idea of what parameters should be measured.

A third limitation to examining risks is that the technology and type of operation proposed for the Chatham Rise has not yet been officially disclosed. Throughout this study the author has made informed assumptions about aspects of the mining operation, such as the type of technology to be used and estimates of mine area and production. Discussions with Fletcher Challenge verified these assumptions, in general terms. Therefore the activity and types of stress that are explored in this chapter are considered to be very close to what can be expected.

As with other aspects of this study, limitations are partly offset by reliance on the published literature. Although it is recognized that the Chatham Rise environment is unique, some comparisons are possible with other mining test sites and the effects documented there. Using this information as a substitute for more comprehensive site-specific data, an attempt is made to gauge the size and/or probability of the impact so that major risks can be predicted.

To identify these areas of potential impact, this chapter will first examine the existing environment and then follow the stages proposed in figure 5.1. The process begins with the identification and description of physical stress caused by mining activity (stage 1 and 2). Stage 3 defines the character of the direct and indirect ecological response to this physical
stress. In this chapter the process is carried only to stage 4: a discussion of the consequences to society and environment from such ecological alterations. Methods of dealing with the risks identified in the process (step 5) will be discussed in the final section of this study, 'Policy Design'.

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**Figure 5.1** Process for identifying the risks or potential ecological impact of mining activity. Adapted from Harte, 1979.
5.2 Existing Environment

5.2.1 Physical Aspects

It is difficult to set physical boundaries for this study since most organisms do not recognize them and environmental effects rarely remain within such confines. Nevertheless for reference purposes, Chatham Rise will refer to the entire submarine plateau as described earlier, extending roughly east-west from the east coast of the South Island to just beyond the Chatham Islands (figure 5.2). Note the smaller western boundary in reference to the Chatham Rise fishery. The license area refers to the 70,389 km$^2$ of the Rise presently under license to Fletcher Challenge Ltd. The mining area is that part of the license area considered to obtain the most favourable deposits and at present extends from $179^\circ$E to $180^\circ$ around $45^\circ$30'S. The mine site is that part of the preferred area that is being actively mined at a particular time.

Characteristics of the Rise have already been examined at both general and site specific levels elsewhere in this study (Chapter 2(2); Chapter 3(2)). Some of the more salient features will be reiterated here. The Chatham Rise is one of three submarine plateaus offshore New Zealand (the others being Campbell and Challenger). It is an area of complex circulation patterns due to the convergence of warm, saline subtropical water and colder, less saline subantarctic water (the subtropical convergence) along its full extension. Tides and currents are erratic and strong with a mean speed of surface and mid-depth (150 m) currents estimated at 15 cm/sec (Heath, 1981). It appears that bottom currents are weaker than surface currents (Heath, in prep.).

In general the crest of the Rise has a very gradual, even surface with no large structures interrupting the relief. The terrain does become more rugged, with greater slopes and hummocky surface, in areas of high nodule concentration.
Figure 5.2. Physical boundaries as referenced in this study.
5.2.2 Biological Assemblages

Unfortunately, the description of the living resources of the Chatham Rise presented here is very incomplete. Public access to biological information, housed at NZOI, is restricted partly due to the secrecy agreement discussed earlier; the author has been able to garner only the following.

Plankton distribution and primary productivity in the Chatham Rise area is characterised by a great deal of natural variability, although data is scarce (Bradford, in prep.). Surface productivity changes markedly between winter and summer and even within seasons. Upwellings may locally boost concentrations of chlorophyll and zooplankton biomass (op. cit.). One obvious cause of this variability is the influence of the Rise itself, notably the mixing of subtropical and subantarctic water (the subtropical convergence) along its axis. The "natural" variability may well be an inherent feature of this sort of topographical influence and/or it may be refined into more distinct trends once the physical oceanography of the area is better understood. Colonies of the branching coral Goniocorella dumosa are found growing on the Rise in small patches. They are found in deposit areas as phosphorite nodules furnish a good substrate for attachment for corals and other benthic species such as crinoids (plate 4, p.22). The galatheid shrimp (plate 1) and cidarid echinoids (plate 4) are examples of the more active members of the bottom community. Burrowing organisms, such as the lugworm Arenicola, are also present in the area, churning up and aerating the soft sediment.

5.2.3 Special functions

The Chatham Rise supports an extensive commercial fishery. Both a deep-water trawl and a bottom long-line fishery operate year-round along the north and west boundaries and southern boundary, respectively (Francis and Fisher, 1979). The main commercial species are ling, hoki, hake, orange roughy, oreo dory and silver warehou. The value of total catch
(based on price per green tonne) for the area in 1980 was $10 million but this has increased substantially due particularly to the high value and catches of orange roughy, estimated to return about $20 million itself in the coming year (D. Robertson, pers.com.m.). At present the fishery in the Chatham Rise area operates as a joint venture between New Zealand companies and foreign companies.

The area holds special significance as a spawning ground. Patchell (1981) reports that hake spawn on the Chatham Rise in depths of 400-500 m during summer months. It seems probable that ling and silver warehou may also spawn on the Chatham Rise but this has not yet been determined. The western edge of the Chatham Islands is a known spawning ground for teraki and red bait (D. Robertson, pers.com.m.).

The area holds scientific interest in that it is a modern analogy for the lower Tertiary paleoenvironment in New Zealand. Several of the benthos on the Chatham Rise have fossil equivalents on land and could therefore contribute to reconstruction of a paleoenvironment and its ecological relationships.
5.3 ACTIVITY AND STRESS

General features of the technology likely to be employed on the Chatham Rise have been described elsewhere (Chapter 2(2)). In this section, emphasis is placed on those aspects of the operation which are thought to cause significant stress to the environment.

The area to be mined in any one year (the mine site) has been calculated to be $16 \text{ km}^2$ or $1600 \text{ km} \times 10 \text{ metres}$ in line dimensions. This estimate accounts for inefficiencies in present mining systems and is based on a yearly production of 200,000 tonnes, probably obtained over a course of 4-5 months (100 working days). Each day then, $16 \text{ km} \times 10 \text{ m}$ will be mined at water depths of between 380 and 400 metres. This mine area is not large by deep ocean mining standards and the actual disturbed area is a small part of the entire Rise. However, it must be equally noted that the production rate and hence mining area may well increase.

To identify particular stresses of mining activity, the operation will be traced from the sea floor to the processing plant.

The collecting vehicles measures about 8 m by 10 m and will be towed along the sea floor, disturbing a 10 m wide swath and cutting into the sediment about 500 mm. It is often depicted that the collector will mine in strips or patches leaving adjacent areas undisturbed. This does not seem very practical, however, and I suggest that this will not be the case on the Chatham Rise for two reasons. One, the low efficiency of the mining system suggests that an area will probably be mined over again to ensure that all the recoverable nodules have been collected instead of superficially covering several patches. Within an area of dense concentration, an operator will be anxious to exploit its full potential. Two, the collecting vehicle will be quite difficult to manoeuver through
a 400 metre water column and it is doubtful that evenly-spaced patches or straight lines with intermittent, undisturbed rows will be easily negotiated.

The nodule pick-up device is likely to be mechanical as the tendency is to keep the collector as simple as possible. Collected material will pass onto a conveyor and be roughly sorted at the bottom. Some glauconitic sand, ooze and perhaps glacial erratics will be removed before the trip to the surface. Nevertheless it is estimated that of the total dredged material that is lifted to the surface, one third is debris (see Chapter 3(3)). This means that 2000 tonnes of nodules and 1000 tonnes of other sea floor sediments will be recovered each day.

Material in the dredge path will be placed in suspension and this amount is estimated to be 2½ times the volume of total material lifted to the ship (Amos and Roels, 1977). For the Chatham Rise operation, this means 7500 tonnes each day of disturbed bottom sediment. Some of this material will be pumped to the surface in the bottom water while some of the material, particularly the large heavier pieces and maybe some of the sand, should resettle in the area. But most of the material will remain in suspension and be carried by currents to form a "bottom plume".

The nodule slurry is then pumped to the surface where the nodules are recovered and tailwater, containing bottom sediments, nutrients, spores, and bottom water, is released.

The bottom sediments released at the surface will consist predominantly of fine (clay-size) foraminiferal ooze. Some nodule and other rock fragments may also be present as well as the material contained in the water as resuspended bottom sediment. Nutrients, dormant spores from
the bottom, and pieces of macerated biota (caught in the dredge path) will also be contained in the tailwater. Large amounts of bottom water will be brought to the surface daily. Gerard (1976) suggests that hydraulic pumping will raise 10-20 times more water than nodules, which means that for the Chatham Rise operation about 30,000 tonnes of water will be released at the surface each day. Although bottom water is colder, it undergoes sufficient warming and mixing during the trip to the surface to remain in the upper layer after discharge (op.cit.). The release of tailwater therefore results in a "surface sediment plume" which is dispersed by currents.

The nodules are then either loaded onto a barge at sea or more likely, the mining ship will make the trip to port itself. There the nodules are offloaded via a slurry pipeline to the processing plant. Mining stress is summarized in table 5.1.
Table 5.1 Summary of proposed operational statistics and mining stress on a yearly and daily basis (assuming 100 operating days per year).

<table>
<thead>
<tr>
<th></th>
<th>Yearly (100 days)</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production (tonnes)</td>
<td>200,000</td>
<td>2,000 (nodules)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,000 (sediment)</td>
</tr>
<tr>
<td>Density</td>
<td>50 kg/m²</td>
<td>50 kg/m²</td>
</tr>
<tr>
<td>Mine Site</td>
<td>4 km²</td>
<td>4 km x 10 m</td>
</tr>
<tr>
<td>Mine Site (inefficiencies)</td>
<td>16 km²</td>
<td>16 km x 10 m</td>
</tr>
<tr>
<td>Disturbed Bottom Sediment (tonnes)</td>
<td>750,000</td>
<td>7,500</td>
</tr>
<tr>
<td>Surface Tailwater Discharge (tonnes)</td>
<td>3,000,000</td>
<td>30,000</td>
</tr>
</tbody>
</table>
5.4 DIRECT AND INDIRECT ECOLOGICAL EFFECTS

To determine what these activities mean for the Chatham Rise environment, site-specific information is incorporated with results from two main test sites in the North Pacific and North-west Atlantic. These tests were conducted under the auspices of the National Oceanic and Atmospheric Administration (NOAA), Deep Ocean Mining Environmental Studies (DOMES).

In this section there has been strong reliance on the following references: Amos and Roels, 1976; Amos et al., 1977; and Lane, 1978, for the North Pacific; and Gerard, 1976 for the North-west Atlantic.

Effects will be examined according to the sequence used in the activities description.

1. One of the direct effects that can be expected with certainty is the mortality of all benthic organisms in the path of the collecting vehicle. This will include all levels from coral and large holothurians to the smaller organisms that live within the sediment, and the protozoans that occupy the cracks and fissures of the nodules themselves.

2. The collector will also destroy the habitat for other organisms which may not be directly killed. It appears that ling (Genypterus blacodes), one of the commercial fish species on the Chatham Rise, will be affected in this way. Ling are cryptic fish, i.e. they like to hide among hummocks or corals and it has recently been determined that they also burrow into the soft sediment (D. Robertson, pers.comm.). It is no surprise, then, that they tend to inhabit areas of the Chatham Rise with greater relief and more rugged terrain - areas that also enjoy the greatest concentration of phosphorite nodules. Therefore, ling will be directly affected through destruction of their habitat. It is not known for sure whether any species spawn in this particular area of the Rise and hence, if spawning grounds will also be destroyed. Other bottom
feeding fish and cephalopods may be affected, indirectly, through destruction of their food source in the mining area.

It is difficult to say whether this affect will be temporary or not. Presumably after mining the sea floor will still provide a soft substrate for organisms although it will be churned up and many of the nodules removed.

3. As explained in the previous section, the collecting vehicle will stir up considerable amounts of sediment (about 7,500 tonnes per day). Some of this will be lifted to the surface in bottom water; some should resettle fairly quickly, but much of this will remain in suspension and be carried by bottom currents. The bottom currents on the Chatham Rise are cold, dense Antarctic water and are quick moving. Recent current measurements taken at a depth of 393 m recorded a maximum speed of 24.2 cm/sec. (Heath, in prep.) which suggests material may be moved considerable distances. Apparently, silt-size particles (0.06-0.004 mm diameter) placed into suspension will be displaced by a current of 10 cm/sec about 3 kilometres (Gerard, 1976). The material placed in suspension in bottom waters of the Chatham Rise is likely to be fine silt and clay-size (.004-.001 mm diameter), subject to stronger bottom current and may therefore be carried much greater distances.

During tests in the Pacific it was noted that the bottom plume persisted for a few days, considerably longer than the surface plume (Lane, 1978). It is contended that the behaviour of the bottom plume and the potential effect of all this material in suspension is one of the greatest unknowns in deep ocean mining (Amos and Roels, 1977).
4. Tailwater discharge at the surface will contain fine sediment and nutrients from the bottom. The dispersal of sediment will reduce light penetration in the surface layers (the euphotic zone) and additional nutrients may increase biological activity. Plankton are dependent on light and nutrients and as such, changes in these parameters may affect productivity. Spores transported from the bottom may introduce new species into the surface waters.

In all the tests by the DOMES study, surface plumes created by the tailwater discharge dispersed very quickly: in the North Pacific, surface currents of 15 cm/sec completely flushed an area 30 x 150 km in eleven days; in the northwest Atlantic, a plume was diluted to 0.05% of its original concentration eight minutes from discharge (Amos and Roels, 1977). The current speed measured for the North Pacific case of 15 cm/sec is the same as the mean speed reported for the Chatham Rise (Heath, 1981) suggesting that a surface plume there would disperse just as quickly.

It is maintained that this rapid flushing is not likely to cause the posited changes in plankton productivity through increase in nutrient concentration or reduction in light penetration (Gerard, 1976; Amos and Roels, 1977; Lane, 1978). Gerard adds the proviso that mixtures of 10% bottom water and 90% surface water will significantly affect phytoplankton growth. The mixtures resulting from hydraulic mining systems are substantially less than this (probably about 1-2% bottom water).

5. Tailwater discharged at the surface will also contain spores and bacteria from the bottom. There is serious concern that spores transported from the bottom may introduce new species into the surface waters. Organisms which may be dormant in bottom sediments may grow in surface
waters, ultimately changing species composition in the area (Gerard, 1976; Amos and Roels, 1977; Lane, 1978). As well, sediment discharge may result in increased bacterial growth due to the increased availability of surfaces for attachment (NOAA, 1975).

6. Some other effects are more difficult to predict. Trace elements, derived from the fine (abraded) nodule pieces in the discharge may be removed from sea water by plankton, especially zooplankton in a variety of ways. Small fish and other organisms feed on these microorganisms which in turn are food for larger predatory fish and eventually, if they are commercial species, make their way to humans. At each trophic level, substances become more concentrated, i.e. less is excreted than ingested (Forstner and Wittmann, 1981) and the final concentrations of trace metals in particular may have very damaging effects on health.

The composition of trace and major elements in the Chatham Rise phosphorites is recorded in tables 1.2 and 1.3. Of these trace metals considered "very toxic and relatively accessible", (op.cit.) only one, lead (Pb), is present in the phosphorites. Apparently rock phosphates usually have high levels of trace elements, particularly cadmium (Cd) (op.cit.), another very toxic metal, but there is no Cd present in the Chatham Rise samples. From the other trace elements present in relatively high concentrations in the phosphorites, three are considered "toxic but very insoluble" - zirconium (Zr), barium (Ba) and lanthanum (La). The others present, rubidium (Rb), strontium (Sr), fluorine (F) and chlorine (Cl) are considered non-critical. The greatest risk to health therefore, appears to be from Pb assimilation. It has been expressed (D. Cullen, pers.comm.) that trace metals would probably not be released into seawater in the first place. The nodules have a glauconite coating which seems to armour them fairly well, reducing abrasion and the subsequent release
of any trace metals. However, the glauconite coating has not been analyzed for its trace metal content; it is known to contain uranium, although in lower concentrations than the "inner" nodule. Trace metals could also be present in the associated sands and muds on the Rise but these have not yet been analyzed. As well, it remains to be seen whether abrasion will not occur once 3000 tonnes of nodules and associated sediment are pumped daily to the surface when mining commences.

As well as trace metals other compounds will be released from the interstitial water of bottom sediments or the sediments themselves and may be retained (in solution) in seawater.

7. The effect of the sediment plume on larger pelagic species is expected to be insignificant since they tend to avoid turbid areas (Lane, 1978) and if food supply is affected, fish and birds will simply shift to areas where food is more plentiful.

8. Although dispersal of the surface plume is quick, the ultimate settling of this material is an unknown. Once subject to the erratic currents of the Chatham Rise, the fine sediment, mostly ooze, may be carried for hundreds of kilometres; settlement of ooze may take anywhere from 4 to 104 years (World Environment Report, 1982, p.7.). The effect of this material on marine life in the various depths it will occupy en-route to final resettlement remains a question mark. In particular, only 278 km (150 nautical miles) to the east of the mining area, the Rise breaches the surface to form the Chatham Islands. This sort of natural barrier would cause deposition of the fine sediment on its western margin - a build up which may, over time, change that environment considerably.
5.5 CONSEQUENCES OF ECOLOGICAL EFFECTS

Simply identifying the effects never seems to satisfy the question of how the environment will be affected or what does this mean for society. One consequence of the removal of benthic organisms in the mining area is the loss, for scientific purposes, of modern analogs of Tertiary fossils found in New Zealand. Presumably though, similar communities can be found elsewhere on the Rise. Nevertheless some argue that organisms have a right to preservation (an intrinsic value) even if they have no particular social or economic value (Stone, 1974).

The presence of Pb as a trace metal in the phosphorites and hence in the sediment discharge at the surface raises some important questions. Preliminary investigation suggests the glauconitic coating of the Chatham Rise nodules may minimize this risk. This is an aspect that must be pursued because if lead is ingested by zooplankton and eventually concentrated in various trophic levels, it may damage the health of larger fish species and humans who eat the fish.

An issue of mounting concern is the potential impact of mining on the commercial fishery of the Chatham Rise. This will be examined in the following paragraphs.

5.5.1 Chatham Rise Fishery

The Chatham Rise supports a major commercial fishery based at present on six demersal (bottom-feeding) species: ling, silver warehou, hake, hoki, orange roughy and oreo dory. The total biomass estimate for these species on the Chatham Rise (from 176°E eastward) was 600,000 tonnes in 1980 (J.A. Colman, pers.comm.). Total allowable catch (TAC) for that same year was placed at 80,000 tonnes with about 26,000 tonnes recovered for a total value of $10 million (op.cit.). For the coming year (1982-83) the
TAC recommended by Fisheries Research Division is about 70,000 tonnes (D. Robertson, pers.comm.). As shown in table 5.2 the price for most species has risen considerably, thereby greatly increasing the value of the Chatham Rise fishery.

It was determined in the previous section that ling is the species that will probably be most affected by mining through direct destruction of its habitat. The Koreans and to a lesser degree, the Japanese, have been most active in the ling longline fishery on the Chatham Rise but their fishing effort has reduced dramatically since 1979 with only a small amount of trawling for ling now done in the area. The reason for this is not clear but is suspected to be due to either higher costs to foreign vessels fishing on the Rise under the terms of the Exclusive Economic Zone as declared in 1970, or else because of declining fish stocks. Unfortunately, there is no way for fisheries scientists to monitor fish stocks except through catch reports of vessels fishing in the area, and quotas are established on this basis. Although ling catch was down in 1979 from the previous year it is not known how catch related to fishing effort. So the state of the ling stocks on the Chatham Rise remains an unknown.

In 1978 total catch of ling on the Chatham Rise was 6,405 tonnes. The area currently held under license by Fletcher Challenge has recorded good catches of ling with two "hot-spots" of anomalously high amounts in the south-east corner.

In the two block square around the preferred mining area (179°E to 180°; 43°30'S) ling catch in 1978 is estimated at 115 tonnes. At a price per green tonne of about $500, the value of ling in the proposed mining area in 1978 was about $57,500.
Table 5.2. Total allowable catch and value of six commercial species on the Chatham Rise. (Source: Fisheries Research Division, Wellington.)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Ling</td>
<td>10,000</td>
<td>$500</td>
<td>$1100</td>
</tr>
<tr>
<td>Silver Warehou</td>
<td>2,000</td>
<td>$1000</td>
<td>$1000</td>
</tr>
<tr>
<td>Hoki</td>
<td>15,000</td>
<td>$500</td>
<td>$1000</td>
</tr>
<tr>
<td>Hake</td>
<td>1,000</td>
<td>$500</td>
<td>$1100</td>
</tr>
<tr>
<td>Oreo Dory</td>
<td>5,000</td>
<td>$250</td>
<td>$250</td>
</tr>
<tr>
<td>Orange Roughy</td>
<td>20,000</td>
<td>$850</td>
<td>$1000</td>
</tr>
</tbody>
</table>

Notes:
1. Total allowable catch as per FRD recommendations for 1982.
2. Value per green tonne – present and projected prices.

In the next year, total catch of ling on the Rise dropped about 17% to 5,347 tonnes. In the preferred mining area the catch is estimated at 100 tonnes, giving a value of $50,000 in 1979. The distribution of the 1979 ling catch in the license area is shown in figure 5.3.

The significant increase in fish price (table 5.2) from $500 to $1100 per tonne as projected for 1982 means the value of the ling fishery on the Chatham Rise has more than doubled. Using this figure the value of ling in the mining area, if a similar catch as 1978 was obtained, would be worth $126,500 in the coming year. Net return estimates were not available for the ling fishery.

This figure represents a component of the opportunity cost of mining to the ling fishery if mining destroyed all the ling in the mining area.
As such, there exist many disclaimers. First, although it is fairly certain that mining will destroy the ling's habitat, there is much uncertainty over the response of ling to this stress. Will they simply move to undisturbed areas with no decrease in total numbers or will the change in distribution somehow adversely affect population dynamics and total ling catch in the area? Secondly, mining will occur in phases so only small areas will be affected at any one time. In addition, if the operation proceeds for only part of a year (the rental option) these stresses will be confined in time. Thirdly, how 'healthy' are ling stocks on the Chatham Rise? The difficulty in obtaining such information on stocks and the lack of recent data from fishing vessels means it simply is not known. This alludes to the final point: at present the potential value (of the ling fishery) is not being tapped.

There is a small trawl fishery for ling on the Rise but this is severely reduced from the foreign effort (Korean and Japanese) prior to the EEZ regulations. During that pre-regulation period, New Zealand itself did not receive much benefit from its ling resource with the exception of license fees and small tonnage payments.

The ling fishery has been emphasised here because ling are common in the mining area, and will probably be most directly affected by mining. It is difficult to say anything about species that do not occur in the mining area but may be indirectly affected by the introduction of quantities of fine sediment and other gradual changes in the environment. Oreo dory and orange roughy, for example, occupy deeper depths than ling (about 500 m to 1000 m) and in recent years have become the most important commercial fish species on the Rise. They will probably be the only species to reach their full catch limits next year (D. Robertson, pers. comm.). The projected prices for 1982 gives orange roughy alone a value of $20 million and oreo dory $1.25 million. It is little wonder that the
area has become so important to the New Zealand joint venture fleet (which, as of May 1982, includes Fletcher Fishing, a subsidiary of Fletcher Challenge Ltd).

Consequences for the Chatham Island fishery are also difficult to assess. The Islands may act as a natural trap for some of the sediment in suspension, something which may have adverse effects on the rock lobster fishery which is the mainstay of the economy on the Chatham Islands.
5.6 CONCLUDING COMMENTS

The DOMES tests have been very useful in documenting the stresses and potential effects of deep ocean mining on marine ecosystems. But these studies have been concerned with the short term effects only; there is much uncertainty in predicting the response of benthic organisms and demersal fish to the stresses of mining over the long term. Many of these responses are gradual changes which are not only difficult to predict but also difficult to measure.

One of the main variables in determining the overall effect on benthic populations in the mining area is the pattern of recolonization. It is simply not known how much time is necessary for recolonization or what type of species can be expected. It is alleged that the undisturbed patches or strips will aid recolonization considerably but as discussed in the previous section, the pattern of mining adopted for the Chatham Rise is not expected to leave such untouched areas. Generally speaking, most benthic organisms in similar water depths have very slow reproductive and growth cycles; the corals on the Rise for example, are thought to have a slow growth rate.

As well it is difficult for tests at a mine site to determine how these effects will spread in space. Mining activity, initially at least, will be confined to a relatively small area of the Chatham Rise; however, the effects of mining will recognize no set boundaries. Therefore, there are many questions about how these effects will spread, the magnitude of the consequences - physical, social and economic, and how these consequences will be distributed. There is no guarantee that impacts will gradually diminish in space and time as shown in figure 5.4a. Instead of becoming diluted, some consequences may become very dramatic for some "sectors" not connected to the development or its timing as shown in the
alternative viewpoint of impact distribution (figure 5.4b). It is not the intention here to suggest that the alternative viewpoint represents the Chatham Rise case but rather to show that we cannot assume the simpler version.

![Diagram of impact distribution patterns](image)

**Figure 5.4.** Alternative patterns for the distribution of development impacts (From Holling, 1978a, p.29).

Figure 5.5 is a summary diagram of the major risks identified in this chapter. It is an attempt to fill in some of the blanks for the Chatham Rise and in the process has opened up a myriad of others. How will the destruction of benthic organisms in the mine area or the possible introduction of trace metals and other materials reverberate throughout the ecosystem? Although aquatic ecosystems have small biomass relative to land systems, it occupies a greater variety of trophic levels making them more susceptible to pollution influences (Forstner and Wittmann, 1981) and providing more pathways for effects to travel. What will be the impact of long term build up of fine sediment in near bottom waters, probably over
ACTIVITY
- Phosphate mining on the Chatham Rise

STRESS
- turbation in dredge path
- bottom sediment plume
- release of tailwater at surface
- surface sediment plume

DIRECT ECOLOGICAL EFFECTS
- destruction of benthos in dredge path
- destruction of ling habitat
- introduction of bottom spores at surface
- no predicted effect on plankton production
- ingestion of trace metals by zooplankton?
- destruction of spawning grounds in mine area?

INDIRECT ECOLOGICAL EFFECTS
- decrease in demersal fish and other bottom features?
- decrease in ling population in mine area?
- concentration of trace metals at higher trophic levels?
- adverse effect on benthos on Chatham Rise over long term?
- decrease in population of spawning species?

CONSEQUENCES
- decrease in commercial ling fishery?
- decrease in other commercial species on the Chatham Rise?
- health risks from eating (metal) contaminated fish?
- destruction of area of scientific interest

Figure 5.5. Summary points: Potential impact of mining on the Chatham Rise.
much of the Rise? And, as just demonstrated, may questions surface about the consequences for the Chatham Rise fishery. The efforts of environmental investigators in this project must be channelled toward a general determination of how the marine environment on the Chatham Rise will respond to stress and whether the effects of mining will be irreversible.
Conclusion to Part II

In the introduction to Part II it was posited that the net present value, or net social benefit, of a project was subject to various constraints: resource potential, technology, economics, legal and administrative considerations, and risk. This last factor, risk, was earmarked as being a significant influence on costs and benefits in projects such as the proposed mining of the Chatham Rise. In Chapter Four, risks were identified for each investor in light of the objectives proposed for them in this study. The potential impact on the marine environment was then discussed in Chapter Five to illustrate the implications of development for the natural environment. What has a perspective of risk determination yielded about the proposed mining? The following paragraphs sum up the more salient risks and discuss the consequences or conflicts that result.

For Fletcher Challenge the mining option which appears to entail less risk is the rental of a mining vessel, probably from the Germans. It allows them a smaller production; does not involve large stockpiles or a large initial capital investment (a mining ship); and it confines their operations to 4-5 months per year. For New Zealand, this option allows the resource to be spun out over a longer time; disruption to the sea floor and sediment discharge is confined in time; but, employment opportunities (in mining) are fewer.

One of the risks which emerges as having far-reaching consequences is that, once underway, mining may be more costly than anticipated. For Fletcher Challenge it appears that one of their first moves, according to the economies of scale argument, would be to increase production. There are several options available for use of the additional phosphorite:

1) stockpile

2) market as a blend with super, or
3) export.

Stockpiling increases economic risk for Fletcher Challenge, costs which would probably be passed on to the consumer. To market it as a blend would advance their manufacturing interests but cause consternation among present fertilizer manufacturers who feel Fletcher Challenge should be more tightly tethered. Exporting New Zealand's phosphorite resource is not in the national interest, nor is it likely to be economic for Fletcher Challenge. In addition, from an environmental standpoint, increased production means increased stress on the environment: more suspended sediment, among other things, at the surface and the bottom.

Let us examine the alternative: if mining costs increase but production is not stepped up to offset rising costs. Such costs would presumably be passed on to the consumer but Fletcher Challenge must keep the price low or else risk market rejection. Even if the cost of mining per se does not rise, the unstable international phosphate market may cause them to drop their price to remain lower than super. Obviously Fletcher Challenge will seek an arrangement with the government, incentives that minimize the risk of inhibiting profits. The most familiar of such incentives is the guaranteed price which entails a government subsidy - although it was observed earlier that the government is moving away from subsidizing fertilizer in this country. Such a double standard will raise more than eyebrows among fertilizer manufacturers. Another risk to Fletcher Challenge's marketing success is the import of other types of reactive rock and they will certainly require a restriction on such imports before they commit themselves to such a small market (direct application fertilizers). Environmental regulations, may also increase mining costs and a trade-off may be sought between such impositions and a guaranteed price in the market place.
So the risk of mining costs increasing, for whatever reasons, produce several options for Fletcher Challenge to maximize economic efficiency and these options all have consequences for the nation. This illustrates well the conflict between an economic notion of efficiency and a political notion of equity.

It is a curious aspect of the Chatham Rise project that the joint venture partners, the German interests, share none of these risks. "A joint-venture is an association of two or more partners who share the risks and benefits of a commercial venture." (Kaczynski and LeVieil, 1980, p.2). Therein lines the answer - the Germans are apparently not interested in capturing the benefits of marketing the phosphorite and hence share none of the risks. As proposed, their objectives centre around testing their technology toward advancing their other deep ocean mining projects and the risks identified for them centre around this concern. They shoulder much of the technology risk but at the same time, the success of the technology is the underpinning of the whole project and as such, is also a risk for Fletcher Challenge and the New Zealand government. Coincident with their other interests, economic risk to the Germans is minimized because it can be spread among their various deep ocean mining ventures. In the feasibility study, at least, Fletcher Challenge has assumed 75% of the costs, which suggests that their manufacturing interests are worth the greater share of economic risk that they have assumed. The Chatham Rise mining is very much a means for Fletcher Challenge (to gain entry into fertilizer manufacturing) and an end for the Germans (a test of their technology and nothing more). This does, however, heighten the risk of delay for the German partners. In fact, they may be anxious to proceed before Fletcher Challenge can see a profit, or a market, for the Chatham Rise phosphorite.
Finally, let us turn to the government. The benefits of developing the phosphorite can be summarized as: revenue from license payments and taxes; foreign exchange savings; the availability of an alternative fertilizer to consumers; and, a secure (indigenous) supply of that fertilizer during the mine life. Some of the costs of opening up the phosphorite for development may be: damage in the short term to the benthos and demersal fish, ling in particular, in the mining area; potential adverse effects over the long term on marine life, including commercial fish species, over much of the Rise; and, disharmony among fertilizer manufacturers over Fletcher Challenge's presence in the industry.

The New Zealand government faces the inevitable decision over whether, broadly speaking, benefits outweigh costs. First, alternative fertilizers could also be made available by importing reactive rock, some of which is higher quality than CRP. Second, if an indigenous supply is the operative factor, just how secure is the supply? A brief look at the international legal situation demonstrated that a risk, albeit small, exists over the security of New Zealand's property rights over the Chatham Rise. But a greater risk to supply security may lie with the objectives of the commercial interests. Let us posit that after a few years of operation, rising mining costs begin cutting into profits for Fletcher Challenge and it has already firmly established itself in fertilizer manufacturer. How committed will they be to continue developing the phosphorite resource? Obviously any commitment by Fletcher Challenge to mine for X years will have to be met by an attractive price guarantee from the government to assure a continuous supply for consumers. Interruptions in supply may not even be so deliberate - German interest may well wane after their test objective has been achieved. Increasing commitments for the mining ship may affect its availability for the
Chatham Rise operation. Ironically, for the government, advancement of one of its objectives may be threatened by protection of some of its others. For example, to minimize social and environmental costs, regulations may be imposed on the operations which may, in turn, delay its incipience and the supply of the phosphorite resource to consumers. This highlights one of the significant conflicts for the New Zealand government: a goal of maximum social welfare involves many objectives, some of which, as in the mining project, produce risks for the others.

Risks have been identified and it has been determined that some objectives are conflicting because of the risks they introduce for the other investors. As well, ways of minimizing risk for one may be conflict with another's objectives for investment in the Chatham Rise development. The next question is how should these risks and conflicts be dealt with. To that end, the policy and decision-making process for developments such as the proposed Chatham Rise mining will be examined in the final section of this study, Part III.
PART III - POLICY DESIGN

"... the proper focus for policy is on the consequences of the inherent uncertainties that will always remain. If prophecy is impossible, then go for understanding." (Holling, 1978a, p.133).
CHAPTER SIX

EXISTING POLICY AND RECOMMENDATIONS

6.1 INTRODUCTION

A project may be appraised from several different angles as witnessed by the myriad of analytical techniques that exist. The approach adopted in this study is risk assessment, more particularly risk determination as discussed in Part II. This tool was chosen because of the nature of deep ocean mining which suggested that many risks exist for such developments, and the early stage of the Chatham Rise mining project which indicated that identification and recognition of risk could be used effectively in planning for the development. This conceptual framework has yielded much about the proposed mining.

Several risks have been identified for the three investors (New Zealand, Fletcher Challenge Ltd., and German interests) based on their objectives, and risks have been identified for other resources which are not the target for development but may be adversely affected. As well, it has been demonstrated that some methods of minimizing risk may have adverse consequences for other objectives, thereby creating new risks. For example, actions by the mine operator to avoid unwanted consequences imposed by nature on the operation may in turn, cause unwanted consequences for the environment. So the identification of risks associated with the development has led to the determination of conflict, or conflicting objectives.

Dealing with conflict inevitably involves trade-off. "Trade-off" is an economist's term which simply means more of one thing is associated with less of another (Mishan, 1981). In this instance, a trade-off must also
recognize risk, a significant aspect of the Chatham Rise mining project, if a balance is to be achieved between conflicting objectives.

Such balance will have to be negotiated between the commercial interests in the Chatham Rise venture because of the German concern with timing, for example, and Fletcher Challenge interest in market factors and a profitable mining venture. Balance will have to be achieved even within Fletcher Challenge where trade-off may be necessary between profit from mining and a timely debut into fertilizer manufacture. But the emphasis in this chapter is on the national rather than private interest and the balance that must be achieved within New Zealand. The narrower private interests do not use the same criteria to make decisions as the wider social interests. New Zealand's overall goal of maximizing social welfare encompasses many other national objectives which may be affected by a particular resource development. As well, New Zealand holds property rights to the phosphorite resource, logically placing resource management in the hands of the national government. It is over to decision-makers then, to balance conflicting objectives. Trade-offs will be necessary between private gain - extracting and marketing the phosphorite at least cost, and social and ecological well-being. Furthermore a balance will have to be realized between immediate national goals and concern for the welfare of future generations; between short-term benefits and long-term risks.

In the jargon of multiple-objective analysis, this means determining the "optimal", the best course of action according to some agreed criteria (Young, 1977). Risk is stressed here as a significant criterion for the mining project although it is acknowledged that it is by no means the only one. Whatever the criteria, an optimal solution will not maximize the interests of each investor, harking back to Mishan's
definition of trade-off. Ideally though, the optimal solution is one that "... maximizes private and social benefits and minimizes attendant social and private costs" (Paget and Lloyd, 1982). To accomplish this, the decision-maker must make vexing value judgements or value trade-offs - the so-called "decision-makers dilemma" (Bell et al., 1979). This process involves accepting or placing lower weight on some objectives to obtain higher value on others. Such optimal decisions regarding the allocation of resources, made within a given economic, social, political and institutional framework is labelled by O'Riordan (1971) as wise resource management.

The framework for decision-making or resource management is policy. As predicted by O'Riordan and Sewell (1981), project appraisal is inextricably tied to policy appraisal, and often leads to policy review. What is present policy for development of resources such as the Chatham Rise phosphorite? In this chapter, existing policy governing resource use on the Chatham Rise will be examined and reviewed, followed by recommendations for a more comprehensive policy.
6.2 PRESENT SITUATION

6.2.1 Existing Institutional Framework

Legislation:

New Zealand holds property rights to the minerals of the Chatham Rise under the terms of the Continental Shelf Act 1964 and the Territorial Sea and Exclusive Economic Zone Act 1977. The Continental Shelf Act, administered by the Ministry of Foreign Affairs, is the legislation specifically concerned with the exploration and exploitation of marine minerals. Mineral licenses are granted in accordance with Section 5 of the Act and they are administered by Mines Division, Ministry of Energy. There are no fixed terms for the license outside the general conditions set out in Section 5, so licenses may vary according to application.

A mineral license was granted to Fletcher Challenge Ltd. for an area of the Chatham Rise (see Chapter 1) on 21 May, 1981. The term of the license is three years with an option of renewal for a further three year period. The license authorizes them to "prospect and mine for, and carry on operations for, the recovery of any minerals ... in the [license] area" and prescribes several conditions. As well, the licensee must comply with any New Zealand laws that apply or may in future apply to activities conducted under the license. Some of the key conditions of the license will be discussed in the following paragraphs.

A minimum work program is stipulated in Section 3

3. Within the term of this license, the licensee shall carry the following minimum work programme:

(a) Carry out exploration to further evaluate and delineate known occurrences of marine phosphorite and associated minerals and to develop and test mining devices for their extraction. Within the areas delineated on the attached plan as being areas of prime importance for commercial fishing no mining devices shall be tested;
(b) During the course of prospecting operations, the licensee shall undertake studies which will provide information for inclusion in an environmental impact report which is to be prepared in support of any application for a further license under section 5(2) of the Continental Shelf Act 1964, as provided for in condition 23 of this Schedule, in respect of the area specified in this license or in respect of any part of such area.

This work programme shall not be varied without the prior approval of the Ministry of Energy.

Part (a) describes the type of exploratory/development activities that must be executed and specifies three areas which cannot be used for testing. One of these is the ling "hot-spot" area, described in Chapter Five of this study, and the other two areas (Mernoo Bank and Veryan Bank on the western edge of the Chatham Rise) have since been excluded from the license area. Part (b) is for the provision of information by the licensee for inclusion in an environmental impact report (EIR) which is necessary only if another, further license is pursued. Every six months details of the work program, including expenditure, must be submitted to the Inspector of Mines.

Sections 11-21 of the license are regulations concerning existing navigation and fishing activities. Sections 16-18 are particularly important to the Chatham Rise case and are self-explanatory:

16. All proper precautions and any specific precautions may from time to time be required by the Director General of Agriculture and Fisheries and the Secretary for Transport after consultation with the Inspector of Mines, shall be taken to prevent adverse effects on fish or shellfish or any marine farming.

17. Works shall not interfere with the rights of the public or commercial interests to take natural stocks of shellfish or fish.

18. At all times prospecting shall be carried out in a manner that will cause as little disturbance to the seabed as is reasonably possible in carrying out the work programme permitted under this license or any renewal thereof.
Conditions 6 and 7 govern the availability of information: operations reports, geological material, hydrographic and oceanographic information must be made available to specified government departments. Other conditions of the license are concerned with fees, rights of renewal and transfer and surrender rights. If the licensee fails to comply, or make an effort to comply with the conditions of the license, the licensee will be given notice by the Ministry of Energy to remedy the situation in 90 days. If this is not complied with, the license may be revoked (Section 10).

Parties Involved:

The main actors and investigators in the proposed Chatham Rise development are shown in figure 6.1. Since the granting of the mineral license in May, 1981, activity has centred around processing and examining the resource data collected on the exploration cruises, particularly the more recent Sonne voyage, and investigations of agronomic, economic and technical aspects. This mandate has been dispatched among various government agencies and private consulting groups. New Zealand Oceanographic Institute (NZOI) appears to be the principal government investigator, examining plankton productivity, benthic species, the geology of the deposits, and physical oceanography of the Chatham Rise. Some work is proceeding at Fisheries Research Division (FRD), a department of the Ministry of Agriculture and Fisheries (MAF) on commercial and other fish species in the area but without additional data research in this area is limited. Agriculture Research Division (ARD) of MAF is researching the agronomic potential of the phosphorite; other trials have been conducted independently at the Department of Soil Science at Massey University.
Figure 6.1. Parties involved in various stages of Chatham Rise resource development.

KEY (ABBREVIATIONS NOT EXPLAINED IN TEXT)
NZGS - New Zealand Geological Survey; DSIR - Department of Scientific and Industrial Research
MFA - Ministry of Foreign Affairs; <F-C> - Consultants to Fletcher Challenge Ltd.
NZFMRA - New Zealand Fertilizer Manufacturers' Research Association
Several other government departments are involved in the Chatham Rise development but not in active research. The Ministry of Trade and Industry (MTI) takes a promotional interest in new products or projects within New Zealand and so have been involved at ground level with CRP, examining its potential and advising the government. Commission for the Environment (CPE) are involved in as much as they are responsible for the EIR clause in the license and may have to prepare an audit.

In similar fashion, Mines Division of the Ministry of Energy (MOE) only active involvement at this stage is to receive the semi-annual reports of the work program. Ministry of Transport (MOT) is included because of their responsibility for navigation in the license area. Fisheries Management Division (FMD) of MAF is keeping an eye on commercial fishing interest in the area.

Fletcher Challenge has engaged several private consulting groups for various aspects of the project: GeoResearch Associates (marine geophysics and resource assessment); Subsea Surveys Ltd (oceanographic equipment); Beca, Carter, Hollings and Ferner Ltd (Geotechnical investigation); ANZDEC Ltd (agronomic potential); and a group from the University of Otago (environmental aspects). Investigations by the latter group are at an incipient stage only and contract work by GeoResearch Associates is near completion; the status of the other three groups is not known. The Germans have continued their own technical investigations on the design of the mining system.

It appears that the only interaction of the various factions occurred in April, 1982, at a meeting organized by Fletcher Challenge in Wellington. The Germans were not present; they liaise mostly with Fletcher Challenge and their research information effectively stops there. The purpose of the meeting was to identify problem areas and future research needs and
on that score it has been labelled a success by most participants. There has been no obvious progress or additional meetings scheduled since the April meeting. It appears that most activity is on hold until the commercial interests make a decision on mining.

6.2.2 Implications of Existing Framework

Legislation:

A framework has not yet been devised to govern commercial mining specifically on the Chatham Rise and, as such, a discussion of the implications of existing policy will concentrate on the conditions of the mineral license and the institutions involved, as just outlined.

In researching this study various terms were encountered for the license granted to Fletcher Challenge - exploration license, mining permit, prospecting license. The confusion appears to be rooted in the type of legislation governing the grant of a license. Under the Mining Act 1971 and Amendment 1981, there is a three tiered system starting with an "exploration" license, followed by a "prospecting" license, and ultimately a "mining" license. However, under the Continental Shelf Act 1964, the term is simply "mineral" license which does not immediately clarify the intended activity. Indeed, this confusion is further extended by the wording in the current mineral license held by Fletcher Challenge.

As explained in the previous section, Section 5(2), of the Act authorizes "... the licensee to prospect and mine for, and carry on operations for the recovery of, minerals or of minerals of any specified kinds in any specified area of the continental shelf." This general authority is of course subject to the conditions set out in the license. However, the terms of the license are very weak in defining the type of activity permitted. Section 3(a) of the license (see previous section 6.2.1)
outlines a minimum work program which stipulates what must be done during the term of the license but nowhere is it specified what must not be done. In other words, there is really nothing in the present license to prevent pilot mining or even full-scale mining to take place. It is little wonder that there has been confusion over the proper term for the license. It may be argued that the short term of the mineral license, three years, is sufficient to restrict such activity but under Section 22 of the license renewal for a further three year term is possible. Considering the "head start" Fletcher Challenge has enjoyed with earlier reconnaissance work done before the granting of the license in May 1981, it is by no means inconceivable that pilot mining and maybe even full-scale mining could occur within a six year period.

A further implication of the "minimum work program" concerns the conditions surrounding the EIR as provided for in Section 3(b) (see previous section). First, an EIR is not required until a "further" license under the terms of the Continental Shelf Act 1964 is applied for. This "further" license is not to be confused with a renewal; this means an EIR is not necessary until possibly six years from the start of activity under the original mineral license. Second, the wording is very vague concerning how much the licensee should contribute in time or money to the EIR: "... the licensee shall undertake studies which will provide information for inclusion in an environmental impact report..." (Section 3(b)).

Both of these points have already produced consequences for the Chatham Rise project. Since an EIR is not required until five years down the road, there is no pressure on Fletcher Challenge to commit money to environmental surveys at an early stage. Species information, particularly of benthos, was obtained during the recent Sonne cruise although ecological relationships remain an unknown. Likewise, understanding the
distribution and behaviour of fish populations in that area will require additional data and research. There has already been some dispute and misunderstanding over which party is responsible for data collection and research. The wording of Section 3(b) suggests that Fletcher Challenge may not be responsible for the entire substance of an EIR and they are obviously reticent about commitments toward environmental research until the commercial feasibility of the project is affirmed.

Likewise, government agencies are not willing to spend taxpayer's money to obtain information on what may become a commercial venture. Some also point out that research time is at a premium and the Chatham Rise project may divert attention from other important national projects.

The end result of this Catch 22 situation is that work on establishing an environmental baseline is not being done and may well continue that way even after a decision for commercial development is made, i.e. until a new "further" license is necessary. Another problem with the proposed scheduling of the EIR is that it may not leave enough time for the ensuing audit by CFE, which will probably require at least six months preparation. Clearly, then, the EIR has been introduced as an afterthought, something tacked on the end of activities before permission to proceed is granted. As such, without the necessity of a commitment or appointed responsibility, the EIR will be treated that way by commercial interests and the government.

Some of the other sections related to environmental matters are also loosely worded, particularly sections 16 through 18 (see page 145). Examples are such phrases as: "proper precautions to prevent adverse effects on fish..." (Section 16); "works shall not interfere with the rights of the public or commercial interests .. to fish" (Section 17); and, "prospecting ... in a manner that will cause as little disturbance
to the seabed as is reasonably possible ..." (Section 18). In the first instance, how can proper precautions be established without understanding what aspect of the operation may be causing stress or if and how populations are affected? Baseline studies and data charted over a time period are necessary now to help determine if changes to fish populations and other organisms are the result of mining or natural variability. Yet there is no complementary provision for the implementation of such studies. Likewise, for Sections 17 and 18, there is no method proposed to determine whether these conditions are being upheld. "Interference" with fishing may occur over the long term from the cumulative effects of mining and it is not something a patrol boat can determine. It is obvious that measurement and enforcement of such regulations is only possible if baseline studies and a monitoring program also become regulation. As well, how much disturbance is "reasonably possible" with an unfamiliar, novel technology? These regulations have been drafted without an understanding of the technology planned for the Chatham Rise.

Parties Involved:
As illustrated in figure 6.1, steps in the development of the Chatham Rise project have involved several government agencies. Add to this private consultants to Fletcher Challenge and other independent groups and the result is a vast array of interest with no real co-ordination.

On the face of it, Fletcher Challenge cannot take the helm and direct research because of their obvious bias and similarly, a government-lead project would soon straddle the fuzzy line between assistance and intervention. So the project has proceeded very much in piecemeal fashion with the only attempt at integration being the April 1982 meeting of interests organized by Fletcher Challenge. In an effort to obtain information for this study, some consequences of this piecemeal approach became apparent.
Some of the problems simply stem from the heady combination of industry and government. Obviously, Fletcher Challenge and their consultants operate on a schedule with a sense of urgency not equally shared by government departments. As well, the intentions and research of the German commercial interests have been largely unknown at this end owing to the confidentiality the Germans have demanded for technologic aspects. The secrecy agreement over research and cruise reports has added headaches and some of the parties involved seem confused over what material is restricted, which does not assist members of the public who are seeking information.

Other problems are rooted in the lack of a broad policy directive to guide research. Some departments are not sure what answers are required, for whom, or what priority the Chatham Rise project should receive. The result has been confusion over whether private or public interests should be conducting research. For example, Fletcher Challenge has expressed concern about access to seismic data and biological samples (from the recent cruises) housed at NZOI but not being actively worked. The situation becomes tangled because of NZOI's involvement earlier in the piece, before the renewed commercial interest in the phosphorites. At present both sides are doing a delicate dance over their roles in the project and attendant priorities.

Moving away from research and into the agencies involved in regulation (figure 6.1) there is conspicuous authority vested with Mines Division, particularly one person, the Inspector of Mines. Although the license is officially administered through the Minister of Energy, it is the Inspector of Mines who stipulates the minimum work program and reviews its progress. That person is the direct liaison with the licensee. It does not seem practical to lodge such control in one department and one
person when that department is not involved in any other aspect of the project nor is compelled to integrate any other aspects into the regulations. The EIR condition in the license was inserted by the Commission for the Environment and will require their continual input to ensure its effectiveness. The many and varied interests in the Chatham Rise project do not have any obvious channels into the process at the regulation stage and this does not augur well for a comprehensive policy.
6.3 RECOMMENDATIONS FOR POLICY

Development of the Chatham Rise phosphorites exacts two types of policy - one to govern exploration and another for mining. Existing policy to guide exploration activities has been examined with the general conclusion that it is not propitious for wise resource management. To recommend a more effective design, it is important to understand the principles of a good mining policy first and then work backwards to determine what is required from an exploration policy.

A large part of this study has been devoted to identifying risk and its consequences for investors, the marine environment and other resource developments. That exercise has revealed two different types of risk for the Chatham Rise venture. One is risk that can be minimized, usually by obtaining more information. Examples include: understanding reproductive and growth rates of some benthic organisms to help define expected periods of regeneration and minimize the risk of no recolonization; obtaining more information on the feeding pattern and habitat of ling to determine the impact of the collecting vehicle; and, more sampling and observation in the license area toward the identification of spawning grounds. Information does not eliminate risk but rather, it makes risks more manageable. The second type of risk evidenced in this study are those that are inherently uncertain and likely to remain unknown. This is sometimes labelled "uncertainty", similar to the definition proposed in this study of uncertainty as "immeasurable risk". These risks are often long range, gradual impacts such as the effect of long term build-up of fine sediment in the bottom waters of the Chatham Rise from the mining operations. It is difficult to predict such response to stress and just as difficult to know what parameters should be measured to obtain information. So some risks can be minimized but some will inevitably remain uncertain.
The main tenet of this study is that risk involved in a marine development, such as the types just described, must first be recognized and second, incorporated into policy. Some of the methods used by large companies to account for risk were discussed in Part II. But how do decision-makers design a policy that is flexible - to deal with the unexpected and with conflict arising from differing objectives? The first step in the process recommended here is to establish trade-offs and the second step is to set boundaries to those trade-offs.

6.3.1 Trade-Offs

As discussed in the introduction to this chapter, not all risks can be accommodated equally and there must be trade-offs between risks and their related objectives. This balance is the essence of good policy and must be arbitrated by government. The nature of these trade-offs has already been discussed in general terms; following are some of the trade-offs involved in the Chatham Rise development, as determined in this study:

a) trade-off in timing of the venture between a means of entry into fertilizer manufacture for Fletcher Challenge and a technology test for the German partners.

b) trade-off between a rental option for mining which entails less economic risk and a supply commitment from the operator.

c) trade-off between higher production rate (lower mining cost) and optimal depletion of the phosphorite resource.

d) trade-off between mining efficiency and the timing of development i.e., between the low mining efficiency presently possible and recovering the most value from the resource.

e) trade-off between mining entire patches repeatedly (for economic and technologic reasons) and mining in strips or patches which would be more favourable environmentally.
f) trade-off between increased rates of production and the degree of environmental stress (increased dispersal of sediment at the surface and the bottom).

g) trade-off between gathering information toward understanding consequences of mining for the marine environment and minimizing delays and added costs for commercial interests.

h) trade-off between potential end use of the phosphorite resource and disruption to the existing fertilizer manufacturing industry.

6.3.2 Boundaries

It seems paradoxical that the course to a flexible policy must at the outset recognize limits. But it is germane to effective policy to establish boundaries to trade-offs. Traditionally, economic boundaries have defined the trade-offs necessary in resource management. But as demonstrated in this study, the extraction and marketing of the phosphorite at least economic cost does not embrace the objectives of all investors, particularly some national concerns such as the well-being of the marine environment and its living resources. Realization of the short comings of the exclusive use of economic limits has led proposals for energetic limits (Odum and Odum, 1976) and ecological limits (Holling and Goldberg, 1971; Holling, 1978a and b; Carpenter, 1980, among others).

The thesis here is not that any one discipline will provide the total criteria for making trade-offs or assessing projects. Development projects such as the Chatham Rise involve too many variables to effect a simple solution. Nevertheless, some boundaries are more effective than others for a particular situation. At this point, some boundaries will be explored with emphasis on those more appropriate to this development.

A) Ecological Boundaries

Establishing ecological boundaries means natural systems set the limits
to trade-offs. This allows natural systems to become the organizing concept toward achieving overall balance (op.cit.). Using this concept it is possible to allow exploitation while preserving options for future generations by maintaining the health of the marine environment.

A design that emphasizes natural limits is particularly important when some of the effects of development may be irreversible - that is, the environment is changed beyond recovery to its original state. The traditional trial and error approach of dealing with risk or the unknown has often resulted in costly environmental failures which may cause irreversible changes. For example, if mining proceeds without understanding if the license area is used as spawning grounds for several fish species, the result may be to foreclose future options for a commercial fishery. Since some of these risks cannot be redressed, it follows that natural systems should define the limits of development, the point where other variables involved in the development must bend or compromise.

These limits of natural systems are referred to as its "resilience" (Holling, 1978a): how well a system can absorb or even utilize change. It is this feature, the resilience of a system, that investigators must attempt to define toward understanding how much the environment can tolerate before an incremental change oversteps the ability of the system to absorb that change.

This approach has much relevance for the Chatham Rise situation. Some of the more significant risks to the marine environment determined in this study concern how well benthic communities will recover from the stress of mining, and how much suspended sediment at the bottom and the surface can be accommodated before the system is overloaded and organisms are affected. To understand the nature of a system and its resilience, it must
be accepted that a special effort is necessary: information must be actively pursued. Unfortunately, this is often misconstrued as a mandate to measure everything. Although systems are linked it is not mandatory to examine all parts of the system to understand it. This is indicated in the following policy statement of the National Research Council (USA):

"... [the NRC does not support that] exact or detailed prediction is necessary in order to estimate impacts with a degree of reliability that is adequate for policy analysis." (National Research Council, 1980, p.8).

Obviously data will have to be gathered but some broad brush homework can prevent furtive attempts to collect reams of material, some of which will never be examined and/or reveal anything. Two basic steps are posited here: 1) to determine, as in this study, where the major risks lie and their implications and 2) to determine the significant ecological connections. The emphasis in this approach is on change, on documenting natural fluctuations. It therefore must involve an understanding of the environment prior to development (a baseline) and monitoring of various parameters. None of these has been incorporated into current regulations (policy) for the Chatham Rise. Data collection has proceeded with no stated direction and no selectivity, resulting in the inevitable stacks of data, much of which has not been examined. Although species information and some static measurements of features of the environment exist, ecological connections are not yet understood and a baseline has not been defined.

The approach of defining a system's resilience may also extract additional information from existing data. For example, natural fluctuation in primary productivity on the Chatham Rise has been reported (Bradford, in prep.) and has been regarded as a limitation in establishing a baseline
for the area. Viewed from a "resilience" approach, this natural variability might be the baseline and in fact may be a source of resilience for the Chatham Rise environment. It must also be acknowledged that, whatever approach is adopted, some data should not be wrung dry; some data embody uncertainty or entail risks of their own. For example, data on fish populations of the Chatham Rise are obtained mostly from fishing vessel reports which may be inaccurate due to unreported catches or otherwise biased statistics. Depending on the end use of such information, the embodied risk may restrict its application and additional data will be required.

So the use of ecological boundaries has consequences for the methods and approach of collecting information. It also has strong implications for policy. Using natural systems to define limits to trade-offs means that ecological considerations move into a prominent position in policy. They should not be afterthoughts tacked on to the end of a minimum work program — instead, they should be used to define what activities may occur within a program. For the Chatham Rise operation, ecological limits based on how well sediment dispersed at the surface is tolerated could help define production rates; understanding regeneration or recovery rates of benthic species could be used to circumscribe the pattern of mining; and, additional knowledge of spawning in the area may restrict operations to certain seasons. Moving forward ecological considerations and hence the EIR, will also allow public input to the project (through the audit) at a much earlier stage. In this way, the concept of ecological boundaries becomes the nucleus of a policy to govern marine developments. It embraces many of the risks and minimizes the chance of causing irreversible changes in the environment.
B) Economic Boundaries

Development of the Chatham Rise phosphorites will be a commercial venture and company objectives must be considered in setting terms for the operation. Government policy must understand the risks borne by the commercial investors and their acceptable levels of risk. Therefore establishing guidelines for rates of production, for example, must consider ecological boundaries, as just shown, yet must recognize the economic limits for investors. As another example, the mining path selected for the collecting vehicle must appreciate the regeneration pattern of benthic species but also serve to contain mining costs.

The thesis presented here is that ecological boundaries must have predominance. If they are overstepped, the result may be irreversible changes in the environment: risks that cannot be redressed. The point is that staying within the ecological boundaries will probably involve trade-offs, compromise of investor's objectives. This cost of minimizing risk to the environment may change the companies notion of their acceptable level of risk and to compensate for increased costs, some of their risks may have to be lowered. An operator may still proceed with the operation and accept these costs if gains remain sufficiently high. Otherwise, increased costs to the operator are simply passed on to the consumer. To protect the consumer, government may intervene in the form of a flexible tax system for, in this case, Fletcher Challenge. Government may also offer protection for the product through a guaranteed price for the mined phosphorite, or protection of the market by restricting imports of direct application fertilizer from other sources.

For the German interests, trade-offs might involve efforts by the government to minimize bureaucratic or operational delays once ecological boundaries are accepted.
There are economic costs associated with recognizing ecological boundaries. Some of these may be accepted by the investor but other costs will probably become bargaining material with the government to determine whether mining proceeds.

C) Social Boundaries

There also exist some societal bounds and commitments that policy must subscribe to. For example, resource allocation must account for the needs of future as well as present generations. This will influence the optimal depletion rate of the phosphorite resource and perhaps even the timing of the development. This latter point refers to the low recovery efficiency of present mining systems (see Chapter 3). These efficiencies are expected to improve as deep ocean mining becomes more commonplace, allowing more value to be recovered from any one deposit area. This could possibly lead to a minimum efficiency requirement for a mining operation built into policy.

Resource allocation considerations for present and future consumers may also mean securing a commitment from the operator to mine for a minimum time period. As discussed earlier, the loose commitment involved in the rental of a mining ship, as proposed for the Chatham Rise operation, may be a risk to the security of continued supply. Again, though, a guarantee from a company to mine for a given number of years may have to be met by a price guarantee over that period.

Other social boundaries exist in a tacit responsibility of government to existing fertilizer manufacturers and importers of reactive rock. The impact of the Chatham Rise development and of any government incentives toward that development will have to be assessed and trade-offs determined. The same procedure may be necessary for the Chatham Rise fishing industry
but many of the risks to it should be considered in establishing ecological boundaries.

To determine society's level of risk acceptance or perception of the risks involved in a project, there must be provision for public input. As discussed earlier, the only forum at present is the audit of the EIR. As such, opportunity may not occur until six years after a license is granted, after wise use of resources has already been decided. At this late stage, public input is merely perfunctory, it does not contribute to policy. O'Riordan (1979b) terms this the "consensus" approach - a confidential approach where discussion occurs only between the regulators and the regulated with very little public input. If society, through interest groups or concerned individuals, is to help decision-makers establish boundaries to trade-offs, there must be an avenue for their participation earlier in the license procedure.

D) Institutional boundaries

It is relatively straightforward to discuss policy design in absolute terms. The real question is how effective is that policy when placed back into the institutional or decision-making framework - what are the institutional boundaries? The existing framework for the Chatham Rise situation and some of the implications of that policy have already been discussed. One of the factors garnered from that is the need for continued interaction between government and industry so that information and intentions may be shared. Another requirement that has been highlighted is co-ordination among government departments. Sectoral responsibility means many departments can be involved in various aspects of one project. As Holling (1978a) notes, institutional constraints are often more perceived than real and therefore it is not necessary to suggest sweeping changes in the status quo. Sweeping changes are not
advocated in this situation either but co-ordination of research activities, access to information and clarification of each ministry's responsibility is the prescription. This sense of direction should emanate from policy; research needs, for example, should come from policy and not the other way around. The many interests in the Chatham Rise project suggests that an integrative committee, perhaps with representatives from key government departments is necessary. Responsibility for a project that stands to affect other resources and other generations should not be vested in one person.

Policy must also remain within the bounds of existing law. Both the Continental Shelf Act 1964 and Territorial Sea and Exclusive Economic Zone Act 1977 govern the phosphorite license area and both of these may be amended according to any conventions adopted at the Law of the Sea Conference. Therefore trade-offs will have to be made in consideration of these factors.
6.4 CONCLUSION

A common thread among the different types of boundaries discussed is that none of them are fixed. This is an important consideration when making trade-offs and stems from the fact that systems - ecological, economic, institutional, are not static (Holling, 1978b). As emphasized for the Chatham Rise operation, costs and operating particulars, reserve estimates, and mining efficiencies will inevitably change. Additional information will alter opinions and ideas about the living resources of the Chatham Rise. Indeed, even investors' objectives may change. Much of this variability has been labelled as risk.

If this variability or risk is not recognized in policy, or if policy is aimed at reducing risk to non-existence, the result will be harmful. There will be no guidelines or response ready to help the system survive when uncertainty occurs. Holling and Clark (1975) describe this as opting for the "fail-safe" route of avoiding risk rather than a "safe-fail" method which is designed to cope with the unexpected.

"There exists a serious trade-off between designs aimed at preventing failure and designs that respond and survive when the failure does occur." (op.cit., p.250).

This introduces a concept already discussed for the marine environment but presented here in the context of policy - resilience. A resilient policy is simply one that can absorb change and variability and still persist (Holling, 1978b). This approach, a flexible policy, is obviously necessary for the Chatham Rise development which involves a novel operation, a novel product, and a marine environment that is far from understood. It follows, therefore, that project assessment must be an ongoing process, continuously adapting (Carpenter, 1980). Curiously, companies often engage in this type of accounting, adjusting estimates
to changing conditions. Yet for ecological systems, or for that matter social and institutional systems, it is too often assumed that snapshot predictions do the trick. But of course, circumstances change and new risks emerge. An adaptive approach means policy will be continuously held up to the light for flaws and cracks.

This should also be attractive to commercial investors. It is an unfortunate aspect of reality that decisions often must be made before all the facts are known. An adaptive policy, because it is ongoing, is designed to recognize changing factors and could ultimately prevent delays and rising costs.

To date there have been no actual tests of such a policy in New Zealand. The principles discussed here could be used as guidelines for mining under the Continental Shelf Act but could also be extended to other non-living marine resource developments such as oil and gas and other minerals. Whatever its application, these principles will help to ensure that policy does not itself constitute a risk.
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APPENDIX A:

Some specific limitations and assumptions from the cost estimates presented in Table 3.1.

Mero (1964):


TOTAL CAPITAL COSTS: US(1964)$4.5 million.

Costs are based on Mero's study of manganese nodule mining in the North Pacific. Hydraulic suction dredging is the assumed technology. The water depth over the Chatham Rise has been substituted in the formulae and a yearly production rate of 1.5 million tonnes is used. Operating costs can be expected to triple for the Chatham Rise case (500,000 tonnes production). It is not specified whether wet or dry tonnes are used.

Mero's study assumes the mining ship will be chartered and therefore is built into the operating cost estimate, which is similar to option one. Distance to port is much greater for Mero's Pacific example (2000-3000 km) than for the Chatham Rise (600-700 km).

Power costs used in Mero's equations include the use of an auxiliary generator necessary for the great depths of the manganese mining ventures. It is unlikely that this will be necessary for the intermediate depths of the Chatham Rise.
Global Marine Inc. (USA) Survey - 1970

JBL Exploration (NZ) Ltd - 1973

A report prepared for JBL Exploration re-evaluates data on the Chatham Rise deposits compiled earlier by Global Marine.

**OPERATING COSTS:** US(1970)$6.70/ton (JBL); $10.40 (G.M.)


**CAPITAL COSTS:** US(1970)$4.5 (G.M.); $6.75 (JBL)

Estimates are based on a 10,000 ton mining vessel and a hopper dredge system using two large buckets. In the Global Marine report, the mining vessel itself transports nodules to port; the JBL estimate involved two barges and a tug for transport. Hence, the higher capital costs but lower operating costs of the JBL proposal. Estimates are based on a production rate of 360,000 tons/year.

With the benefit of ten years of advances in deep ocean mining since these reports were written, a proposed Chatham Rise mining operation will be of larger scale and use more complex technology than is the basis of these reports.

Tronsden and Mead (1977)


**CAPITAL COSTS:** US(1976)$8.3-8.9.

A study of the economic potential of phosphorite deposits offshore California. Two production rates are examined - the lower one (900,000 tonnes P per year) being the most applicable to the Chatham Rise. Nevertheless it is almost twice that proposed for the Chatham Rise year round operation, thereby almost doubling operating costs.
Average water depth assumed in the California study is 250 m but the sea bottom is quite variable and depths range from 75 to 400 m. Over the Chatham Rise, water depths are fairly constant at about 400 m, which may serve to lower operating costs over the long term.

Hydraulic suction dredging is the proposed technology in the California case. Distance to port is much less for the California example (160 nautical miles return) than for the Chatham Rise (674 nautical miles return).

Dames and Moore (D&M) and EIC Corp. (1977) in Earney, 1979


**Capital Costs:** US(1976)$48 million

Cost estimates are based on air lift system for manganese nodule mining. For adjustment to the Chatham Rise case, the power component of the operating costs is reduced by 67%. This cost estimate is still tailored for the depths and scale of manganese nodule mining and is likely to be higher than for the Chatham Rise case.

A yearly production rate of 900,000 tonnes is used.

Kauffman and Rothstein (1973) and Mero (1977)


**Capital Costs:** US(1977)$30-100 million

Costs are computed by Mero (1977) incorporating an earlier study by Kauffman and Rothstein (1973). Both are studies of manganese nodule
mining so the scale of operations is larger than for the Chatham Rise, (for example water depths are about 10 times greater than the Chatham Rise depths).

Hydraulic suction dredging is the technology used in the calculations. Estimates are based on a yearly production rate of 900,000 tonnes dry nodules and therefore, operating costs could expect to almost double for the Chatham Rise case, if 500,000 tonnes is used.
APPENDIX B:

Inflation and currency correction procedure as applied to costs of deep ocean mining (Section 3.4).

1. Inflation of US$ prices to US$ May 1980 using US "All Commodities" Producer Price Index:

   e.g. US(May 1980)$ = US(1964)$ \times \frac{263.7}{94.7} \text{ (Price Index for May 1980)}
   \text{ (Price Index for 1964)}


2. Conversion of US(May 1980)$ prices to NZ(May 1980) prices:

   Exchange rate in May, 1980: US$0.9837 = NZ$1.0

   This exchange is approximated as 1:1


3. Inflation of NZ(May 1980)$ to NZ(1981)$ using the Consumer Price Index:

   NZ(May 1980)$ \times \frac{1072}{932} \text{ (C.P.I. for June, 1981)}
   \text{ (C.P.I. for June, 1980)}

   NZ(1981)$ = NZ(May 1980)$ \times 1.15.