GCAS 07/08

Mineral Activities and Environmental Issues in Antarctica

Nicholas Carson – 77434928

Mineral Activities and Environmental Issues in Antarctica

Contents

Figures

1. Introduction.

Mineral exploration in Antarctica is a controversial topic due the environmental impact that mining creates. All human activities are governed in Antarctica by the Antarctic Treaty which states that the continent is devoted to peace and science (Antarctic Treaty, 1959). Geologically, the continent is the least explored in the world (Willan et al, 1990) and may hold many resources within. The remote ice covered continent has prevented the exploration and exploitation of resources, but now with improving technology the possibility of the continent being opened up to activity is increasing. The global concern shifts to a more environmental friendly conception, as the impacts of human are being noticed around the world. Therefore, with the possibility of mineral activity in the future, we need to secure the future of the Antarctic and its environment. Can we protect this fragile environment and would is be economic for mining companies to investigate and develop mining activities.

2. Political Position on Mineral Exploitation in Antarctica.

The mineral issue arose in the 1975 Consultative Party meeting in Wellington, New Zealand, and was the first time non living resources had been discussed. It was agreed that there was a possibility of potential mineral exploitation to occur in the Antarctic area and therefore regulations needed to be established to control any activity. The Antarctic Treaty had not addressed resources or the environmental concerns that exploitation of the resources would create. The Consultative Parties formed over the next 13 years a convention to regulate any future mineral resource activity.

The Convention on the Regulation of Antarctic Minerals Resources Activities (CRAMRA) was negotiated in 1988 to control mineral activity. The convention was agreed upon in Wellington in 1988 but never ratified by the all treaty members, due to some parties wanting an 'absolute ban' on mineral activities due to the environmental concerns. CRAMRA would have restricted mineral activity to only prospecting, which allows mineral deposits to be indentified. The later exploration and development stages would need the consensus of the all the members before activities could begin. Some of the members, Australia and France, felt that an "absolute ban" was needed due to the interpretation of the word prospecting. In CRAMRA the word prospecting was defined by

"Prospecting" means activities, including logistic support, aimed at indentifying areas of mineral resources potential for possible exploration and development, including geological, geochemical and geophysical investigations and field observations, the use of remote sensing techniques and collection of surface, seafloor and sub-ice samples. Such activities do not include dredging and excavations, except for the purpose of obtaining small-scale samples, or drilling, except shallow drilling into rock and sediment to depths not exceeding 25 metres, or such other depth as the Commission may determine for particular circumstances. (CRAMRA, 1988)

The definition of the word prospecting was design to allow scientific investigation of areas to continue and some commercial investigation can be conducted into possible mining. A commercial company would need a 'sponsoring state'. A 'sponsoring state' is that companies home country that must agree to allow them to prospect and make sure both the company and the country itself has both the financial and knowledge to protect the environment. This also includes funding for any clean-up operations if required to return the environment back susceptible standard. The negotiators of CRAMRA knew the meaning of prospecting can be interpreted as have greater environmental impact, which would be considered to be unacceptable for the Antarctic environment. For that reason they made a very restrictive definition as stated in Article 1 of the convention and stated above. The CRAMRA definition of prospecting was created to cover the geological and solid earth geophysical research carried out for scientific purposes (Heap, 1990). Those striving for an 'absolute ban' want the ban of all mineral activity in Antarctica including prospecting except for scientific purposes. The argument was that once prospecting has been allowed, exploration and development are sure to follow (Heap, 1990). This point was one of the main arguments for parties not to ratify the convention. One of the differences between CRAMRA and an "absolute ban" is that under CRAMRA the results found by the prospecting could be kept confidential for a period of time.

There were other reasons for abandoning CRAMRA which were contemplated by parties. These included the concept that by ratifying CRAMRA and starting mineral activity it might cause a renewed political tension over sovereignty (Willan et al, 1990). Sovereignty claims are frozen by the creation of the Antarctic Treaty in 1959, but with important economic resources available countries may want to claim the rights for the minerals within their claim. In particular the sector of UK-Chile-Argentina territorial counter-claims twenty degrees west to ninety degrees West (Willan et al, 1990) would become controversial.

Media also played a role in the demise of CRAMRA as they communicate to the public in everyday life and rise topically issues. The popular media have further exaggerated these reports and, with non-governmental organisations have suggested that CRAMRA will clear the way for mining operation to start on the Antarctic continent (Willan et al, 1990). CRAMRA did not make an easy route for mining operations and the only allowed prospecting to start without consensus. CRAMRA actually at the time was preventing the start of mining by placing regulations and criteria, companies/countries had to comply with, before mining activities could commence. CRAMRA provisions do not specify economically viable or logistically feasible exploitation (Willan et al, 1990).

After the demised of CRAMRA, there was realisation that there were no regulations for the protection of the environment. The Antarctic Treaty stated the continent was devoted for peace and science and also stated that no nuclear waste could be disposed of within the Antarctic Treaty area. These were the only environmental restrictions in the Antarctic Treaty, and the reasoning for this is most likely because the era of when the treaty was created, these were not major global concerns. In 1959 the environmental impact produce by humans were not seen as major concerns as the Cold War was happening and peace issues were more concerning. A demand for protection for Antarctica environment was required and within 2 years 'The Protocol on Environmental Protection to the Antarctic Treaty' (1991) was created to attend to all environmental concerns. This protocol also banned any mineral activity except for scientific purposes, for a 50 year period or indefinite unless a consensus was agree for mineral activity to begin and regulations have to be created to control the environmental impacts.

3. Mineral Exploration Globally.

The world's economies are manipulated by the price of many minerals. There are common minerals that are required for everyday use and the some valuable or precious minerals that are economically important. The organic minerals such as coal, oil and gas that and used for energy and from the manufacture of plastics and steel. The world mineral reserves are known to be diminishing, which increases the global price and therefore makes it more economic to explore for remote mineral reserves, such as the Polar Regions. Depletion of known reserves leads to an increase in demand and price; hence, at some future time, Antarctica will be exploited (Willan et al, 1990). Antarctica has been identified for having potential hydrocarbon resources, the quantities are unknown. Two areas of the Weddell Sea have good potential for oil and gas reserves (Anderson J.B. 1989)

Hard rock minerals tend to be mined in a more environmentally harmful method than that of oil and gas, which creates a greater concern on the environment. High grade ores can be mined by underground methods but lower grade open cast mines are more common, allowing more of the rock to be refined. An open cast mine is extremely environmentally damaging due to the nature of removing overburden. Globally the methods of extraction are controlled by the country in which the mining activity is occurring. The country has to create its own standards and regulations for the industry to comply to.

World mineral reserves are calculated by quantifying discovered mineral deposits, so that the measured amount of mineable rock becomes a reserve. A resource is a mineral deposit to be known to have an anomaly geochemical quantity. A reserve is defined by a known minable quantity of material which is from a resource. As the reserve decreases the price for the mineral increased due to the demand for the product. The mineral is then more economic to mine in small concentrations or mine in remote areas where the costs of mining have been too high to make profitable before.

Prices for minerals globally have increased over the pass 50 years, for example gold priced on the London Gold Bullion Market has increased from about £150/oz in 1965 to a £450/oz in January 2008 (The London Bullion Market Association, 2008). Platinum prices have risen from US$ 475/oz in 1983 to over US$1800/oz in 2008. This increase in price has allowed lower grade host rock material to be processed but also this means it is more obtainable to mine in remote locations where cost are high for transportation.

The profitability of mining is seen in most stock exchanges, with large mining companies at the top of the listed companies. These companies have increased the value of their shares around 600% in the last forty years making it very profitable. The increase of the global population can be link to the increased demand for some mineral products, which provide material and energy for everyday life. The trend for demand for the minerals predicted to increase due to the increasing global population. Minerals and products of minerals are used in the construction of homes and buildings and the production of plastics, metals and glass. China imports around a third of all iron ore produced from around the world. China and India are on an economic boom and have seen major population growths in the last century. Iron ore is one of the major traded minerals as the material is used throughout everyday life. The ore is refined and then used in the production of steel. The iron ore industry is experiencing an unprecedented boom as the commodity price witnessed a spectacular increase of 71.5 per cent in 2005 (United Nations, 2006).

Mineral exploitation around the world is regulated by the country in which the activity is in. This means there are no global environmental regulations for how to protect the environment. Countries like Australia and New Zealand have strict terms and conditions for mining and what discharges can occur into the environment. Waste water is one of the main discharges in mining activities and sometimes with interaction from the rocks the water can become acidic. Remediation is required from this water before it can be released back into the environment; this is often done by oxidation of the water or by adding lime to reduce the pH. Dissolved particles are another concerns and need to be reduce before release, this is often done by settling ponds. There are many other impacts that mineral activity put onto the environment, such as draw down of water table, ground disturbance, dust and noise.

4. Mineral Potential of Antarctica.

"The risk one runs in exploring a coast in these unknown and icy seas, is so great that I can be bold enough to say that no man ever venture farther than I have done; and that the lands which may lie to the south will never be explored." (Cook, 1777).

Antarctica is the great southern land and geographically isolated from any other landmass. The remote location and the ice cover of the continent have made investigation very difficult. The remote position of the continent meant the discovery of the Antarctic continent didn't occur to the 1820's. The geographical position means that there is a permanent ice sheet which covers about 98% of the land. Geologically the continent is the least explored in the world (Willan et al, 1990). Geological mapping of Antarctica began only after 1945 due the remote locality of Antarctica. The current knowledge of minerals resources in Antarctica is minimal because of the lack of exposed land and logistics.

Antarctica has been investigated geologically for the creation of models of plate tectonics and the formations and spread of land masses today (Willan et al, 1990). The evidence suggests that 180 million years there was a super continent which included Antarctica. The super continent was called Gondwana and contained all of the southern land masses and India. By the reconstruction of this super continent a diagram can be made and the known mineral deposits can be plotted on the continents.

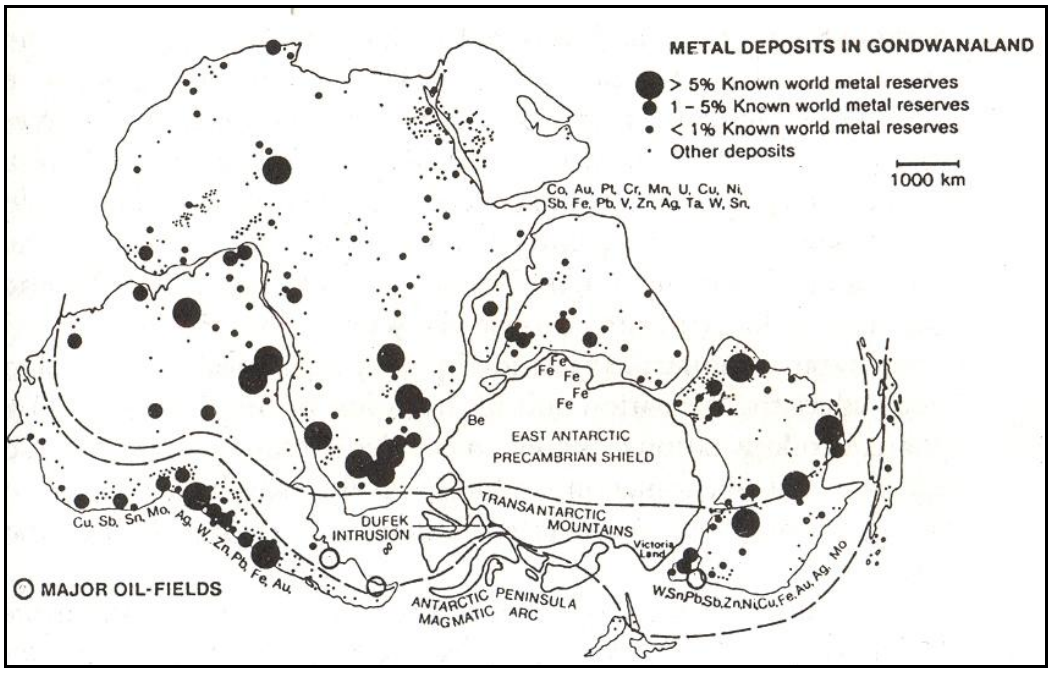

Figure 4.1 Reconstruction of Gondwana about 180 million years ago, mineral deposits are indicated by the solid dot and oil fields by a circle (Figure from Willan et al, 1988)

The above figure (figure 4.1) of Gondwana, Antarctica will appear to be surrounded by mineral-rich continents (Willan et al, 1990). Because it is suggested that Antarctica was surrounded by the other major continents with large mineral deposits concentration, it is then suggested that Antarctica will contain mineral deposits as well. This past relationship with the other continents suggests that the Antarctic crust is probably as mineralised as the other continents (Willan et al, 1990).

There are known mineral occurrences in Antarctica however these locations have been mapped mainly by geologists without economic geology experience (Willan et al, 1990). Many of these occurrences are small in size, only occurring in centimetre to metre scale. The term occurrence is also been misinterpreted to mean an economic deposit or ore deposit. The actual meaning of a mineral occurrence is a locality where the rock contains an anomalous mineralogy and geochemistry (Willan et al, 1990). This means a sample that has a higher or lower quantity of a mineral than normally expected. Although there are no proven mineral reserves in Antarctica, the size and the geological history of the land suggested that there should be economic deposits within the continent. In Western Antarctica, earlier US geologic and geophysical investigations delineated the Dufek igneous complex which they recognised as a vast potential 'storehouse' for economic minerals because some of the worlds richest ore deposits are contained in similar igneous complexes (De Wit, 1985). This igneous complex has been

compared with the Bushveld complex in South Africa, and will be investigated further as a possible minable area for platinum later.

The mineral potential of Antarctica is proven to have many economic minerals and development of mining activity is likely to begin if the global reserves of mineral decline. The development of these resources is going to be more costly than most other areas of the world due the increased risk and the isolated location. The experts stress that only a very high-value deposit would command economic interest (World Resources Institute, 1988)

5. Environmental Impacts.

The topic of mineral activity created a stir in the international community, as the negotiations of an Antarctic mineral convention had alerted the public to the dramatically increased potential for the degradation of one of the world's last wilderness regions (Rigg, 1990).

The concern of mineral activity started in early 1970 in which at the meeting of the Antarctic Treaty Consultative Meeting 1972 in Wellington , New Zealand, a recommendation was adopted recommending to the governments "that the subject: Antarctica Resources – Effects of mineral Exploration be carefully studied and included on the Agenda of the Eighth Consultative Meeting." (Recommendation VII-6, 1972). After this meeting an informal meeting of experts, was conducted to discuss problems related to mineral activity. The meeting had environmental concerns about gross disturbance and the likelihood of the area to recovery. It was generally accepted that the Antarctic ecological system was sensitive to disturbance, that parts of it would be unlikely to recover from gross disturbance for tens if not hundreds of years and that the present relatively undisturbed state of the Antarctic environment rendered its continued protection a matter of greater rather than lesser importance (Meeting of Experts, 1973). The acknowledgement of the concern with mineral activity having a permanent was a good set for the protection of the wildness of Antarctica. Protection was needed to ensure that large environmental impacts were not going to be created.

The environmental impacts of allowing mineral activity to commence in Antarctica can be viewed in two ways, one is on the local scale and the other is in terms of maintaining the integrity of the Antarctica environment as a whole (Institute of Polar Studies, 1977). The local scale would be extensive as any major human activity will disturbed the fragile ecosystem in Antarctica. There is no question that any

resource exploitation will cause severe, and in many cases permanent, local impact on the environment (Institute of Polar Studies, 1977).

In 1977 the Institute of Polar Studies prepared 'A Framework for Assessing Environmental Impact of Possible Antarctic Mineral Development' for the US Department of State. This report evaluated the potential for mining in Antarctica and also addresses environmental areas of concern. The impacts that could be possibly caused by mineral activity were identified in many ecosystems and were split and dealt with in separate areas as follows:

- Soils and permafrost – construction of infrastructure to operate mining activities will destroy the soil profile. This will create artificial horizons in the soil records and destroy any further research potential at the site. With large scale operation the risks for the contamination of the size by hydrocarbons. Any spillage would contaminate the localised area and there is a potential for heavy hydrocarbons to be contained within the soils for a long period of time, due to the slow rate of degradation. Chemicals used in mining or refining ore could also contaminate the soils and change chemistry and nature of the soils/permafrost. Permafrost can act an impermeable layer trapping chemicals at the surface.
- Glaciological environments – natural snow records would be effected by the increased concentration of dust in the air. The dust concentration will affect the colour and translucency of the ice, which may affect the albedo effect created by the white snow. Local surface disturbance would occur where transportation route and other infrastructure interact with glacier surfaces, preventing any research activity.
- Meteorological consideration – atmospheric dust particles could increase with mineral activity and therefore and change present 'clean air' research projects operating in Antarctica. These projects are designed around the Antarctic atmosphere being the cleanest in the world due to remote location far from built-up industrial centres.
- Oceanographic environment – the ocean environment could be impacted by leaching of chemicals and sediment from disturbed land surfaces adjacent to the sea. The possibility of oil spills and loss of chemicals from ships would also be an increased effect. This would affect the marine fish, mammal and bird life, which is used presently for research and tourism in Antarctica.
- Terrestrial ecosystems – are restricted to the 2% of the continent that is ice-free (Institute of Polar Studies, 1977). Due to the nature of ice free land for building stable foundations these are

areas that would be used from the infrastructure of mineral activity. Surface activity will destroy vegetation that often occurs in the microscopic scale, even if the actually infrastructure does not affect it; the change in the environment will change drainage patterns. Again the affect of hydrocarbon and chemicals spills will affect the localised area and will damage and change the ecosystems. The terrestrial environment is also a breeding place for animals such as penguins and therefore the breeding colonies would be affected by activity within the area.

At the Sixteenth Meeting of Scientific Committee for Antarctic Research (SCAR) the delegates were asked to consider a response to the requests from the Antarctic Treaty Consultative Parties (ATCP) contained in Recommendations X-1 and X-7 (AEIMEE, 1981). Recommendation X-1 'Antarctic Minerals Resources' was the start of the ATCP being concerned that the unregulated mineral resource activities could significantly harm the fragile Antarctic Ecosystem (Recommendation X-1, 1979). This was the start of environmental concern associated the exploitation of mineral resources and brought the issues into the international arena. Recommendation X-7 focuses more on oil contamination of the Antarctica marine environment, which identified the need to reduce the environment risk. The presence of ice in Antarctic waters gives rise to particular hazards for operation of ship (Recommendation X-7, 1979). Many of the potential mineral resources would need the aid of ship for supply and transport of ore. This is a major environmental risk as the potential impact could be horrendous. An oil spill would effect many ecosystems and potentially permanently damage areas. The AEIMEE report suggested the baseline hydrocarbon levels are needed to be found, then levels can be monitored if mineral activity beings.

These foreseen environmental impacts of mining activities is one of reasons for the collapse of CRAMRA, parties to the signing of the agreement discussed environmental issues and possible impacts. CRAMRA was then negotiated and placed regulations for companies to comply to before and during mining activity. These environmental regulations were agreed upon after the area had been approved for mineral activity. The Regulatory Committee would create a Management Scheme that regulates all activity in the block of mineral activity. The Management Scheme shall prescribe the specific terms and conditions for exploration and development of the mineral resource or resources concerned within the relative block (CRAMRA, 1988). These terms and conditions shall cover:

a) duration of exploration and development permits;

b) measures and procedures for the protection of the Antarctic environment and dependent and associated ecosystems, including method, activities and undertakings by the Operator to minimise risks and damage;
c) provision for necessary and timely response action, including prevention, containment and clean up and removal measures, for restoration to the *status quo ante*, and for contingency plans, resources and equipment to enable such action to be taken;
d) procedures for the implementation of different stages of exploration and development;
e) performance requirements;
f) technical and safety specification, including standards and procedures to ensure safe operation;
g) monitoring and inspection;
h) liability;
i) procedures for the development of mineral deposits which extend outside the area covered by a permit;
j) resources conservation requirements;
k) financial obligations of the Operator;
l) financial guarantees and insurance;
m) assignment and relinquishment;
n) suspension and medication of the Management Scheme, or cancellation of the Management Scheme, exploration or development permit, and the imposition of monetary penalties, in accordance with Article 51;
o) procedures for agreed modifications;
p) enforcement of the Management Scheme;
q) applicable law to the extent necessary;
r) effective additional procedures for the settlement of disputes;
s) provisions to avoid and to resolve conflict with other legitimate uses of Antarctica;
t) data and information collection, reporting and notification requirement;
u) confidentiality; and
v) removal of installation and equipment, as well as site rehabilitation. (CRAMRA, 1988)

This is an intensive set of regulations in which the company must apply or their permit can be cancelled. This authority is needed to ensure companies know their environmental conditions; the committee also have the right to observe the operation at any time. The environmental criteria of having to have a

sponsoring state which would prove that the company has enough financial funds to pay for any environmental accidents, is one of insurance for the Antarctic community.

CRAMRA includes:

- A ban on activity in environmentally sensitive zones e.g. Specially Protected Areas (SPA)
- Consensus to agree the opening of an area for exploration or development
- Stringent procedures to protect the environment during exploration and/or development
- Proof of technically feasible and safe procedures
- Monitoring and random inspection of activities
- Liability and penalty provisions for environmental damage (Willan et al, 1990)

Environmental concerns need to take account for further possible disturbances such as noise, dust, water and tailings, when methods of mining are decided upon. Presently environmental impacts involved with mineral exploitation are by the country of the operation. Because of the different economic and social states of countries there are different standards around the world, some harsher than others. To negotiate a set of regulations for Antarctica, it would be necessary to satisfy all environmental concerns which countries involved in the Antarctic Treaty have. CRAMRA needed a consensus to allow mining activity to commence and agreeing upon the environmental measures needed for each mining activity. Australia believes that mining in the Antarctic would be grossly incompatible with proper environmental protection (Burgess, 1990). This belief meant that CRAMRA was not ratified and then no environmental regulations were in place in 1990.

The formation of the Protocol on Environmental Protection to the Antarctic Treaty (1991) manages all the environmental concerns of any activity in the Antarctic Treaty area. The protocol bans mineral activity for a fifty year period or indefinite unless voted upon by a consensus. The Environmental Protocol made an Annex 6, to cover what CRAMRA had done by the need for a 'sponsoring state'. Annex 6 of the protocol is a liability annex for environmental impacts caused by human activity. This annex holds those responsible of the impact to response and remediated any environmental damages caused by their activity. If mineral activity was to begin in Antarctica, this annex could be one of the economic deciding factors as the insurance for liability may be too costly for many companies.

6. Hypothetical Mine Economics.

Antarctica has been suggested as a 'storehouse' for economic minerals, but the exploitation of this resource may more difficult than predicted. In this section two hard rock minerals are going to be investigated for economic potential. Banded Iron Formation (BIF) in East Antarctica and platinum metals from the Dufek complex will be examined to understand the complexity of mining in Antarctica and whether it is economically possible. The lack of knowledge into the geology of Antarctica means that estimations on possible resources are very difficult. The size and quality of possible resources have been calculated and modelled by the limited geophysical data, and a few geochemical analyses of collected samples.

6.1 Iron Ore

Iron ore is found often in Banded Iron Formation (BIF) which occurred in basement shield areas. They are a layered sequence of iron rich marine sediments. They often contain about 30% iron which then can be enriched after formation. The iron is contained within the BIFs as hematite (Fe_2O_3) and magnetite (Fe_3O_4) in the ore, which is mined and then refined for manufacture into steel. Iron is a common mineral ore that is found in many parts of the world, Australia has one of the largest deposits. Australia had an economic iron ore resources estimated at 21,600 million tons in 1980 (Bureau of Mineral Resources, 1980).

There are known BIF at a number of localities extending around the coast from Enderby Land to Wilkes Land in East Antarctica (Tingey, 1987). The potential of these known deposits have been suggested to be large enough to be considered a potential ore deposit. Mount Ruker in the Prince Charles Mountains has the largest known deposit and will be the focus of this investigation.

In 1987 R.J. Tingey wrote a paper 'Banded Iron Formations in East Antarctica' which investigated the economic potential of the BIF deposits in the Australian sector. He concluded that the Mount Ruker deposit was the largest and therefore the most potentially economic. Mount Ruker is located on the southern flank of the Fisher Glacier, 650km from the Mac. Robertson Land coast, which is only accessible for about 6 weeks of the year (Tingey, 1987). Mount Ruker is a metasedimentary sequence of rocks that have been highly tectonically disturbed. Because of the tectonic disturbance of the rocks, a reliable stratigraphic sequence cannot be deduced (Ravich et al, 1982).

Tingey's paper went on to investigate the Mount Ruker deposit, by creating a hypothetical mine the economics of a mine. The size of the resource was calculated by the use of chemical analysis on a few

collected samples and basic geological mapping of the area. The chemical analysis produced results of Iron (Fe) contents ranging from 24.1% to 45.9% and average 33.5% (Tingey, 1987). Iron concentrations of this level are mined in Russia and USA however the ore is usually put through a process called beneficiation at the mine site to refine the ore. Beneficiation is a process of refining the ore so that less host rock needs to be transported from the area. These mines also are connected to heavy industrial centres by convenient and relatively cheap surface transport (Tingey, 1987). The increase costs of having to transport ore from the remote locations of Antarctica would increase the cost, especially with the increase in hydrocarbons prices. If the Mount Ruker deposit was exploited the closest port and inhabited area is Australia where there are some of the largest iron ore producing mines in the world with concentrations of iron above 55%.

The excess cost of transportation of the ore from Antarctica thousands of miles over ocean would increase the cost of mining the ore. The access to the continent is also limited to about 6 weeks during the summer months, meaning that there is a small period of time where the ore can be removed from the continent. The ore is then sold on to manufactures, which are mainly in the northern hemisphere. The price of the ore is controlled by demand and quantity of ore being mined around the world. There is so much ore of better grade and more accessible, therefore this ore would not be economic. The current knowledge about the deposits only allows estimations on the quantity of ore and therefore any mineral activity would be risky as there are no proven resources. Financial partners and investors would not be willing to enter into such a risky investment. The investors may also have either personal or social views that may put off investing in mineral activity in Antarctica. The cost of exploration is typically around 1-2% of the development budget, but with the increased cost of even getting to Antarctica wouldn't allow for the usual budget. An increased environmental budget would also be needed as restriction would be put in place by the regulating committee of the industry. The conclusion is that iron ore would not be profitable to mine with the current prices, increased transportation and environmental costs would make it non-profitable. The fact is at the present time there are much larger and better grade deposits around the world, which are more accessible than that in Antarctica.

6.2 Platinum Metals

In the Dufek complex in West Antarctica has been compared to the Bushveld complex in South Africa. The igneous complex is known as a mega-intrusion and samples taken have confirmed that intrusion is similar to the Bushveld and Stillwater complexes. With the construction of Gondwana, South Africa is

positioned next to West Antarctica, where the Dufek complex is situated. These two other complexes are known for the mineral resources of chromite, platinum-group metals, nickel and minor cobalt, copper and gold (De Wit, 1985). Because of the evidence of the similarities of Dufek complex and the two proven mineral areas, it is suggested that the Dufek complex could be a mineral deposit. The complex could contain precious mineral such as platinum which might have a potential to be more economic than common ores.

From samples taken from the complex geochemical analysis has been completed. The concentration of platinum group mineral are similar to those found in the Bushveld complex, which could mean the Dufek complex is a real possibility for a profitable mine. The size of the intrusion has been estimated by the use of geophysical, a combined aeromagnetic and radio echo ice-sounding survey indicates a minimum area of over 50,000km² (Behrendt et al, 1980). The intrusion is estimated to be about 8-9km in thickness (Ford, 1970).

De Wit (1985) published a paper 'Evaluating the economics of developing The Dufek Platinum Metals mine' placed a hypothetical mine and infrastructure. Hypothetical plans of the layout of the mine, runways, roads and ship loading facilities were all planed for. The plans for the mine was to extract from a underground which because of the shallow dip would be possible for at least 20km into the complex, over a strike length of more than 15km and probably up to 50 km (De Wit, 1985). The quantity of ore mined will be of the order of 750,000 tonnes per year (De Wit, 1985). The method of transporting the ore was to load ships during the favourable summer period of 8 to 10 weeks. This large operation would work year round creating ore for shipping in the next summer season.

The economics of starting this mine were calculated in terms of 1983 costing and prices for selling the platinum. Several models were used keeping the platinum price constant, changing the price, inflation and taxation. Some of the suggested models concluded that it would be profitable under the right circumstances, however the profitability of the hypothetical Dufek Platinum Metals mine is closely tied to the platinum price (De Wit, 1985). The price of platinum has increased from the 1983 price (US$475/oz) in which these models were formed, to US$1800/oz presently. It was a greater increase than predicted in the models however the price for hydrocarbons to fuel shipping and machinery have also increased over the same period. In conclusion De Wit came to the conclusion that even though it would be profitable by these models, the returns are too small or unattractive for a financial investor to consider the project seriously (De Wit, 1985).

After De Wit's paper, Beike wrote a paper 'An Engineering Economic Evaluation of Mining in Antarctica: A Case Study of Platinum.' This paper focuses on the engineering and economics of mining platinum group metals and gold from the Dufek intrusion (Beike, 1988). The study modelled the scenario of designing, constructing and operating a mine on the Dufek intrusion.

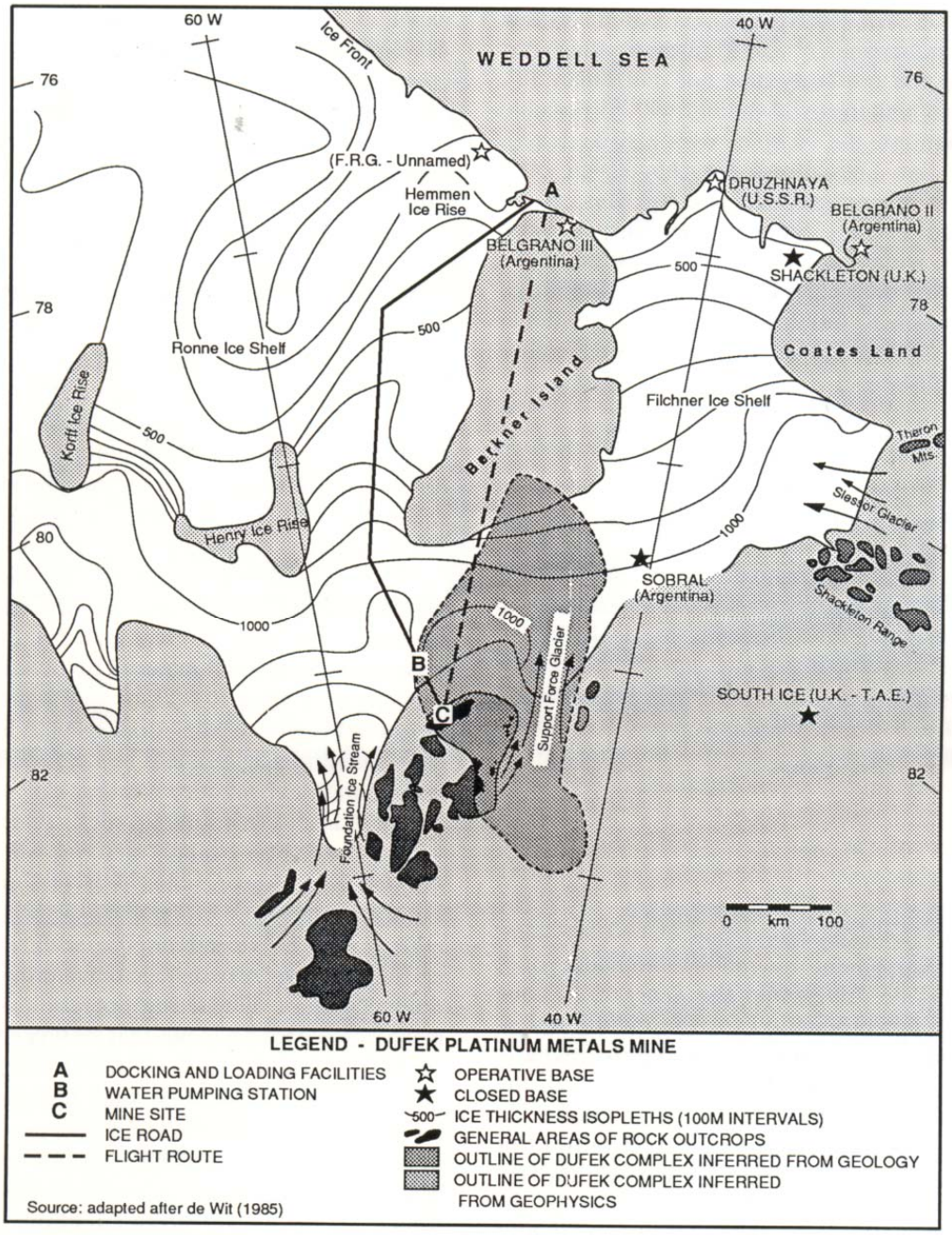

Figure 6.21: Location and logistics of the Dufek platinum mine. Adapted from de Wit, (1985). Beike 1988

The above mine plan was constructed and costing was completed. The mine plan and engineering of the proposed site made the model successful. The suggested mining method certainly allows for successful mining in this region under the given assumptions; consequently, proper mining can be performed with today technology (Beike, 1988). Information on hydrology, soils and permafrost is very sparse, and thus proper engineering design is very difficult for ice covered regions (Beike, 1988). The hypothetical mine is which de Wit and Beike have design and done economic evaluations on are completed with many assumptions but have found that it is possible. The profit margins make the likelihood of the mineral activity beginning in Antarctica unlikely in the current economic situations. The economics are certainly not favourable for any of the minerals found in Antarctica at this point (Beike, 1988)

Capital expenditure (CAPEX)	1983 US $ millions
Mine development	
Shaft, hoist, headframe, equipment	11.5 [1,2]
Transportation to site: 30 per cent of shaft etc. CAPEX	3.5
Underground equipment and rock development	25.34
Extras and escalation: 20 per cent of above	
Concentrator plant and surface facilities	
General (clearing, foundations)	21.95
Crushing, crushed ore handling	4.54
Concentrator	
Site and building	8.075
Power plant	8.075
Processing Plant	8.075
Sledge	0.775
Transportation to ice-front (3000km)	0.825
Transportation to mine-site (550km)	0.125
Concentrate storage and loading facilities	10.575
Trucks ($350 000/50 tonne truck)	3.15 [3]
Extras and escalation: 25 per cent of above	
General	
Construction ice-road ($716/km), bridge, ramp	0.394 [4]
Pipelines for water, sewage, tailings ($115.9/km)	0.356 [5]
Town site accommodation, recreation facilities	14.988
Development services (engineering, legal, management, fees)	15.525
Extras and escalations: 20 per cent of above	
Project overhead costs: 6 per cent of mine development and 8 per cent of remainder capital expenditure	
Exploration	
Drilling (20 000 m)	3.00 [5]
Salt ($200/tonne; 0.04 tonne/m drilled)	.16 [5]
General transportation (1340 flight h; $4000/h)	5.36 [6]
Operational expenditures (OPEX)	**1983 US $—per day**
Power	6714.00
Mine — Labour	10493.00
Mine — Supplies	12138.00
Mill — Labour	4373.00
Mill — Supplies	6483.00
Surface — Labour	10045.00
Surface — Supplies	2383.00
General administration	17707.00
Transportation costs/tonne concentrate : mine to ice-front	73.15 [3]
Transportation costs/tonne concentrate : ice-front to smelter	68.75
Smelting charges /tonne concentrate	76.88
WORKING CAPITAL : 33.3 per cent of operational costs	

Sources: Comminco (1979) and authors' estimations unless otherwise indicated;
[1] R. Spencer, personal communication 1983.
[2] O'Hara (1980).
[3] J. Stocks personal communication 1983.
[4] Adam (1979).
[5] Comminco, personal communication (1983).
[6] NSF, personal communication (1983).

Figure 6.22 The costing of the Dufek platinum mine constructed by De Wit et al (1988)

De Wit and Kruger also published a paper in 1988, 'The Economic Potential of the Dufek Complex' further exploring the potential of platinum metals mine. This was a continuation of De Wit's study in 1985. The study included some geopolitical issues in the demand for platinum as the demand was increasing but some countries wanted to move away from the largest producers. Despite the desire need for platinum, there is also a great global pressure to move away from South Africa's supplies (De Wit et al, 1988). This shows how politics control more of the demand and pricing. The move away from South Arica could move a movement to start looking into resources in Antarctica.

Mining in Antarctica is geologically possible as there have been outcrops and areas with similar grades and quantities to that mined in other parts of the world. The two above hypothetical models have concluded that it would not be economically/financially possible in the current situation due to other global resources and the lack of knowledge of the deposits that we have. The future may hold a different future for the continent as history has shown us predictions of the future are often flawed. James Cook stated the lands which may lie to the south will never be explored in 1777 after exploring south. The continent has now been explored from the coastlines to the interior. Mineral exploitation is hypothetical possible but the risky nature of the investment may put off commercial companies, but with backing by a country a mineral operation could begin. The possibility that mineral-resource-poor nations like Japan and the Federal Republic of Germany (FRG) may subsidise operations that would not produce sufficient return to be of commercial interest to private companies (World Resources Institute, 1988).

7. Discussion.

Exploitation of economic mineral in Antarctica is a controversial topic, as it is the only continent on Earth not affected largely by humans. The isolation of Antarctica from any other landmass made the discovery relatively recent 1820's, and with no year round occupation till the mid 20th century. Therefore the Antarctic continent is one of the least explored parts of the world, and geologically, the continent is the least explored in the world (Willan et al, 1990). However with the conception of plate tectonics forming in the 1960's and 1970's, relationship of the geology in Antarctica can be linked to that of other large continents. This relationship suggests that the Antarctic crust is probably as mineralised as the other continents (Willan et al, 1990).

Economic minerals are used throughout the world and are profitable. Depletion of known reserves leads to an increase in demand and price; hence, at some future time, Antarctica will be exploited (Willan et al, 1990). The prices for many minerals have been increasing over the past century due to inflation, demand and the diminishing size of the known reserves. This puts the pressure to discovery more mineral resources and the increase profit allows further remote development. Mining activity is more likely to affect the Antarctic continent in the future as the reserves diminish around the world. Peak oil has been estimated to have been reached or will be in the next 10 years; this will create a need to find more reserves. Mining in Antarctica will definitely be looked at as an option when other global resources become depleted (Temminghoff, 2007).

With mineral exploitation predicted for the future, environmental impacts have to be considered and regulated before mineral activity begins. The wilderness value of Antarctica is appreciated by everyone that visits the continent and needs to be protected. The wilderness of Antarctica needs to be protected as it is part of the major industry of tourism. A ban is in place presently after the demise of CRAMRA which was setup to regulate. However CRAMRA was seen by media and others, to be opening up Antarctica for mineral exploitation, but in fact a ban could be implemented on any mining activity. CRAMRA was the international instrument that had been negotiated to ensure that such a conditional ban on exploration and development of Antarctic minerals could be implemented (Heap, 1990). The reason for CRAMRA not being ratified may have been due to the wording and definitions rather than the environmental concerns. CRAMRA was thought by some countries to be the 'thin edge of the wedge' and that once any kind of mineral activity was allowed then the industry would develop.

All countries with an active interest in Antarctica are intent on protecting the Antarctic environment (Burgess, 1990). Environmental protection needs to be in place for any mineral activity that may begin. CRAMRA tried to place environmental regulations to protect the environment. By CRAMRA, 'damage to the Antarctic environment or dependent or associated ecosystem' means any impact on the living or non-living components of that environment (CRAMRA, 1988). The CRAMRA regulation of having a three quarter agreement on the opening of areas and environmental regulations have to be complied too. The environmental regulations were going govern by the Regulatory Committee which was advised by the Advisory Committee. The Regulatory Committee once an area was opened for mineral activity, created a Management Scheme which indicated environmental levels to amend too. This legal framework of governing mineral activity seems to satisfy most of the environmental concerns as any of the Consultative Parties can bring any concern up. Environmentally the CRAMRA system appears to

work but from the point of view of the industry legal requirements maybe costly and time consuming. There is also the possible of having a discovery, shared by other interested parties which would reduce the profits of the company.

One of the key points that have come up from this study is that the knowledge of Antarctica is minimal and therefore environmental measures are hard to quantify. The need for baseline research to be conducted before any activity commences is critical. These baseline measurements maybe included in an environmental valuation before any mineral activity commences. An important step is to address all possible environmental concerns and from all countries interested in Antarctica. The use of countries regulations may speed up the process of forming terms and conditions. Many of the countries around the world have strict environmental concerns and therefore enforce strict regulations on the mineral industry. The use of these regulations have proven results for both the industry and environmentally. There maybe some regulations that requires alteration to work in the Antarctic environment and provide more environmental cover than they do in the country of origin. For the iron ore deposits, Australian regulations should be used a template to speed the negotiations.

It is proven the economically it is possible to mine in the Antarctica and increasing prices for ore is making it more profitable. Transportation and isolation of the continent are major factors that increase the price for mining ore, and also make any operation risky. The risky nature of the investment will deter potential investor, and the profit margins are not large enough to get large investors. The initial construction and setup of the mining is extreme, estimated in 1988 at US$203,900,000. This is a major investment for a risky business where only basic geology of the deposit is known.

8. Conclusion.

In my opinion mineral activity in the Antarctica should not be allowed, as Antarctica is the only continent in the world that has not been exploited by human for mineral resources. The continent has been stated by the Antarctic Treaty to be devoted to peace and science. Peace maybe disturbed if mineral action was allowed to begin. The is no agreement between countries interested in Antarctica as to who any mineral resources in Antarctica belong to, and because of this mineral activity will create political tension between nations. The wilderness value of Antarctica is extremely special as this is the only continent with little impact from human activity. The environment needs to be secured and protected. Australia said the environment would be affected with any mineral activity so the ‘absolute ban’ has

been put in place for the next 50 years from 1991. I hope this ban will continue as the continent need to be retained for a nature reserve for the world.

However the economics of mining is profitable and may cause pressure as reserves diminish. This creates demand and the need to find more reserves which may include Antarctica in the future. There are large quantities of deposits around the world which are being exploited and should be consumed before the need to disturb the great southern continent. These deposits are more accessible than any on the Antarctica continent, and are more economic because the shorter distance to transport ore. The increasing prices of cruel oil are making the profitability of mining in Antarctic for hard rock mineral less likely. However the potential to mine hydrocarbons in the continental shelf surrounding Antarctica may become more appealing. The fact is the reserves are known to be decreasing which increases the price and demand for product. This makes it economically interesting to look at exploring what potential mineral reserves are available in Antarctica. Pressure by large companies will be placed on the countries to allow mining activity to begin in Antarctica.

The environmental concerns need to be address before the pressure to open mineral activity is placed on the Antarctic Treaty. The CRAMRA system of having a graduated system moving from prospecting to exploration and finally to development, is a system of great control. The system could stop activity at any stage if the environment concern was too high. The system could also control the opening of the areas for mineral activity, this meant that no activity apart from prospecting could begin until the commission opened the area and had setup environment regulations. CRAMRA seem to be a great system to regulate mineral activity, as the environmental concerns were addressed before any environmental impacting activity were allowed to begin. CRAMRA maybe the regulation in which the Environmental Protocol needs to adopt if there is a consensus to allow mineral activity.

9. References

AEIMEE, (1986) Reports of the SCAR Group of Specialists on Antarctic Environmental Implications of Possible Mineral Exploration and Exploitation (AEIMEE), SCAR, Cambridge, UK

Anderson, J.B., (1989), Geology and Hydrocarbon Potential of the Antarctic Continental Margin, Minerals Resources Potential of Antarctica, Washington DC, USA pp.175- 201

Antarctic Treaty, (1959), The Antarctic Treaty, Washington DC, USA www.ats.aq

Behrendt, J.C., Drewry D.J., Jankowsky, E., Grim, M.S., (1980), Aeromagnetic and radio echo ice sounding measurements show greater area of the Dufek intrusion Antarctica, Science USA pp.1014-1016

Beike, D., (1988), An Engineering Economic Evaluation of Mining in Antarctica: A Case Study of Platinum, Mineral Resources Potential of Antarctica, Washington DC, USA pp. 53-67

Bureau of Mineral Resources, (1980), Australian identified mineral resources, Aust. Miner. Ind., Australia pp. 170-174

Burgess, J., (1990), Comprehensive environmental protection of the Antarctic: new approaches for new times, The Furture of Antarctica; Exploitation Verses Preservation, Manchester University Press, UK pp. 53-67

CRAMRA, (1988), Convention on the Regulation of Antarctic Mineral Resource Activities, Wellington, New Zealand, www.ats.aq

Cook, J., (1977), Voyage Round the World; reproduction of original in Legislative Library of British Columbia

De Wit, M.J., (1985), Minerals and Mining in Antarctica, Oxford University Press, UK

De Wit, M.J., Kruger F.J, (1988), The Economic Potential of the Dufek Complex, Mineral Resources Potential of Antarctica, Washington, D.C, USA pp. 33-53

Environmental Protocol, (1991), The Protocol on Environmental Protection to the Antarctic Treaty, Madrid, www.ats.aq

Ford, A.B., (1970), Development of layered series and capping granophyres of the Dufek intrusion of Antarctica, Special Publisher of Geological Society, South Africa pp. 492-510

Heap, J., The Political Case for the Mineral Convention, The Furture of Antarctica; Exploitation Verses Preservation, Manchester University Press, UK pp.44-52

Institute of Polar Studies, (1977), A Framework for Assessing Environmental Impact of Possible Antarctic Mineral Development Part 1 & Part 2, Ohio State University, Ohio, USA

London Billion Market Association, (2008), www.lbma.org.uk

Meeting of Experts, (1973), Antarctic Resources; Report from the informal meeting of experts, Fridtjof Nansen Foundation, Polhøgda

Ravich, M.G., Fedorov, L.V., Tarutin, O.A., (1982), Iron Deposits of the Prince Charles Mountains, Wisconsin University Press, Wiscosin, USA

Recommendation VII-6, (1972), Recommendation VII-6, Antarctic Resources – Effects of Mineral Exploration, Report of the Seventh Consultative Meeting, Antarctica Treaty, Wellington, NZ

Recommendation X-1, (1979), Recommendation X-1, Antarctic Mineral Resources, Report of the Tenth Consultative Meeting, Antarctic Treaty, Washington DC, USA pp. 11-13

Recommendation X-7, (1979), Recommendation X-7, Oil Contamination of the Antarctic Marine Environment, Report of the Tenth Consultative Meeting, Antarctic Treaty, Washington DC, USA pp.21-23

Rigg, K., (1990), Environmentalists' Perspectives on the Protection of Antarctica, The Future of Antarctica; Exploitation Versus Preservation, Manchester University Press, UK pp. 68-80

Temminghoff, M., Kruetzmann, N., Danninger, M., Lawton E., Rynbeck, S., (2007), Minerals Under Ice; How far do we go to utilize Antarctic resources

Tingey, R.J., (1987), Banded Iron Formation in East Antarctica, Mineral Resources Potential of Antarctica, Washington DC, USA pp.125-131

United Nations, (2006), Executive Summary World Economic Situation and Prospects 2006, http://www.un.org

Willan, R., MacDonald, D., Drewry, D., (1990), The Mineral Resource Potential of Antarctica: Geological Realities, The Future of Antarctica; Exploitation Versus Preservation, Manchester University Press, UK pp.25-43

World Resources Institute, (1988), Special Report on: The Antarctic Mineral Convention, Washington DC, USA pp.1-22 & 26-31