THE EXPLOITABILITY OF PEGMATITE DEPOSITS IN THE LOWER ORANGE RIVER AREA (VIOOLSDRIF – HENKRIES – STEINKOPF)

By

Hendrik Minnaar

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Hendrik Minnaar

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Declaration:

I, Hendrik Minnaar, declare that this treatise is the result of my own research and that cited literature is properly acknowledged.

Signed at Upington on 17 October 2005.

CONTENTS

Abstract

This study aims to investigate the exploitability of the pegmatite deposits in the lower Orange River area, situated between the settlements of Vioolsdrif, Henkries and Steinkopf in the Northern Province, in the light of current methods of financial analysis. A summary of the prevailing ore deposit model and a description of the geology are presented, and a financial analysis is undertaken taking into account the resources, current market conditions, and the legal requirements associated with a mining venture on the pegmatite bodies.

The most acceptable ore deposit model for the formation of pegmatites currently presents the pegmatite body as the final stage of crystallization of a cooling magma (Cerny, 1998a). Recent studies suggest that the crystallization of the pegmatite occur at an unexpectedly fast rate by the working of undercooling, in which the rate of cooling exceeds the rate of crystallization (London, 2005).

The pegmatites of the study area are mostly developed in granites of the Vioolsdrif Suite, in a post-orogenic tectonic setting and in many respects, fit well into the model of Ginsburg *et al.* (1979).

Although resources are difficult to estimate, it can be said that individual pegmatite bodies in the study area host reserves of up to 50 Mt of pegmatite ore. The markets for feldspar, currently the primary commodity in pegmatites, show an increase in price and a positive outlook for the future.

Legal requirements (licensing) are rigorous, under the new Act even more so than under the old, especially with regard to environmental issues.

A financial analysis suggests that, although mining operations on pegmatite bodies are highly sensitive to changes in commodity prices, revenue and fuel-related expenses, they are feasible under the current market conditions.

Zebrakop pegmatite is identified in this study as a potential target for the exploitation of a homogeneous pegmatite, coupled with the necessary development of bulk mining methods and a beneficiation plant.

CHAPTER 1. INTRODUCTION

According to Cerny (1998a, p. 29), small scale mining of pegmatite deposits at communal to family scale, contributes a significant proportion of world production of some of the pegmatite-derived commodities.

The pegmatites of the Vioolsdrif - Steinkopf - Henkries area in the Northern Cape Province, have historically provided a sporadic source of income. They are hosts to a wide variety of economic minerals and at times in history were the source of exceptional wealth, such as during the times of the beryl boom which started in 1929 and followed closely on the discovery of the spectacular diamond deposits at Alexander Bay (Gevers *et al.*, 1937, p.11).

The sporadic nature of mining activities on these pegmatites is caused by a variety of factors. The most important ones are:

a) The mineral or minerals which are in demand at the given point in time.
b) Highly variable commodity prices over time.
c) The decision between domestic and export markets.
d) The influence of transport costs - the largest single contributor to operational costs.
e) The unpredictability of the yield for the accessory minerals (caused by the nugget manner in which they are distributed in the ore body), some of which are currently fetching high prices on the international markets, and did so historically.
f) The low yield due to inefficient small scale mining methods.

In this study it is recommended that exploitation should be based on the production of feldspar as primary, and if necessary, the only commodity, as there is a consistent demand from the growing South African ceramic and glass industries. A large part of these industries are currently dependent on supply from the pegmatites in the study area. The selection of feldspar will be further justified in chapter 5.

1.1 Aims

The aims of this study are:

a) To provide an introduction to the pegmatite ore body model in order to provide the reader with an indication of the commodity types that may be encountered as well as the physical aspects regarding the deposits.
b) To present a selected area where such deposits are being exploited and additional resources may be delineated.
c) To review the markets of pegmatite mineral commodities and prioritize these.
d) To review the regulatory conditions which would need to be met.
e) To incorporate all the related issues into current methods of financial analysis in order to evaluate potential operations.

1.2 Delimitations

The study will concentrate on the pegmatites in the area south of the lower Orange River, i.e. a pegmatite field situated approximately in the central part of an imaginary triangle between the settlements of Vioolsdrif, Henkries and Steinkopf. This area was selected because:

a) It incorporates all the pegmatite deposits in the westernmost part of the Northern Cape pegmatite belt which have historically shown to be economically viable.
b) It is rather neatly delineated by outcrop in the area.
c) It is situated within the area where the writer is currently busy with a mapping project, as such keeping the cost of field work to the minimum.

In the financial analysis, only the South African market will be considered as marketing area. A consideration of the export market would require many assumptions for which there are currently no bases, as well as additional information and data to which the writer currently doesn’t have access to. The upside potential for highly lucrative revenue from by-product minerals such as mica, tantalite-columbite, spodumene and beryl, is not considered in this study. Only the production of feldspar will be taken into account. If, with the proposed mining methods, it can be shown that a mining venture will be feasible with feldspar as stand-alone commodity, then all other commodities produced from the mining operation will be extracted as by-products. The maximum production rate will be taken as 3,000 ton per month as this is currently the precedent and available data are dependent upon it. This also restrict the method of extraction to the current hand-picking method. Alternatives to all these issues will however, be discussed.

1.3 Method

Feldspar is considered, for the purpose of the study, to be the primary commodity of interest and it will be assumed that no other commodity would be mined. This is indeed currently the situation with only one operational pegmatite mine in the area (Blesberg Mine), which is currently producing only feldspar.

In order to assess the potential of other pegmatite ore bodies in the study area, a study of the available literature is undertaken with the emphasis on a number of the more important bodies that were previously investigated and on which data is available. This study of the literature is supplemented with field investigations. A survey is made of all costs related to an envisaged mining operation. Included in these costs are those related to regulatory requirements (licensing) which will be properly reviewed in the process. The markets for pegmatite minerals are evaluated. Finally a financial analysis is made aiming to start a mining venture similar to the existing mine at Blesberg. In doing this, a financial model (Discounted Cash Flow Model) is created in which the variables can be accounted for.

1.4 Acknowledgements

The writer wishes to thank everyone from whom information was obtained, especially Mr. J. Gagiano, mine manager at Blesberg, who kind-heartedly shared his extensive knowledge on pegmatite mining and also provided up to date financial data.

The writer further wishes to thank Mr. H.F.G. Moen, not only for the initial editing, but also for knowledge that comes from sharing in his many years experience as field geologist, and for inspiration that comes from working alongside him.

Finally, thanks to Prof. H.F.J. Theart for the considerable time and effort he devoted to improving the standard of this treatise, as well as the input and suggestions he made to the contents.

CHAPTER 2. GENERAL ORE DEPOSIT MODEL

2.1 Introduction

The American Geological Institute's Glossary of Geology (third edition) defines a pegmatite as "an exceptionally coarse-grained (most grains 1 cm or more in diameter) igneous rock, with interlocking crystals, usually found as irregular dykes, lenses or veins, especially at margins of batholiths". Pegmatites are hosts to a very wide variety of unique minerals in relatively high concentrations and usually in exceptionally large, well developed crystals.

Cerny (1998a, p. 43) states: "… the late-magmatic nature of pegmatite crystallization in a restricted system is confirmed today. Considerations of multiphase injection ('*Nachschub*'; e.g. Nikitin, 1957; Norton, 1981; Gaupp *et al*., 1984; Möller, 1989), metasomatic origin of extensive albitic and micaceous units (e.g. Ginsburg, 1960; Solodov, 1962, 1971; Norton *et al*., 1962; Stewart, 1978; Cerny, 1982a, b; Foord and Cook, 1989; Thomas and Spooner, 1988a, b), recrystallization plus metasomatism of granitoid rocks (e.g. Schaller, 1925; Landes, 1933; Nikitin, 1957), open-system syndilational crystallization from streaming vapour (Kretz *et al*., 1989), or exsolution of immiscible liquid (e.g. Melentyev and Delitsyn, 1969) may be either relegated to marginal, quantitatively insignificant phenomena or entirely abandoned."

In Cerny (1998b, p. 53) he discusses observations which lead to the practical abandonment (currently) of anatectic concepts as an explanation for the origin of the pegmatite-forming fluids. Again he concludes (p. 55): "The classic model of igneous derivation of rare-element pegmatites is the only one that has withstood the test of time, and become reinforced in the process. None of the multitude of aqueous and anatectic hypotheses reviewed earlier can seriously compete with this model. On the contrary, several investigators who started their research seriously considering or advocating the anatectic mechanism largely abandoned it because of evidence to the contrary generated by their own research …" This is indeed a strong argument and although the debate is surely not settled as yet, this treatise will discuss the model which is currently widely accepted and favoured, namely that in which pegmatites are regarded as the late crystallization phase of a consolidating granite intrusion, as it is not the primary goal of this treatise to address these issues.

2.2 Classification

A simple classification, based the internal zoning and replacement phenomena in pegmatite bodies, is provided by Cameron *et al.* (1949):

a) Homogenous pegmatites are generally regarded as uneconomic, consisting mainly of a homogeneous mass of quartz, potassium feldspar, plagioclase feldspar and muscovite, with or without accessory minerals such as magnetite, ilmenite, apatite and zircon (example see plate 2).

b) Inhomogeneous pegmatites display zones, from the margins inward, which are more or less concentric shells or envelopes generally conformable to the shape of the pegmatite (see plate 1). Zones are defined mainly by their texture and mineralogy and are termed, from the margins inward, the border, wall, intermediate and core. There may be more than one intermediate zone. The zones are primary crystallisation features which show increasing grain size and a decreasing number of rock-forming minerals, from the margin to the core.

d) Fracture fillings are generally tabular bodies which fill fractures in pre-existing units. They are easily recognised, though scarce and volumetric insignificant.

c) Replacement bodies are formed at the expense of pre-existing units under lithological or structural control. They are not as easily recognised and the effects of metasomatism vary in intensity from selective replacement of individual mineral species to pervasive replacement of the whole unit.

Pegmatites have been classified by Ginsburg *et al*. (1979) according to their depth of formation, mineralization, and their relationship to igneous processes and metamorphic environment:

a) **Miarolitic pegmatites**. These are generally intrusive into low-grade metamorphic rocks and often contain cavities bearing optical fluorite, gem quality beryl, and topaz. They are found within, or in close proximity to, granites, and their direct relationship is unquestionable. Where they intrude the country rocks, they extend for only limited distances.

b) **Rare-element pegmatites**. These are enriched in granophile elements (Li, Rb, Cs, Be, Ta, Nb and minor Sn) and often fill fractures in cordierite-amphibolite facies rocks. They are generated from differentiated granites which, in general, have been transported. These pegmatites are often associated with granites which have been intruded into tectonically active regimes along deep fault systems (Cerny, 1982a). The genetic relationship of these pegmatites to their granitic source is often displayed but many pegmatite fields reveal no exposed granitoid parent. The potential granitic source could, however, still lie at depth, below the current level of exposure. Pegmatite melts are highly mobile in tectonically active regions. Granites that generate rare-element pegmatites of intermediate depth tend to be late- to post-tectonic granites of calc-alkaline affinity which have been emplaced along previously formed faults and fracture systems during the waning stages of tectonic activity. These granites are typically leucocratic, biotite-bearing, two-mica, or muscovite-bearing granites and contain accessory garnet, tourmaline, cordierite and/or andalusite.

c) **Mica-bearing pegmatites**. These are usually hosted by upper amphibolite facies metamorphic rocks and commonly carry extensive mica reserves and minor, if any, rare-earth elements. They are products of anatexis (partial melting) or are separated from anatectic, more or less in place or autochthonous (S-type) granites. These pegmatites are often dispersed over large areas in which there is a paucity of granitoid plutons. Granitoids that form the mica-bearing pegmatites vary considerably in composition from trodhjemites through granodiorites to granites and are mostly two-mica granites with accessory garnet, tourmaline, kyanite, zircon, apatite and monazite.

d) **Abyssal**. These pegmatites are generated in granulite facies terrains and are usually barren, though locally they may contain allanite, monazite and corundum. Furthermore, these pegmatites often grade into migmatites and display no direct relationship with granitic bodies. They are usually conformable to the host rocks.

According to this classification system, the pegmatites of the study area fall in the rare-element class; this is illustrated in Figure 1.

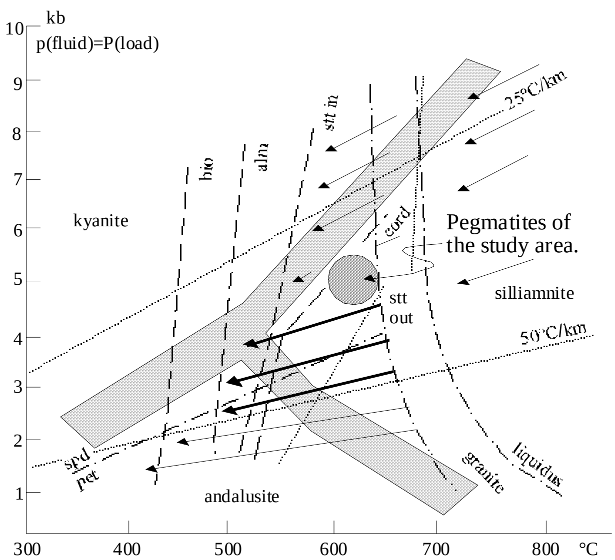


Figure. 1: An illustration of the Ginsburg *et al.* (1979) classification modified after Cerny (1998a) to illustrate the environment hosting the pegmatites of the study area.

Arrows indicate regional fractionation trends relative to metamorphic grades of the host rocks. Aluminosilicate boundaries from Robie and Hemingway (1984), cordierite in metapelites after Schreyer and Seifert (1969), spodumene-petalite from London (1984), granite liquidus-solidus after Jahns (1982), other boundaries from Winkler (1967, 1976).

2.3 Origin

The origin of the pegmatite-forming melts have been a crucial question from the start. According to Cerny (1998b), the present state of our knowledge distinctly favours derivation by fractionation of igneous intrusions, where the pegmatites are seen as igneous derivates of fertile granite intrusions, products of advanced fractionation of pluton-size batches of granitic magmas. Evidence supporting this include:

a) physical links are observed between mineralized pegmatites and their plutonic parents;

b) Continuous textural, mineralogical and geochemical evolution is documented from the parent granites to associated pegmatites;

c) Late-crystallizing pegmatite pods trapped within parent granites are locally exact duplicates of exterior pegmatites in metamorphic roofs of these granites;

d) Bulk compositions of rare-element pegmatites correspond to the experimental minima in granitic systems modified by accumulation of Li, B, F and P, ± other "pegmatitic" lithophile elements;

e) Temperatures of crystallization determined for rare-element pegmatites correspond to such modified granitic magma.

Classic rules of crystal-chemical selection of compatible versus incompatible trace elements apply to crystallization of the fertile granites. In this way a substantial proportion of lithophile rare elements (e.g. Nb^{5+}, Ta^{5+}, Li^{+}, Cs^{+}) are relegated to residual melts.

These residual melts are mostly intruded into the country rock via forcible intrusion (evidence reviewed by Chadwick, 1958). However, the notion of passive pegmatite emplacement into pre-existing voids (or openings generated by mechanisms independent of the pegmatite intrusion itself) is also recognised today (Cerny, 1998b).

Pegmatite emplacement is actually subject to the same controls as any small-scale igneous intrusion, i.e. melt pressure, rheologic state of the host rock, lithostatic pressure, deviatoric stress, and strength anisotropies in the host rock. Brisbin (1986) successfully applied the general mechanism of igneous intrusion to the specific case of granitic pegmatites, documented by selected examples.

The distance of an individual pegmatite body from its source is proportional to the thermal stability of its particular melt composition. Melts with the lowest liquidus temperatures should migrate farthest down the regional thermal gradient (which generally coincides with the pressure gradient). This is evidently the dominant reason for the regional zoning of pegmatite groups, the lithophile elements being relegated to the latest melts (Figure 2). Most of the liquidus-depressing constituents also tend to reduce viscosity, and thereby considerably increase the overall mobility of the melt (e.g. Manning and Pichavant, 1985).

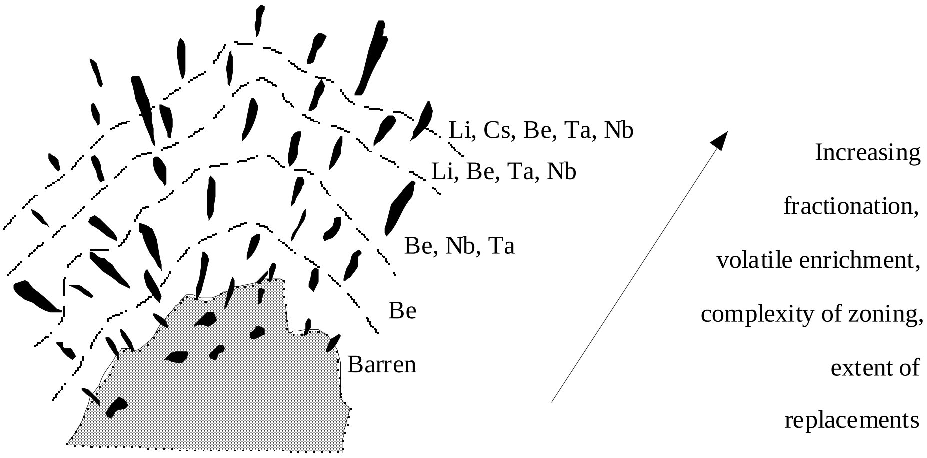


Figure 2: Schematic representation of regional zoning in a cogenetic granite + pegamatite group (modified from Trueman and Cerny, 1982).

2.4 Internal pegmatite consolidation

Investigations of recent years seem to favour one of the classic views of pegmatite consolidation, namely that the crystallization proceeds, under decreasing temperature (and variable pressure) and conditions of restricted exchange with wall rock in a volatile-rich, highly hydrous granitic melt, complemented by (or grading into) precipitation from an aqueous fluid. Extensive interaction among the solids, melt and fluids at different stages of consolidation, and particularly toward its termination, is characteristic. Some of the observations supporting this model are:

a) The bulk composition of both the homogeneous and zoned pegmatites are very close to the thermal minima and eutectics in the Ab-Or-Qz-H_2O system (Tuttle and Bowen, 1958; Luth *et al*., 1964).

b) Temperature ranges, bracketed by fluid inclusion, two-feldspar thermometry and other indicators, are between 750°C to 150°C and generally decrease from the margins inward.

c) The zonal structure of inhomogeneous pegmatites.

Many explanations have been proposed for the internal zonation of granitic pegmatites. Jahns and Burnham (1969) said that pegmatites owe their distinctive textural and zonal characteristics to the buoyant separation of aqueous vapour from silicate melt, giving rise to K-rich pegmatitic upper portions and Na-rich aplitic lower zones of individual pegmatites. In this model both silicate melt and vapour are present in the system. Potassium is extracted from the liquid by the vapour in preference to sodium, and potassium and other constituents travel rapidly through the vapour in response to a temperature gradient (Jahns and Tuttle, 1963, p. 90).

London (2005) reviews the current status of our knowledge on the internal structure of pegmatites. Various recent studies (London, 1986a, Chakoumakos and Lumpkin, 1990, Morgan and London, 1999; Sirbescu and Nabelek 2003, Nabelek *et al.*, 1992, Thomas *et al.*, 1988) reveal that the temperatures recorded by mineral assemblages, fluid inclusions, and calibrated solid solutions commonly point to temperatures of pegmatite crystallization well below the solidus temperatures of hydrous granitic melts (650 – 700 °C). These studies point to crystallization temperatures ranging between 350 – 450 °C and that silicate melt may persist at temperatures as low as 262 °C.

The low temperatures of crystallization have popularly been attributed to exotic components (commonly called “volatiles”) playing the role of fluxes in lowering the melting and crystallization temperatures. The fluxing components most often cited are H_2O, B, F and P.

Recent studies on the cooling rates of pegmatites (Chakoumakos and Lumpkin, 1990; Morgan and London, 1999; Webber *et al.*, 1999) indicate that pegmatites crystallize very quickly, anything from just over one week to 3 – 5 months. These calculated cooling rates are nothing short of revolutionary because it has always been presumed, based on the coarse grain size, that pegmatites cool very slowly. However, from the synthetic crystal industry we know that giant crystals of normally insoluble silicate and oxide crystals can be grown in weeks to months, given a properly fluxed growth medium and compositional or thermal gradients.

Experimental studies that were done on the crystallization of hydrous silicic melts at geologically relevant pressures (e.g. Fenn, 1977; Swanson and Fenn, 1986; London *et al.*, 1989; MacLellan and Trembath, 1991; Baker and Freda 2001; Evensen *et al.*, 2001) report two important observations:

a) there is a lag time, also referred to as the nucleation delay or incubation time, between cooling and the onset of crystallization, which measures days to months.

b) as the magnitude of undercooling increases, crystal habits evolve progressively from euhedral to skeletal to radial spherulitic. In short, the greater the supersaturation of the melt obtained via liquidus undercooling, the more pegmatite-like the fabric and texture.

The order of crystallization should follow a thermal gradient from the contact with the host rock (supplying heat) to the centre, although practical examples in natural pegmatites do not always conform to this, the reason for which is still speculative.

2.5 Regional context

The regional association of pegmatites can be described as by Cerny (1998b):

Pegmatite groups are the basic components of larger pegmatite populations that have common structural, igneous and geochemical links, related to specific periods of geological evolution.

Pegmatite fields are territories populated by pegmatite groups within a common geological and structural environment, usually less than 10,000 km^2 in extent. They are generated during a single tectonomagmatic stage of regional evolution, have the same type of granitoid source, and are of about the same age.

Pegmatite belts consist of pegmatite fields related to a large-scale linear structure such as a deep fault lineament, a mobilized cratonic margin, or a trough mobilized within a stable shield. Individual pegmatite fields may (but commonly do not) belong to different classes formed under different conditions; nevertheless, all are related to the geological history of one particular linear structure.

Pegmatite provinces constitute the sum of pegmatite fields and belts within a single metallogenic province, a large-scale geological unit with common fundamental features of geological evolution and mineralization style. Within a province, pegmatite fields and belts may (and commonly do) belong to different classes formed at different stages of crustal evolution, but each class displays repetitive properties throughout the province.

CHAPTER 3. THE STUDY AREA

3.1 Introduction

Given the sensitivity of industrial mineral producers to transport and production costs, the geographical location of the area needs to be addressed in some detail.

The pegmatites that were investigated are situated in an area between Vioolsdrif and Henkries, south of the Orange River, and to the north of Steinkopf, in the Northern Cape Province (Figure 3). This area is served by a road network comprising tarred main roads and dirt roads of variable quality.

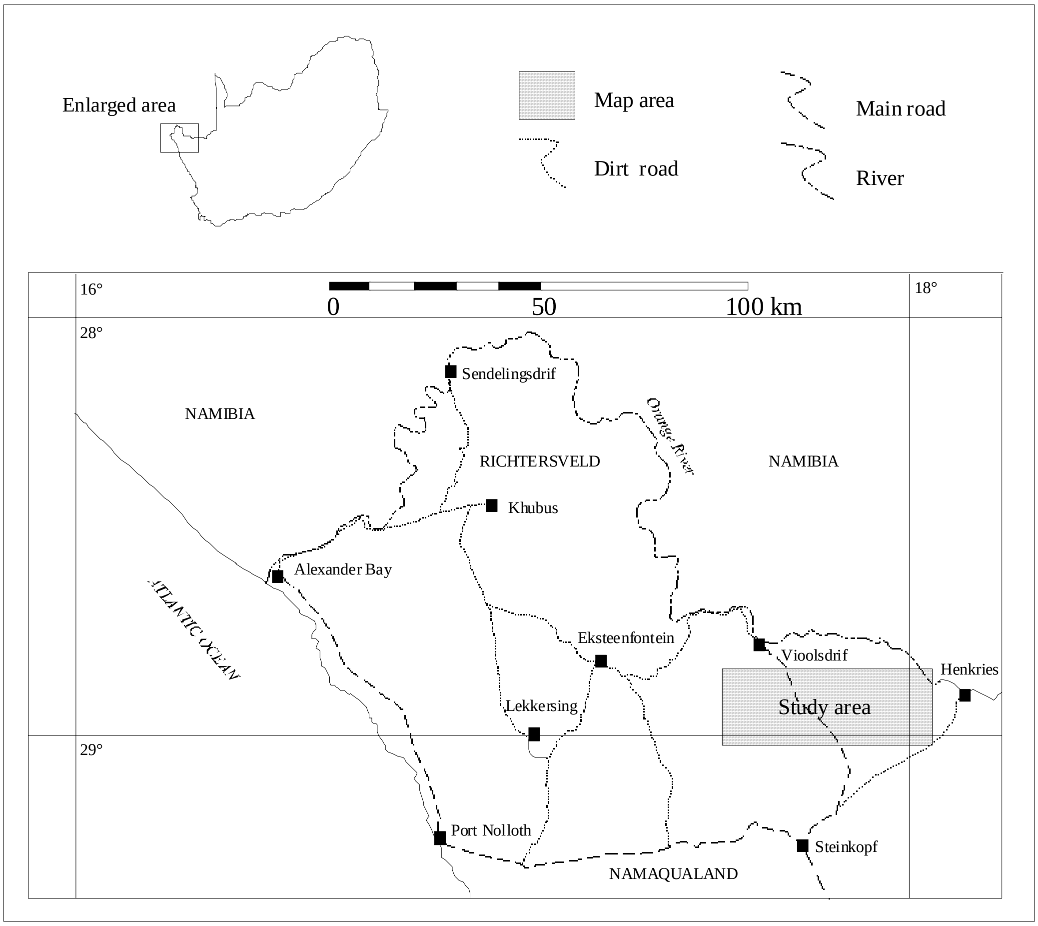


Figure 3: Location of the study area.

The location of the investigated pegmatites are shown in Figure 4. They include, from west to east, Groendoorn I,II,III and IV; Noumas I (also known as Blesberg) an

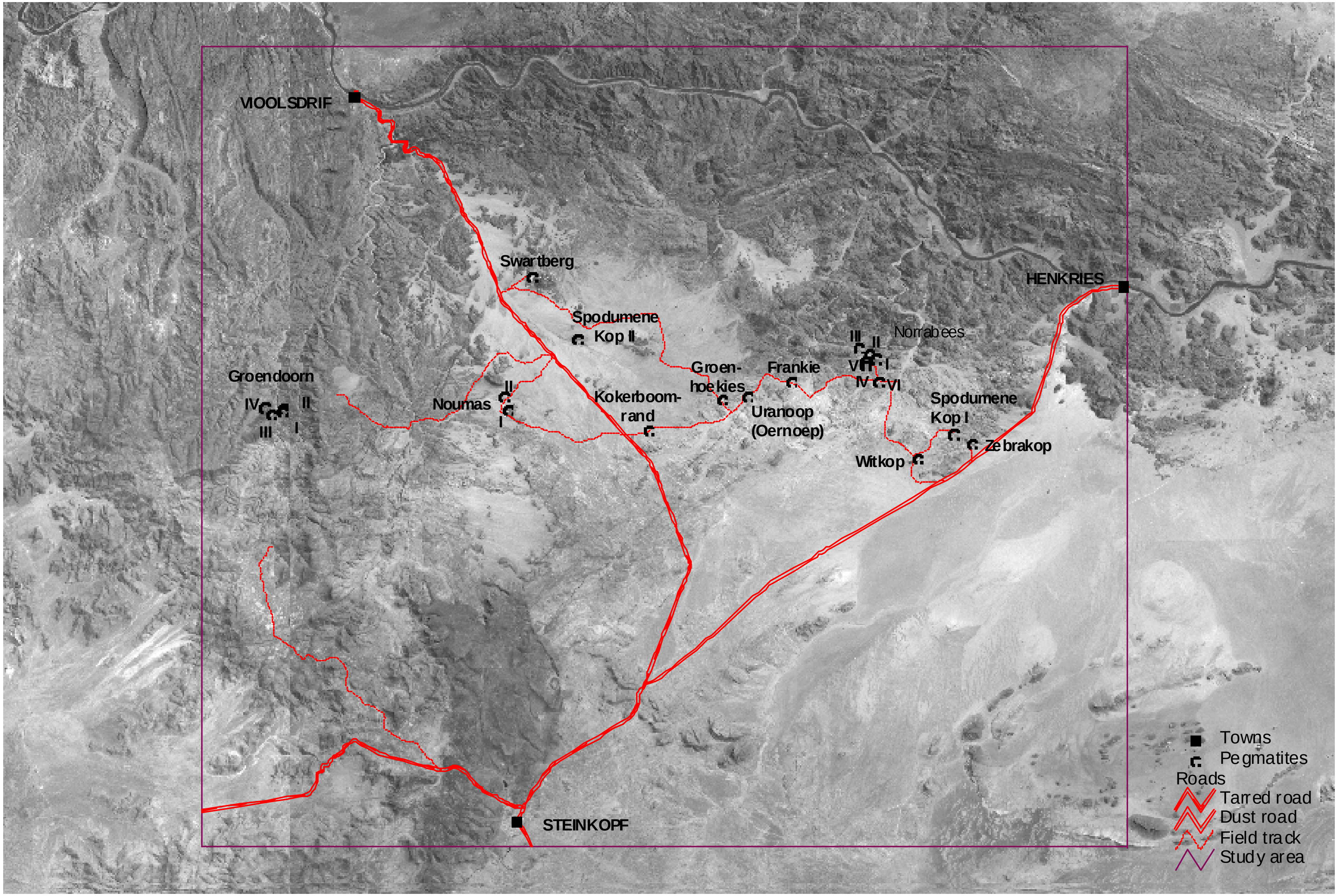


Figure 4: The location of the investigated pegmatites.

II; Swartberg; Spodumene Kop II; Kokerboomrand; Groenhoekies; Uranoop; Frankie; Norrabees I, II, III, IV, V and VI; Witkop; Spodumene Kop I; and Zebrakop.

Except for Zebrakop, all these pegmatites are zoned bodies and serve as classic examples of the traditional pegmatite mining operations in this area. The financial analysis of this study will focus on evaluating a mining operation in this traditional manner as is currently the case at Blesberg involving selective mining and hand-picking operations.

Zebrakop is the only homogeneous pegmatite in the study area that has been included in this study, and the reason for its inclusion is because a recent study on its economic potential is available (Agenbacht *et al*,2003). This pegmatite is envisaged by the author as a potential target for development should more advanced mining methods be considered in future. It is not, however, the focus of this study for the stated reasons that exploitation of homogeneous pegmatites will only be made possible through the development of more advanced mining techniques and the erection of a beneficiation plant and as financial data related to such operations is not currently available to the author, it will not be considered in the financial analysis.

In most literature the study area is referred to as northern Namaqualand, in some others it will be included as part of the Richtersveld. It is really situated at the merger of three distinct areas namely the Richtersveld to the west (the Richtersveld proper lies to the west of the Neint Nababeep Plateau), the Bushmanland to the east (Henkries is already situated within northern Bushmanland), and Namaqualand to the south (Steinkopf is situated in Namaqualand). It is an arid region with temperatures rising deep into the forties (°C) in mid-summer. The average rainfall at Steinkopf is about 150 mm per annum while at Vioolsdrif, it is as low as 40 mm per annum. The bulk of the scanty rainfall is precipitated in the winter months, conforming to climatic conditions of the southwestern Cape, when cold fronts from the ocean reach far enough north. It generally falls in the form of drizzling “mist rains”. West winds blow moisture from the sea over the edge of the escarpment, stretching from a few miles west of Steinkopf into the Richtersveld (Figure 5). Most of the moisture is precipitated on the western slopes and summit of the escarpment. Very little penetrates beyond the Steinkopf plateau into the pegmatite area. Apart from the

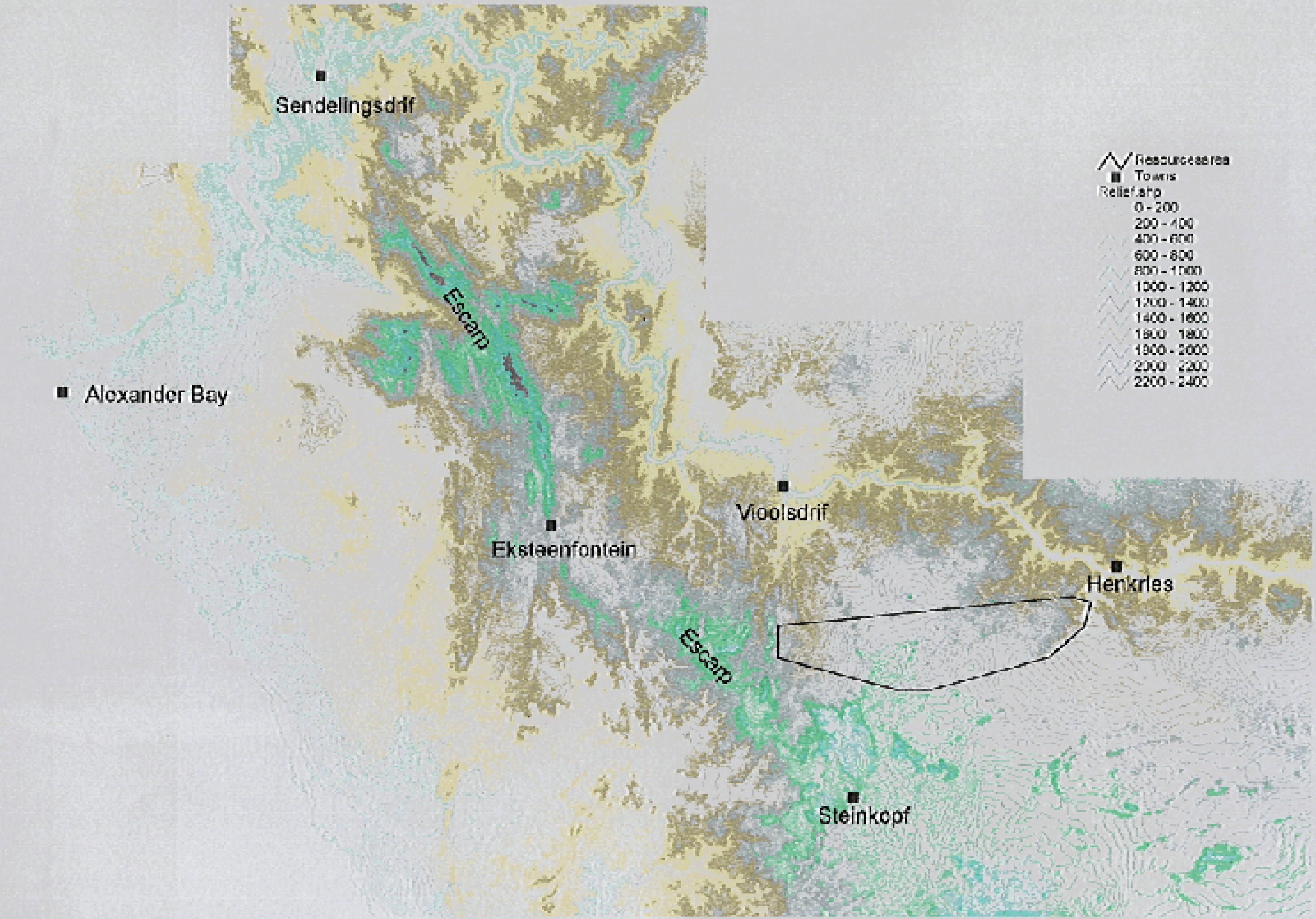


Figure 5: The relief on the 2816 Alexander Bay sheet.

Orange River, water is extremely scarce in this region. Springs and permanent wells occur in a few places such as at Uranoop and Noumas (see Figure 4). Boreholes and windmills are generally not well maintained. Water for mining operations is currently being transported from the nearest settlement. The area is therefore also environmentally sensitive and care should be taken to address this aspect especially where small scale mining is considered.

The relief of the area becomes progressively more mountainous from south to north as the Orange River gorge is approached (Figure 5). In the west, the escarpment of the Neint Nababeep Plateau forms a sharp north-south striking boundary. Except for the Groendoorn pegamatites all the investigated pegmatites are situated in the relatively low-lying southern parts of the study area and are easily accessible. The Groendoorn pegmatites are situated in the Groendoorn River gorge and is currently only accessible by foot. There is an old track leading up to the pegmatite along the river bed from the south but it is badly washed away and is usable only up to about Biesieswater (Figure 4). Another track from the west takes one closer to these pegmatites but in this case a mountain has to be crossed (Figure 4).

Numerous farm tracks and old mine roads provide access to all but the Groendoorn pegmatites. Some of these tracks are shown in Figure 4. These farm tracks and old mine roads all have their origin in the turn-offs from the two main access routes to the area, i.e. the N7 highway leading up to Namibia through Vioolsdrif, and the Steinkopf - Henkries dirt road turning off from the highway just north of Steinkopf (Figure 4). Distances to the main consuming industries in Gauteng and Cape Town are approximately 1,300 km and 700 km respectively.

The study area extends over parts of the Steinkopf and Vioolsdrif communal land and as such entails land belonging to the state and is controlled by community councils which are centred in the towns of Steinkopf and Vioolsdrif. Economic activities in the area comprise predominantly small scale farming with sheep, goat and cattle, and sporadic small scale mining on some of the pegmatites.

Vegetation is sparse with grass and shrubs predominating, trees being few and far apart. Kokerboom (*Aloe dichotoma*, *Aloe pillansii* and *Aloe ramossisima*) occur, however, not in such large numbers as in the Bushmanland and Namaqualand; halfmens (*Pachypodium namaquanum*) occur sparsely throughout the area. Succulents include species like Lithops and Conophytum and turn out to be relatively abundant if searched for.

The area is also wanting of wildlife. Klipspringer are encountered sporadically. Tribes of baboon often inhabit the canyons in mountainous terrain. Red jackal and leopard represent predators and one needs to be on the lookout for scorpion and snakes (black cobra and cape cobra are relatively abundant).

3.2 Previous work, historical background and the current situation

Although mention of the pegmatites in the study area are made in earlier writings of adventurers and prospectors that visited the area, the first comprehensive studies into these pegmatites were those of Gevers *et al.* (1937) and Schutte (1972). Due to the nature of these studies, viz. investigations specifically into the mineral potential of the pegmatites, they are quite substantial and reliable. Ward (1969 - 71, 1972, 1974) reported to the Precambrian Research Unit on the Vioolsdrif pegmatite belt. Hugo (1970) reported on the pegmatites of the Kenhardt and Gordonia districts to the east of the current area of interest.

The Noumas I pegmatite (Blesberg Mine) was one of the first pegmatites to be exploited in the area when it was first mined in 1925 for bismuth and mica (Schutte, 1972). This pegmatite is also the largest known mineralized pegmatite in the area. Shortly after these first mining activities, during the late 1920's, the demand and price for beryl increased and, in Namaqualand led to the well-known beryl boom of the early 1930's (Gevers *et al.*, 1937). During this time the area between Steinkopf, Vioolsdrif and Goodhouse was investigated by the Geological Survey and this investigation was followed by extensive government-sponsored prospecting during 1935 and 1936. The results of these activities were reported by Gevers *et al.* (1937).

After the outbreak of the Second World War, the Geological Survey embarked on a programme of exploration for strategic minerals, mainly wolframite (tungsten) and scheelite, along the valley of the Orange River west of Upington. Although no particular attention was devoted to pegmatites, their distribution became better known through the geological maps produced (Von Backström, 1964). From these maps, an extensive pegmatite belt, some 450 km in length and between 40 and 50 km wide, was identified, extending from the Vioolsdrif area in the west to the Kenhardt-Prieska area in the south (figure 6). With the advent of the nuclear era during the mid-1940's, the Geological Survey initiated an investigation of local resources of reactor raw materials. With pegmatites being the main source of certain of these materials such as beryllium, lithium, and rare-earth elements, high priority was given to a study of pegmatites. Since the pegmatite area of the Northern Cape had already been geologically mapped by that time, it was decided to investigate this region in more detail.

A reconnaissance survey during 1959 showed that the pegmatites in the Steinkopf area of Namaqualand showed potential and were investigated during 1962 - 1966 and the results were compiled by Schutte (1972).

In general, field work consisted of the systematic mapping and investigation of the distribution, mineral content, and mode of occurrence of all pegmatite bodies visible on aerial photographs. Detailed investigations were made of the composition and structure of the more important zoned pegmatites. In addition, large-scale maps were prepared of some of the larger and mineralogically more complex bodies.

The identification and location of pegmatite bodies is usually not very difficult as they show up well on any remote sensing medium such as aerial photographs, ASTER images, Landsat images, etc. It is in their large numbers that the challenge lies, as most are barren of economic minerals and those that do contain economic minerals, are not all economically viable. Pegmatite investigations entail detailed mapping of the pegmatite itself and assessment of its mineral content, zoned nature, as well as the grade and reserves of exploitable commodities. As the potential cash flow to be generated from such mining operations normally do not justify the cost of drilling programmes, the investigations usually have to be carried out without such aid.

Currently only one pegmatite in the area is being mined, i.e. Blesberg Mine (Noumas I pegmatite), with some of the others (such as Groenhoekies and Kokerboomrand) sporadically in operation. Blesberg provides for the demand of nearly the whole of the South African feldspar consuming industries (ceramic and glass industries). The area is, however still richly endowed with pegmatite ore, not only in dormant mines, but also in virgin ore bodies. Interest persists in the possible exploitation of these reserves as indicated for example by two recent studies, i.e. resource evaluations executed on the homogeneous Zebrakop pegmatite (Agenbacht *et al.*, 2003), and Witkop - a previously mined pegmatite, currently lying dormant, with a zoned composition (Hansen *et al.*, 2004). A measured resource of pegmatite material (according to the SAMREC code) of 14.5 million ton was estimated for Zebrakop and 220,500 ton for Witkop.

The results obtained from these two studies are interesting as they deal with two different types of pegmatite (homogenous and inhomogeneous). If the mineral profile counts are compared, it is found that the average ratio feldspar : quartz : mica is the same (6 : 3 : 1) for the two pegmatites. This opens up the possibility of a bulk mining method even for the zoned pegmatite and the viability of other homogeneous pegmatite bodies. Three important factors call for the application of a bulk mining method:

a) Feldspar - the primary commodity - is distributed throughout the pegmatite body.

b) The distribution and concentration of accessory minerals in the pegmatite body is highly unpredictable, even in the zoned pegmatites.

c) Selective mining methods may and have in the past, led to unstable high walls and unsafe working conditions, while a bulk mining method will allow even for the reopening of mines which might have been closed for this reason.

In the past, especially the mica-rich zones were targeted (see plate 1). Due to changing market conditions mica is no longer the primary commodity in the pegmatite deposits. Notwithstanding its higher price, its relative paucity in the ore compared to feldspar and quartz, as well as the preference of a bulk mining method above selective mining, renders mica uneconomical as a stand-alone commodity, but it would form an important by-product.

3.3 Regional geology

The pegmatite field in the study area is situated in a border zone between two tectonic domains. To the north is an area dominated by unfoliated or weakly foliated granites in which the foliation shows no consistent orientation. To the south the country rocks are comprised of gneisses and schists in which a penetrative, generally E-W foliation is developed. These two domains were termed the Richtersveld Subprovince and Bushmanland Subprovince respectively by Kröner and Blignault (1976).

The granites of the Richtersveld Subprovince comprise an intrusive suite, the Vioolsdrif Suite, of batholithic nature and were dated at approximately 1,900 Ma for the mafic members, to approximately 1,730 Ma for the felsic members (e.g. Reid, 1977). They are intrusive into a succession dominated by volcanic rock types and also containing subordinate (in the study area) sediments dated at approximately 2,000 Ma and which are, based on isotope studies, related to the same magmatic event (Reid, 1977). This volcano-sedimentary succession (Orange River Group) occurs as remnants on various scales in the granites and according to Blignault (1977), a synclinal structure related to pre-intrusion deformation can be recognized in the unit to the east of Vioolsdrif.

In the Bushmanland Subprovince the intrusive gneisses (granodioritic) are intrusive into schists and gneisses, some of which the protoliths are controversial but a large proportion of which are clearly metasedimentary (such as the biotite schist in which the Groendoorn pegmatites are developed). Geochronological ages of 1,200 Ma (e.g. Joubert, 1986) are accepted to represent the metamorphic age related to the peak of deformation in this subprovince.

The pegmatites in the study area are mainly developed in granodiorite of the Vioolsdrif Suite. A large proportion is also developed in the leucocratic alkaligranites of the suite, however, all the studied pegmatites are situated in the granodiorite and most of the pegmatites in the leucogranite seem to be barren. Field observations suggest that a large proportion of the pegmatites occurring in the leucogranite have an *in situ* (replacement or anatectic) origin, as deduced from gradational contacts and the fact that foliation in the pegmatite conforms to foliation in the granite.

The affinity of pegmatites with ultramafic rock types is a well-known phenomena (e.g. Andersen, 1931) and in the present study area this association is especially conspicuous outside the pegmatite belt, where pegmatite development is not so overwhelming. Swartberg is a good example. It is situated approximately 12 km to the north of the pegmatite belt proper and constitutes an ultramafic complex composed of gabbro, peridotite and troctolite. The main pegmatite body associated with this complex has a northeast strike, as opposed to the general northwest strike in the pegmatite belt. In accounting for the dominance of pegmatites in gabbroic and amphibolitic country rock Andersen (1931) suggested that their elastic properties differ radically from those of the other rocks examined and thus they fracture more readily.

Hugo (1970) concluded that there are two phases of pegmatite intrusion in the pegmatite belt of the Northern Cape, viz. an older phase at 1,000 Ma associated with the closing stages of the Namaqua orogeny, and a slightly younger phase at 950 Ma related to the intrusion of isolated bodies of late- to post-tectonic granitoids. These ages represent a problem as to the origin of the pegmatite-forming fluids. The close association of the pegmatites with the granitoids of the Vioolsdrif Suite suggests that these granitoids acted as the parent magmas. However, the youngest phases of these granitoids are dated around 1,730 (e.g. Reid, 1977). This makes the gap between consolidation of the granites and the formation of the pegmatites, approximately 700 Ma, which can not be accepted.

Geochronology puts the beginning of the Namaqua orogeny at 1,200 Ma and its termination at 1,100 Ma, during which time easterly trending shear zones were formed (Colliston and Schoch, 2003). Cerny (1998a) points out that radiogenic isotope systems in granitic pegmatites are notorious for being disturbed, particularly at geologically old localities. However, if the 1,000 Ma age for the early phases of the pegmatites in the Northern Cape pegmatite belt is accepted as representative of the closing stages of the Namaqua orogeny, it would put the development of the pegmatites simultaneous with the development of easterly directed shear zones. This would explain the predominantly northwest strike of the pegmatites, indicating sinistral movement and the pegmatite developing in shear-related tension fissures. This too suggests that the pegmatites are not related to the Vioolsdrif Suite.

Theart (pers. comm.), who conducted a study of an area to the south of the present study area (Theart, 1980), mentioned the possibility that the pegmatites might be related to smaller granitic bodies which intruded along tectonic discontinuities during the later stages of the Namaqua orogeny (suggesting possible plate accretion along these tectonic discontinuities). The Wyepoort Granite (Theart, 1980) is an example of such possible younger intrusions. This suggestion would require a detailed survey of the pegmatite belt coupled with geochronological studies. It should be stated that a proper study of the Northern Cape pegmatite belt has been overdue since the studies of Gevers *et al.* (1937), Hugo (1970) and Schutte (1972).

3.4 Local geology and mineralogy of selected pegmatite bodies

The pegmatite belt of the Northern Cape (Figure 6) has already been recognized by Gevers *et al.* (1937, p. 12). The study area comprises the extreme western extension of this belt. All the investigated pegmatites except the Groendoorn pegmatites, are developed in brown-weathering granodiorite of the Vioolsdrif Suite (see Table 1) of which the average composition is plagioclase, K-feldspar (microcline and perthite), quartz, biotite and varying proportions of hornblende with chlorite and epidote being common alteration products (Minnaar, 2003). The Groendoorn pegmatites are developed in a melanocratic (dark-brown to red-brown weathering) nodular micaceous schist of the Groendoring Formation (Bushmanland Group; Marais *et al.*, 2001). This schist consists of a medium- to fine-grained matrix

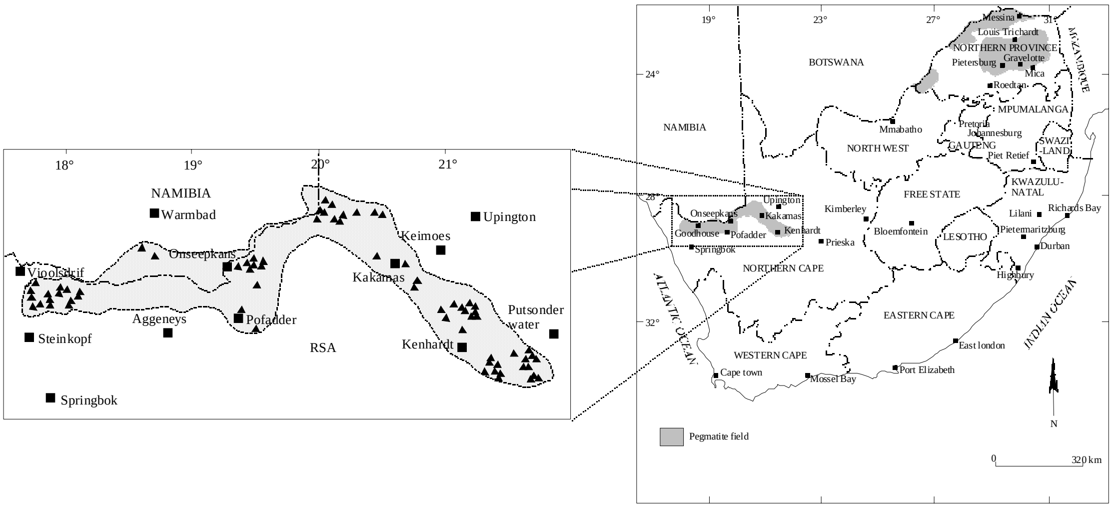


Figure 6: The pegmatite belt of the Northern Cape.

of quartz, muscovite, biotite, chlorite and ore in which oval-shaped (elongated and flattened parallel to the foliation) nodules occur, with dimensions varying from 1 x 1.5 x 3.5 cm to 3.5 x 6.5 x 15 cm (Minnaar, 2003). These nodules consist of very fine-grained mica which was shown to be an alteration product of original cordierite nodules (Atanasova, 2004). Ward (1977) also found andalusite in these schists.

Generally the pegmatites range from bodies measuring only a few centimetres in extent, to more than 3 km in length and about 100 m wide. They also vary in shape from thin veins or dykes to irregular discordant masses. The irregular pegmatite bodies are generally large, whilst the dykes and veins are usually smaller. The great irregularity in outline, dimensions, and continuity in strike is a feature that naturally has an important bearing on their continuity in depth. The pegmatites frequently form ridges as they are more resistant to weathering than most of the wall rocks (see plate 2). The bulk of the pegmatite bodies strike generally northwest, and the remainder in nearly every possible direction. While most of the bodies are markedly discordant, many of them strike parallel to the foliation of the country rock, but transect in depth. Generally the pegmatites dip at high angles, but a few lie at low angles resulting in large surface exposures.

Compositionally, two types of pegmatites can be distinguished, viz homogenous and inhomogeneous. The homogeneous pegmatites are simple aggregates of quartz, feldspar and accessory minerals and cannot be divided readily into units of contrasting mineralogy and texture. In the field, pegmatites of this type are normally found in groups or swarms (example see plate 3). These bodies have not historically yielded minerals of economic importance. The Zebrakop pegmatite is the only homogeneous pegmatite included in this study. Most of the pegmatites show some degree of systematic arrangement of their constituents and are therefore termed inhomogeneous. Each pegmatite consists of two or more structural and lithological units which differ in mineralogy or texture or both - the arrangement generally being related to the walls of the body.

All the basic unit types encountered in the world's major pegmatite fields have been recognised in this pegmatite belt, viz zones, replacement bodies, and fracture fillings. Zones are by far the most important and consist of successive shells symmetrically surrounding an innermost zone or core. Zones can be classified into border zones, wall zones, intermediate zones, and cores. Replacement bodies are generally formed by replacement of pre-existing pegmatites either along fractures or along boundaries between lithological types. Fracture fillings are bodies formed by the filling of fractures that cut across pre-existing pegmatite (Cerny, 1998a).

The inhomogeneous pegmatites can further be classified, according to economical mineral content and degree of complexity of internal structure, into simple pegmatites and complex pegmatites (Hugo, 1970). The former group includes pegmatites having a simple, though well defined internal structure, generally consisting of three, but never more than four zones. In the higher metamorphic (amphibolite facies) area to the east of the study area, these bodies usually contain andalusite, corundum, apatite, or rare-earth minerals (euxenite, gadolinite). Since the cores of the simple pegmatites usually consist of quartz and microcline-perthite, a considerable number proved to be suitable for the production of feldspar. Complex pegmatites all have three or more zones, commonly associated with replacement bodies and/or fracture fillings and are generally producers of beryl, lithium ores, muscovite, tantalite-columbite, and bismuth minerals.

Two different modes of emplacement have been recognised, viz. fluid emplacement and replacement. Most of the pegmatites in the belt are lenticular dyke-like and vein-like bodies and they seem to have been injected into pre-existing tensional openings. The lenticular bodies were emplaced both passively and by forceful injection. The injected material made room for itself by dilation accompanied by subordinate digestion or stoping.

Table 1 is a summary of the investigated pegmatites (see Figure 4 for locations). The pegmatites in the study area conform to the rare-element class of the Ginsburg *et al.* (1979) classification.

A zonation can be distinguished in the Northern Cape pegmatite belt on a regional scale. Pegmatites of the belt occurring to the east of the study area were investigated by Hugo (1970). Although these eastern pegmatites show similar distribution, dimensions, orientation and major constituent composition to those in the study area,

Table 1: Summary of the investigated pegmatites after Schutte (1972)

Pegmatite	Zonation	Dissem. minerals	Dimen-sions (m in outcrop)	Wall rock	Comments	Est. reserves (t) SG - peg = 2.60
Frankie	**Wall zone** – quartz, plagioclase, muscovite, [microcline-perthite], sugary albite, [garnet] **Intermediate zone** – similar to wall zone + spodumene, less muscovite, more quartz **Core** – quartz-perthite	beryl, tantalite-columbite	150 x 10	Granodiorite	Zones not well established. Mined for beryl, spodumene, tantalite-columbite.	To 10 m: Pegmatite – 39,000
Groendoorn I	Composite **wall zone** – homogeneous assemblage of constituent minerals (microcline-perthite, quartz, muscovite, plagioclase, sugary albite, [tantalite-columbite]) Composite **core** – similar to wall zone but coarser + spodumene, amblygonite, [tantalite-columbite, beryl] **Replacement body** – segregated sugary albite.		140 x 30	Biotite-schist	Zonation weakly developed. Core-mica can be up to 22.5 cm, light-green and free of impurities but is not suitable for sheet mica because of it's a-structure which renders it unsuitable for cutting.	To 16 m: Pegmatite – 174,720 *Spodumene – 34 *Muscovite – 200 *Beryl – 22.5
Groendoorn II	**Wall zone** – undifferentiated pegmatite (quartz, plagioclase, muscovite) **Core** – pure quartz **Replacement body** – muscovite, quartz, plagioclase	Beryl, tantalite-columbite	120 x 30	Biotite-schist	Mined for beryl	To 16 m: Pegmatite – 149,760 *(1,200 removed)
Groendoorn III	Composite **wall zone** – quartz, cleavelandite, muscovite, albite, sugary albite, [beryl] **Intermediate zone** – same as wall zone but finer + amblygonite, tantalite-columbite **Core** – microcline-perthite, [quartz] **Replacement body** – sugary albite		110 x 12	Biotite-schist		To 10 m: Pegmatite – 34,320
Groendoorn IV	**Wall zone** – quartz, plagioclase (sugary albite or cleavelandite), muscovite **Intermediate zone** – quartz, cleavelandite, spodumene, muscovite, lepidolite, [microlite, tantalite-columbite] **Core** – pure quartz	microlite	30 x 15	Biotite-schist	Muscovite books up to 15 cm and free of impurities but A-structure.	To 15 m: Pegmatite – 17,550
Groenhoekies	**Wall zone** – graphic granite-quartz, plagioclase, microcline-perthite, beryl, garnet **Core-margin zone** – cleavelandite, quartz, spodumene, [beryl, tantalite-columbite, triplite] **Core** – quartz, microcline-perthite **Replacement bodies** – Lithia-mica greisen, [tantalite-columbite]		95 x 14	Granodiorite	Poorly zoned	To 14 m: Pegmatite – 48,412
Kokerboomrand	**Wall zone** – quartz, plagioclase, muscovite, [microcline-perthite, beryl, spodumene, garnet] **Intermediate zone** – quartz, cleavelandite, spodumene, [beryl, muscovite, tantalite-columbite] **Core** – massive quartz, [microcline-perthite] **Replacement bodies** – lepidolite greisen		45 x 10	Granodiorite	Mined down to 11 m (1972).	To 10 m: Pegmatite – 11,700
Norrabees I	**Wall zone** – quartz, plagioclase, biotite, muscovite, [beryl, garnet] **Intermediate zone** – cleavelandite, spodumene, quartz, [beryl, bismuth minerals]		55 x 25	Granodiorite		To 16 m: Pegmatite – 57,200

	Core – microcline-perthite, massive quartz **Replacement bodies** – Lithia-mica greisen, watermelon tourmaline, cleavelandite, pollucite, lepidolite					
Norrabees II	**Wall zone** – quartz, microcline, muscovite, [plagioclase, beryl] **Intermediate zone** – quartz, spodumene, microcline-perthite		230 x 20	Granodiorite	Mined for spodumene, beryl, bismuth minerals. Mca up to 22 cm but stained with FeO. Microcline-perthite up to 1.2 x 4.8 x 3 m in size.	To 16 m: Pegmatite – 191,360
Norrabees III	**Wall zone** – quartz, plagioclase, perthite, [spodumene, muscovite, biotite] **Intermediate zone** – quartz, microcline-perthite, spodumene **Core** – milky quartz	beryl	110 x 9	Granodiorite	Mined for spodumene and beryl.	To 10 m: Pegmatite – 25,740
Norrabees IV	**Wall zone** – plagioclase, microcline-perthite, quartz, [muscovite] **Intermediate zone** – quartz, plagioclase, microcline, spodumene **Core** – milky quartz, perthite	beryl		Granodiorite	Mined for spodumene and beryl.	
Norrabees V			75 x 9	Granodiorite	Mined for spodumene, beryl and bismuth.	To 10 m: Pegmatite – 17,550
Norrabees VI	**Wall zone** – quartz, plagioclase, muscovite, [microcline-perthite, beryl] **Intermediate zone** – quartz, spodumene, cleavelandite		140 x 30	Granodiorite	Mined for spodumene and beryl.	To 16 m: Pegmatite – 174,720
Noumas I	**Border zone** – microcline, plagioclase, quartz, muscovite, [garnet] **Wall zone** – muscovite, quartz, plagioclase, microcline-perthite, [beryl, bismuth minerals, apatite, triplite, garnet] **Sugary albite assemblage** – resembles a chilled border zone. Albite, quartz, garnet, apatite, microcline **First intermediate (capping) zone** – graphic pegmatite, [beryl, tantalite-columbite] **Second intermediate (spodumene) zone** – spodumene, albite (cleavelandite), quartz, [microcline-perthite, beryl, tantalite-columbite]**Core** – milky quartz, microcline-perthite **Undifferentiated pegmatite** – cleavelandite, quartz, [microcline, muscovite, spodumene, beryl, tantalite-columbite] **Replacement bodies** – muscovite, cleavelandite, [microcline-perthite, tantalite-columbite, microlite, thorite, orangite, gummite] **Fracture fillings** – a) albite, b) quartz		1,000 x 25	Granodiorite	Mined for beryl, bismuth, tantalite-columbite, spodumene, feldspar, mica	To 30 m: Pegmatite – 1,950,000 *Feldspar – 200,000 *Muscovite – 41,000 *Spodumene – 30,000 *Beryl – 6,000 *Tantalite-columbite – 1,200
Noumas II	**Wall zone** – quartz, albite (cleavelandite), microcline-perthite, muscovite, [beryl, bismuth minerals, tantalite-columbit] **Core** – quartz, microcline-perthite **Replacement bodies** – muscovite greisen		250 x 15	Granodiorite		To 15 m: Pegmatite – 146,250
Spodumene Kop I	**Wall zone** – plagioclase, quartz, muscovite, [beryl, schorl, garnet] **Intermediate zone** – spodumene, cleavelandite, quartz, [beryl, bismuth minerals,		60 x 11	Granodiorite	Excelent zonal structure	To 10 m: Pegmatite – 17,160

	triplite, tantalite-columbite] **Core** – milky quartz					
Spodumene Kop II	**Wall zone** – albite, [spodumene] **Core** – quartz, microcline, spodumene, albite, [beryl]		250 x 15	Granodiorite	Mined for spodumene	To 15 m: Pegmatite – 142,875
Swartberg	**Wall zone** – quartz, plagioclase, muscovite, biotite, magnetite, [beryl] **Intermediate zone** – cleavelandite, quartz, spodumene **Core** – quartz, microcline-perthite, [beryl, schorl]		1,200 x 15	Ultramafic Complex		To 30 m: Pegmatite – 1,371,600
Uranoop	**Wall zone** – plagioclase, quartz, [muscovite, garnet] **Intermediate zone** – quartz, cleavelandite, spodumene **Core** – quartz, microcline-perthite, plagioclase, [muscovite] **Replacement bodies** – lepidolite, albite, quartz	Beryl, tantalite-columbite	60 x 17	Granodiorite	Mined for beryl, tantalite-columbite, lepidolite. Lepidolite is of too low grade.	To 16 m: Pegmatite – 41,453
Witkop	**Wall zone** – graphic granite-plagioclase, microcline-perthite, quartz [muscovite, garnet] **Intermediate zone** – plagioclase, quartz, [beryl, tantalite-columbite, bismuth minerals, schorl] **Core** – quartz, microcline-perthite		75 x 105	Granodiorite	Mined for beryl, tantalite-columbite	1,2 mil (whole body, Hansen *et al*., 2004)
Zebrakop	(Homogeneous) microcline-perthite, quartz, muscovite,		1,900 x 50	Granodiorite		14,2 mil (whole body, Agenbacht *et al*., 2003)

Note: [ ] – Accessory amounts
* - After Schutte (1972)

they differ in their accessory mineral content. They contain minerals such as gadolinite, allanite, monazite, euxenite, fergusonite, xenotime and zircon, as such containing elements such as rare-earth elements, U and Th, which do not occur in the pegmatites of the study area.

The sizes of some of the pegmatites in the study area may be compared to those of some international pegmatites. The Noumas I pegmatite is the largest zoned pegmatite in the study area. It measures 1,000 x 140 x 25 m in outcrop. Two of the giant zoned pegmatites of the world are Greenbushes in Australia, measuring 3,300 x 500 x 400 m, and Tanco in Manitoba, measuring 1,650 x 800 x 125 m (cited from Cerny, 1998a). It is clear that the pegmatites of the study area contain smaller reserves and it would probably not be viable to apply mechanised mining and extraction techniques to operations on them. However, if additional reserves from the homogeneous pegmatites are considered, these techniques may prove to be viable in the future.

The Noumas I pegmatite (Blesberg Mine) is the most thoroughly investigated of all the pegmatites in the study area and can be discussed as a representative example of the zoned pegmatite bodies in the area (bearing in mind the diversities in composition and structure among individual bodies) (from Schutte, 1972.)

The main products from this mine until 1960 were beryl, bismuth and tantalite-columbite; the lower-priced minerals such as spodumene, feldspar and muscovite could not be marketed profitably because of the high transport costs. Since 1961 however, prices of these minerals have risen appreciably and they have been marketed, mostly from stockpiles which were accumulated during the previous years from the mining of the main products prior to this time. Due to a number of difficulties such as remoteness from markets, a decline in demand for pegmatite minerals, falling markets, etc., production from the Noumas I pegmatite steadily declined and eventually came to a halt prior to the 1980's. Mining again resumed on a sporadic basis during the 1980’s and at the moment the mine is producing only feldspar, but its potential mica and tantalite-columbite reserves attract attention both from the current owners (Gariep Minerale) and from some other companies that have expressed their interest.

An aerial photograph (Figure 7) shows the pegmatite belt in the vicinity of the Blesberg mine. The predominantly northwest strike of the pegmatites is evident. It also shows that, although the identification and location of pegmatite bodies is not a problem, their large numbers represents a challenge as to the identification of economically viable individuals.

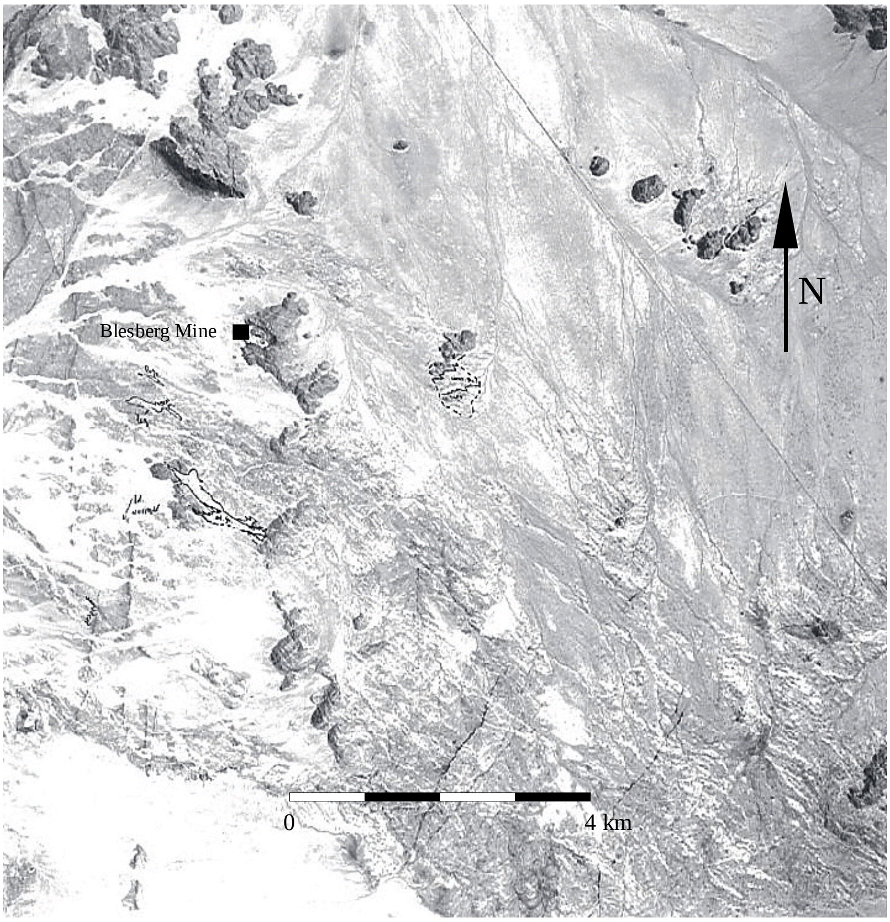


Figure 7: Aerial photograph of the area around Blesberg Mine.

The Noumas I pegmatite represents a simple zoned pegmatite. The body is narrow and dyke-like in shape and discordantly emplaced in granodiorite of the Vioolsdrif Suite (Figure 8). The largest part lies on the western slope of the Blesberg. The difference in elevation between the highest and lowest exposed parts is approximately 140 m. Its length is just over 1 000 m and in width it varies between 9 and 42 m. The pegmatite strikes northwest and dips at angles of between 50° and 80° southward. At the northwestern extremity it disappears beneath sand while at its southeastern extremity (near the top of the mountain) it splits into three separate dykes which terminate within a short distance.

The Noumas I pegmatite is richly endowed with a variety of minerals. Besides the major constituent minerals quartz, felspar and mica, accessory minerals include plagioclase, spodumene, beryl, tantalite-columbite, microlite and other uranium minerals such as orangite and gummite, a variety of bismuth minerals such as bismite, bismutite, bismuto-sphalerite as well as native bismuth, garnet and garnetiferous greisen, apatite, triplite and lithiophilite. Blesberg Mine is also the type-locality of bismoclite, which was first described from here in 1935. The pegmatite has been extensively mined during certain stages in the past and several quarries reveal the regular though somewhat asymmetrical zonal structure of the body. According to Schutte (1972) the following zones can be identified (Figure 8):

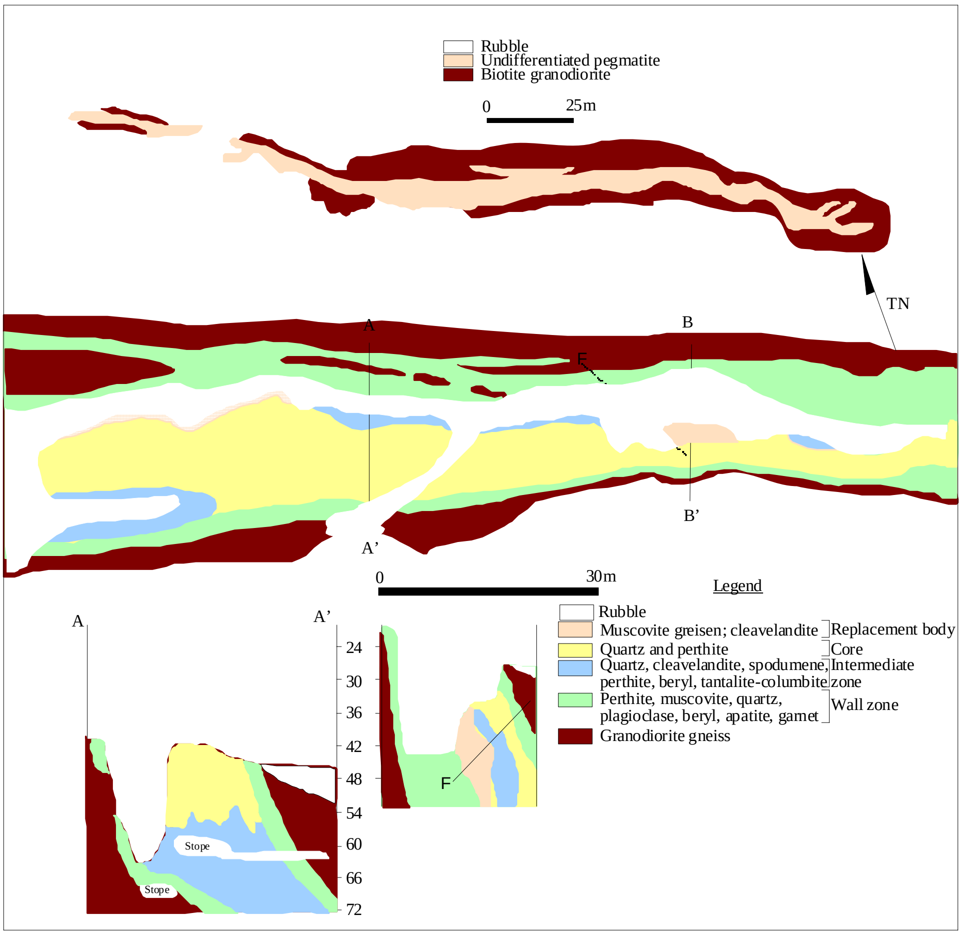


Figure 8: Geology of the Noumas I pegmatite after Schutte (1972).

a) *Border zone*. A fine-grained border zone between 1 and 15 cm wide is present on both the foot- and hanging-wall contacts. It consists of microcline, plagioclase, quartz, muscovite and accessory garnet.

b) *Wall zone*. This zone is also present on both the foot- and hanging-wall sides of the pegmatite. It varies in thickness from about 1 to more than 6 m. The main constituents of the zone are muscovite, quartz, plagioclase, microcline perthite and accessory beryl, bismuth minerals, apatite, triplite and garnet. Muscovite books, the sizes of which may attain 75 cm, are generally found concentrated along the contact with the border zone. Mica production, which averages 100 tonnes per month, comes from quarries opened on this zone on the hanging-wall side.

c) *Sugary albite assemblage*. This fine-grained material is present at or near the contacts and resembles a chilled border zone. The assemblage does not, however, represent a true border zone because it is not confined to the contacts, being also present as irregular bodies and lenses towards the centre of the pegmatite. Albite constitutes most of this material but quartz, garnet, apatite and occasionally microcline may be fairly abundant in places. Garnet and apatite may be concentrated in layers parallel to the contact and impart a banded appearance to the assemblage. The material is closely associated with the wall zone and may represent an earlier variety of it.

d) *First intermediate (capping) zone*. The capping zone is confined to the higher southeastern part of the pegmatite where it caps the other zones. In this zone the quartz and feldspar are largely graphically intergrown. The capping zone grades downwards into the underlying zones. Beryl and tantalite-columbite occur very sparingly in the capping zone.

e) *Second intermediate (spodumene) zone*. An intermediate zone between 6 and 8 cm wide consists of spodumene, albite, quartz and accessory amounts of microcline perthite, beryl and tantalite-columbite. It lies between the wall zone and the core. This zone is best developed on the footwall side of the pegmatite where it dips at an angle of about 30° underneath the core. The zone has been mined for spodumene, beryl and tantalite-columbite by means of a wide stope approximately 70 m long.

f) *Core*. The core consists of anhedral milky white quartz and large subhedral crystals of microcline perthite.

g) *Undifferentiated pegmatite*. In places the wall zones gradually merge with the spodumene zone to form a relatively homogenous pegmatite in which there are no clearly defined structural and lithological units. The most abundant minerals are albite and quartz, the former predominating. In addition to these minerals microcline, muscovite, altered spodumene, beryl and tantalite-columbite are also present. The last two minerals are very sparingly developed, with the result that very little mining has so far been carried out in this part of the pegmatite.

h) *Replacement bodies*. Several replacement bodies consisting of fine muscovite, albite and accessory microcline perthite, tantalite-columbite, microlite, thorite, orangite and gummite, are found scattered along the contact of the footwall, between the wall zone and the spodumene zone.

i) *Fracture fillings*. Numerous thin veinlets of albite are present in the massive microcline perthite and in places merge to form irregular segregations replacing the microcline. A younger generation of fracture filling consists of veinlets of pure quartz.

For extraction purposes it is necessary to look into the mode of occurrence of some of the more valuable minerals and the earlier extraction methods.

All the feldspar (microcline-perthite) that has been produced in the past came from the core zone. Feldspar from the core zone has the advantage that it is free of other intergrown minerals except for some perthite and poikilitically enclosed albite, and also some small fracture-filled veinlets of albite. It can therefore easily be won by hand-sorting. The feldspar also has the advantage that it is pure white, being unstained by iron oxide, and contains very little combined ferrous iron which could discolour the finished product. Except for the occasional fracture-filled albite veinlets, the feldspar from the core is fairly uniform in composition with regard to the amount of perthitic and poikilitic albite present.

The mica books contained in the wall zone, are free from structural imperfections but contain a good many iron oxide inclusions which could render the material unsuitable for certain purposes. All the mica that has been produced so far comes from the wall zone. The replacement bodies contain considerable quantities of mica but it will be exceedingly difficult to separate by conventional methods because of the small particle size of the material. Muscovite is fairly evenly distributed throughout the wall zone.

Tantalite-columbite constitutes 0.3%, 0.2% and 0.1% of the spodumene zone, the wall zone and replacement bodies respectively. The figure for the wall zone also includes the capping zone. Tantalite-columbite appears to be fairly uniformly distributed throughout the spodumene zone and replacement material. The crystals tend to occur in clusters but these clusters are found uniformly throughout the zone. The Ta_2O_5 content is fairly high, usually above 45%.

Spodumene is derived from the spodumene zone which may contain up to 50% of the mineral in places. Certain parts of the zone, especially those areas where it grades into other zones, are rather lean in spodumene as well as tantalite-columbite and beryl. These areas will probably not be economical to mine solely for spodumene by the present methods of recovery (hand-sorting).

The beryl is fairly uniformly distributed throughout the footwall zone but more erratically in the hanging-wall zone. It is also present in the spodumene zone, but here it is less uniformly distributed and tends to occur in exceptionally rich pockets. The recovery of beryl has been low in the past. This is probably due to the difficulty of recovering the beryl in the skeletal crystals. In these the beryl is intimately intergrown with gangue minerals and therefore difficult to recover by cobbing and hand-sorting. Some of the beryl is altered to sericite and bertrandite. The latter has theoretical BeO content of approximately 40% and if present in appreciable quantities in the altered beryl it may constitute a valuable ore.

CHAPTER 4. LEGAL REQUIREMENTS

4.1 Licensing

Mining activities are regulated in terms of national legislation as administered by the Department of Minerals and Energy. Recently the pre-existing law, the Minerals Act, Act no. 50 of 1991, was replaced by the new law, the Minerals and Petroleum Resources Development Act, Act 28 of 2002 (hereafter referred to as "the Act"), in terms of which the industry is governed.

Adhering to the regulatory requirements of the authorities takes up a considerable amount of time, effort and resources especially during the initial planning phase of the operation. Even during the operational and through to the closing phases, the developer would have to comply to these regulations, under the new Act even more so than under the old one. These regulations are often cause to much frustration and often the main reason for this is settled in ignorance and the fact that the developer is unacquainted with the relevant requirements.

All necessary information is obtainable from the Department of Minerals and Energy. For the study area the relevant regional office is located in Springbok. The legal requirements applicable to a small scale mining operation in the study area can be summarized from the following documentation obtainable from the Department of Minerals and Energy (see Appendix 1):

a) *Informative guidelines to apply for a reconnaissance permission, prospecting right, mining right, mining permit, retention permit and the renewal thereof.*
b) *Environmental Management Plan.*
c) Relevant sections of the Minerals and Petroleum Resources Development Act, 2002 (Act 28 of 2002).
d) Relevant application forms.

Any mining operation typically goes through the initial phases of reconnaissance, prospecting (including exploration) and mining, and for each of these activities the necessary permission, rights or permits are required. A reconnaissance operation means any operation which is carried out in search of a mineral, which will not visibly alter the land surface and may include geological, geophysical and photo-geological or other remote sensing techniques. Prospecting means intentionally searching for a mineral in a way which disturbs the land surface or subsurface and includes exploration operations during which the extent and economic value of a deposit is tested (such as drilling, trenching, bulk sampling, etc.). Mining includes all operations relating to the act of mining and matters directly incidental thereto.

Rights to minerals are based on the law of property and a *prospecting right*, *mining right*, *exploration right* or *production right* granted in terms of the Act and regulations are regarded as a limited real right in respect of the mineral as well as the land to which such right relates and as such is a registerable real right. The surface owner owns the land surface by a registered title deed registered in the relevant Deeds Office where the land is situated.

Written reasons for all administrative actions and decisions taken in terms of the Act will be given to an applicant giving affect to the Constitution of the Republic of South Africa and the Promotion of Administrative Justice Act.

Applications are processed in the following way:

a) The application form is lodged at the Regional Manager of the Department of Minerals and Energy.

b) The Department has 14 days to accept or reject the application. The Regional Manager has to inform the applicant in writing.

c) The applicant has 30 days to consult with the land owner. In the study area the land belongs to the state and as such, the Department of Public Works is to be consulted.

d) The applicant has 60 days to compile an Environmental Management Plan. This may already be started within the foregoing 30 days period and as such, the applicant effectively has 90 days in which to compile the Environmental Management Plan.

e) The Department has 120 days to finalise the application.

f) The Department has a further 14 days in which to notify the applicant.

The amount to be paid by the applicant for rehabilitation will be in accordance with the Environmental Management Plan and is determined during the compilation of the Work Plan (albeit the Prospecting Work Plan or Mining Work Plan). It basically amounts to the cost of earth-moving operations and the determination thereof is regulated by regulation 54 of the Act. It is to be approved by the Department and payment is due before the issuing of the license. This money can be claimed back on completion of the rehabilitation work required in terms of the Environmental Management Plan.

The application forms and requirements for all three of reconnaissance, prospecting and mining applications are in many respects the same and quite straight forward, but differ on a few important matters. Some of these matters are potentially time consuming and expensive such as those relating to environmental conservation.

The following issues are common to all four applications (i.e. *permission for reconnaissance*, *prospecting right*, *mining right*, *mining permit*):

a) The application form must be lodged.
b) The relevant application fee must accompany the application (*reconnaissance permit* - R100, *prospecting right* - R500, *mining right* - R1,000 and *mining permit* - R100 as in 2004).
c) The applicant must ensure that no other person holds either a *prospecting right*, *mining right*, *mining permit*, or *retention permit* for the same mineral over the land to which the application relates.
d) A plan of the land relating to the permission must be lodged with the application. The appearance and required information on this plan is prescribed in regulation 2(2) of the Act which requires: coordinates; north point; the scale; the location, name and number of the land; extent of the land; the boundaries of the land; the surface structures and the topography.
e) The applicant must include proof of his financial competency and technical ability which is to be compatible with the project envisaged.
f) An Environmental Management Plan is required.
g) The land owner must be consulted.
h) Certified copies of title deeds in respect of the relevant land is required.

The applications differ in the following ways:

a) *Environmental aspects:* During the application for *reconnaissance permission* the Environmental Management Plan is only required if it is deemed necessary (by the Department) and if it is possible, at that stage, to compile one. During the application for a *prospecting right* as well as the application for a *mining right*, the Environmental Management Plan plays an important role. The Work Programme (albeit for prospecting or mining) will determine the damage that will be done to the environment. Based on this, the amount payable for rehabilitation will be determined. This is evaluated by the Department in terms of regulation 54 of the Act and approved or rejected. These costs practically comes down to the costs of earth moving (per volume) and may vary extensively. Especially in the case of pegmatite mining, this amount is difficult to assess beforehand. In terms of the regulation, the amount should in any event be re-evaluated once a year by a competent person. During the application for a *mining right*, the applicant must conduct an Environmental Impact Assessment with the intent to submit an Environmental Management Programme as soon as possible as described by the Act and regulations. The Environmental Impact Assessment can be done before the lodging of the application for a *mining right* and lodged simultaneously with the application in view to expedite the authorisation of the Environmental Management Programme.

b) *The Work Programme requirement:* For the *reconnaissance permission*, *prospecting right* and *mining right*, a Work Programme is required. (A Work Programme is not required in the application for a *mining permit*, however, the holder of a *mining permit* is limited to a mining area of not larger than 1.5 ha.) In the application for a *prospecting right*, 60 days are granted for the compilation of the Prospecting Work Programme, while in the application for a *mining right*, 180 days are granted for the compilation of a Mining Work Programme.

Regulation 9 of the Act prescribes the Prospecting Work Programme and in terms thereof it entails a detailed description of how prospecting will be carried out in terms of geological descriptions, geochemical surveys, geophysical surveys, excavations, trenching, drilling, bulk sampling, etc. These activities must be conducted in phases and within specific time frames. It will also include documentary proof of the applicant's technical ability or access thereto as well as a budget and documentary proof of his financial ability or access thereto, to conduct the proposed prospecting operation. A cost estimate of the expenditure to be incurred for each phase is also required.

Regulation 11 of the Act prescribes the Mining Work Programme for the application of a *mining right* and requires details of the market concerning the mineral to be mined. It too must contain a schedule of the various implementation phases of the proposed mining operation, and a technically justified estimate of the period required for the mining of the mineral deposit concerned. It furthermore must contain a financing plan taking into consideration the mining technique and production rates, the beneficiation and preparation of the mineral to comply with market requirements (including value addition), technical skills and expertise and associated labour implications, regulatory requirements, capital expenditure and expected revenue, detailed cash flow forecast and evaluation, details regarding the applicant's resources or proposed mechanisms for finance, and provision for the execution of a Social and Labour Plan.

c) *<u>Interested and affected persons</u>:* The application for a *mining right* requires that all interested and affected persons (in addition to the land owner) be consulted within 180 days (30 days in the case of a *mining permit*) from the notice received from the Regional Manager to do so. Documented proof of such sessions has to be provided in the form of minutes, invitations to meetings, notices of meetings in public media, etc.

d) *<u>Social and Labour Plan</u>:* The application for a *mining right* further requires a Social and Labour Plan in terms of regulation 46 of the Act which focuses on the role of the mine in the community and towards its labourers and include a human resources development programme (skills development plan, career progression plan, mentorship plan, internship and bursary plan, employment equity statistics), a local economic development plan, processes pertaining to management of downscaling and retrenchment, and the financial provision for the implementation of the Social and Labour Plan.

All four applications (*reconnaissance permission*, *prospecting right*, *mining right* and *mining permit*) deals with the issue of “historically disadvantaged South Africans” (HDSA) in part B of the applications and allow for a choice between:

i) HDSA controlled (50% + 1 vote),
ii) strategic partnership (25% + 1 vote) and
iii) broad-based ownership (HDSA dedicated mining unit trusts, employee share or ownership schemes).

4.2 The Environmental Management Plan

Regulation 5(4) of the Act states that: “No person may prospect, mine or undertake reconnaissance operations or any other activity without an approved EMP Environmental Management Plan), right, permit or permission or without notifying the land owner.” Other legislation which is relevant to the matter include, but are not limited to: National Monuments Act, 1969 (Act 28 of 1969), National Parks Act, 1976 (Act 57 of 1976), Environmental Conservation Act, 1989 (Act 73 of 1989), National Environmental Management Act, 1998 (Act 107 of 1998), Atmospheric Pollution Act, 1965 (Act 45 of 1965), The National Water Act, 1998 (Act 36 of 1998), Mine Safety and Health Act, 1996 (Act 29 of 1996), The Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983).

The Department of Minerals and Energy issues a guiding document along with the application forms which is specifically applicable to the small scale mining sector, to assist applicants in the compilation of an Environmental Management Plan (see Appendix 2). This document describes small scale mining operations as those which i) use little or no chemicals to extract mineral from ore, ii) work on portions of land not larger than 1.5 ha, and iii) disturbs the topography of an area somewhat but have no significant impact on the geology. The document aims to i) Provide a national standard for the submission of Environmental Management Plan for small scale mining operations, ii) ensure compliance with regulation 52 of the Act, iii) assist applicants by providing the information required by the Department in a simple language and a prescribed format, as contemplated in Regulation 52(2) of the Act, and iv) assist regional offices of the Department of Minerals and Energy to obtain enough information about a proposed prospecting or reconnaissance or mining permit to assess the possible environmental impacts from that operation and to determine corrective action even before such right is granted and the operation commences.

The basis of the document is a very simple Environmental Impact Assessment (Section C). This Environmental Impact Assessment is evaluated by the Department. An Environmental Management Plan is then compiled (Section F) and prescribes the developer how damage to the environment will be limited. Any additional requirements from the Department is added (Section G). Upon acceptance, this Environmental Management Plan becomes legally binding.

In summary the Environmental Impact Assessment addresses the following issues:

a) The landscape surrounding the proposed operation.
b) The characteristics of the soil on the surface of the sight.
c) The plant life in the area around the sight.
d) The animal life in the area.
e) Proximity of game parks, reserves, monuments, etc.
f) The type of equipment to be used.
g) The nature of the envisaged diggings.
h) The nature of the proposed prospecting and exploration operations.
i) The utilization of natural resources such as firewood, etc.
j) Issues concerning the extraction of water.
k) Issues concerning the construction of infrastructure such as roads, etc.
l) The proposed time span of the operation.
m) Issues concerning the socio-economic environment, i.e. amount of people employed along with the relevant labour issues.
n) The proximity of the operation to residential areas or permanent structures.
o) Issues concerning cultural heritage, e.g. the proximity of graveyards, old houses or sites of historic significance.

p) Specific regulatory requirements, i.e. air quality management and control, fire prevention, noise control, blasting, vibration and shock, disposal of waste material, soil pollution and erosion control.

q) Financial provision for rehabilitation after closure is determined by the Department based on information supplied in this document.

r) Monitoring and performance assessment as regulated by Regulation 55 of the Act.

s) Details of the envisaged end-state of the area after closure.

t) A record of consultation with interested and affected persons.

The Environmental Management Plan will address the following issues:

a) A layout plan of the operation.

b) Physical demarcation of the area on which operations will be carried out by means of beacons.

c) Specific restrictions such as the prohibition of operations within a certain radius from specified structures.

d) The responsibility of the developer to rehabilitate the environment, as far as practicable, to its natural state; also to ensure that the manager on site and all employees are capable of complying with the statutory requirements.

e) Infrastructural requirements related to topsoil and the establishment of access roads, dust control and rehabilitation of roads.

f) Offices and camp sites including toilet facilities, waste water and refuse disposal.

g) Vehicle maintenance yard and secured storage areas.

h) Operating procedures in the mining area in relation to limitations (near permanent structures, etc.), mining or prospecting within riverine environment and the impact on river beds and natural water resources (the Department of Water Affairs and Forestry may impose additional conditions. In this regard a document entitled "Best Practical Guideline for small scale mining development" issued by DWAF). In most cases the applicant needs to apply for a *water use license* for the proposed water uses that will take place.

i) Regulations on excavations.

j) Regulations on processing areas and waste piles (dumps).

k) Regulations on the tailings dam.

l) The final rehabilitation and the monitoring and reporting on the progress thereof.

m) Closure of operations must be applied for and such an application should be accompanied by an environmental risk report prescribed in Regulation 60 of the Act. Closure objectives must be stated and a closure plan submitted. At this stage rehabilitation presents the greatest liability and monetary provision should be made either by financing from internal revenue or by means of a loan, bearing in mind that the originally agreed amount (determined during the compilation of the Work Plan) can be claimed back from DME. These liabilities may also be transferred to a competent person following the necessary procedures.

CHAPTER 5. RESOURCES AND MARKETS

5.1 Global resource statement

In order to present any meaningful quantitative figures on the regional resources in the study area, certain factors need to be taken into consideration. Firstly, in a regional survey of resources, no distinction is made between zoned and homogeneous pegmatites. For this to be ascertained, detail mapping is required. Statistically all the larger pegmatite bodies are homogeneous (the zoned Noumas I pegmatite measures 1,000 x 25 m, thus to a depth of 30 m a volume of 750,000 m^3 pegmatite). These homogeneous pegmatites have historically been uneconomical, that is to say, they haven't been mined. The reason for this is probably because historically feldspar wasn't considered to be the primary mineral, but rather the accessories like beryl, tantalite, spodumene and bismuth. Furthermore, the homogeneous pegmatites don't lend themselves to traditional mining methods, i.e. selective mining and hand-picking. Secondly, pegmatite bodies are by nature highly irregular in shape and the dimensions and attitude thereof in depth cannot be known for certain. In this study it is simply assumed that the surface expression is a reflection of the body to a depth equal to its width. As such, a global resource statement neglects the fact that individual detailed studies are necessary in order to delineate a certain volume of ore which has been tested, preferably also with the aid of drilling. This factor also has implications for the classification of ore according to the SAMREC code as it is doubtful whether pegmatite resources can ever be classified as 'indicated', also taken into consideration the possibility of large amounts of waste material – inclusions.

Notwithstanding, an attempt was made to arrive at quantitative global resource figures for the study area. A certain part of the pegmatite belt in the study area was selected and outlined in which to delineate ore resources. This outlined area is indicated on Figure 16 (outlined in green) and nearly incorporates all the pegmatites in the pegmatite belt of the study area. Although some of the investigated pegmatites (Groendoorn, Spodumene Kop II, and Swartberg) fall outside of it, it comprises the area in which the concentration of pegmatites is the highest.

On 1 : 20,000 scale aerial photographs, the most prominent pegmatite bodies were delineated (see Figure 9). From these the surface dimensions (length x width) of the bodies were determined with the aid of graphic paper (1 mm = 20 m). For the depth dimension it was assumed that the body retains its shape in depth and is taken as equal to the width. The specific gravity of pegmatite is taken as 2.60, determined on the basis of a ratio feldspar : quartz : mica of 6 : 3 : 1 as determined by Hansen *et al*. (2004) as well as Agenbacht *et al*. (2003), where the SG of Feldspar = 2.54, quartz = 2.65 and mica = 2.82.

The effectiveness of the delineation of the pegmatites from 1 : 20,000 scale aerial photographs, of course, has its limitations:

a) Only bodies which can be delineated meaningfully on this scale were included. As such, a large percentage of smaller bodies were excluded. In this regard especially the numerous narrow dykes should be mentioned. The resultant figure should therefore not be seen as an accurate indication of the ratio of pegmatite : wall rock in the outlined area.

b) Except for the smaller dimensions, other factors play a role in the prominence of the pegmatite bodies on the aerial photographs. In the southeastern parts of the outlined area, the leucocratic quartzo-feldspathic host rock makes it difficult to distinguish the pegmatites with remote sensing methods, as opposed to the darker granodiorite prevailing in the largest part of the area. The aerial photograph itself doesn't always lend itself properly to the distinction between pegmatite and country rock, due to light contrasts and brightness. This factor specifically played a role in the areas around the Pegmatite Valley (see Figure 9) where the pegmatite development is known to be much better than indicated in Figure 9.

c) Obvious problems related to the large scale are the assessment of the degree of contamination by wall rock material, the grain size, the manner in which minerals are intergrown, and the grade (chemical composition) of the minerals, all factors which cannot be determined with any remote sensing

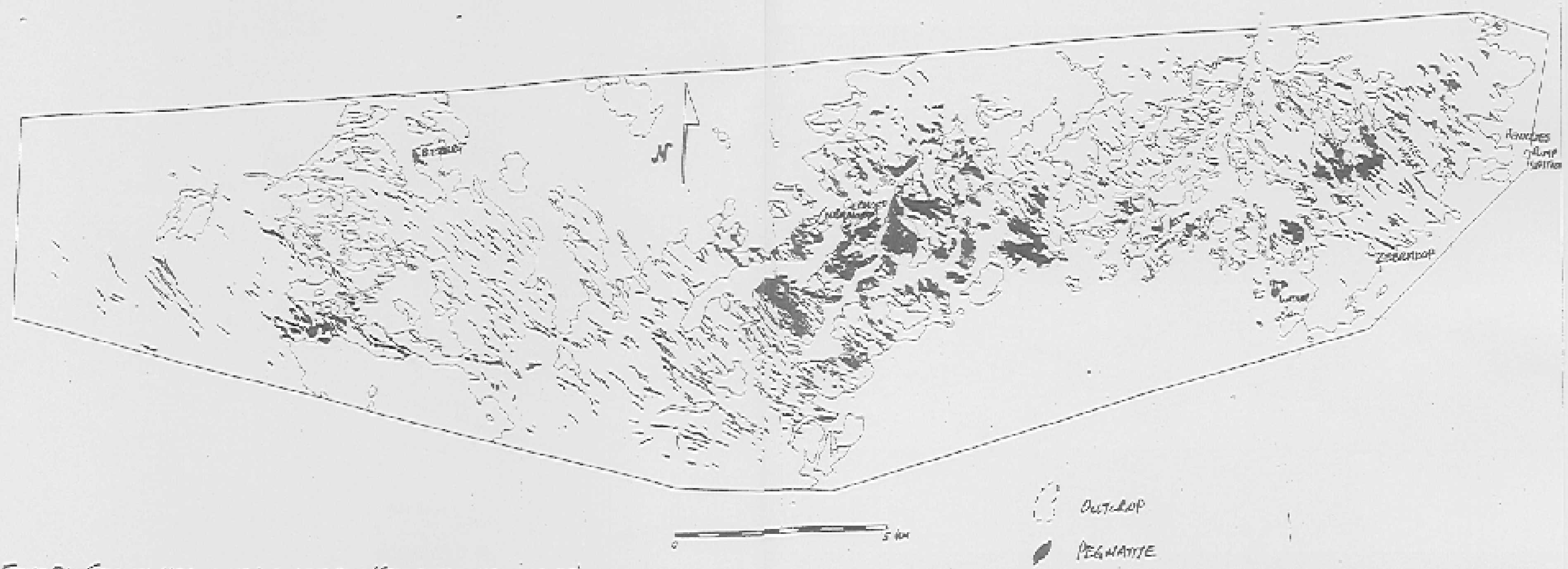


FIGURE 9: SELECTED AREA IN THE PEGMATITE BELT (REDUCED FROM 1:20000 SCALE)

method. Many of these however, can be overcome by a bulk mining method and appropriate beneficiation techniques.

Nevertheless, the results are shown in Figure 9 and Appendix 3. A total of 1,429 ore blocks were identified of which the smallest measured 20 x 20 x 20 m, i.e. 8,000 m^3 (20,800 t) and the largest 220 x 200 x 200 m, i.e. 8,800,000 m^3 (22.9 Mt). These are ore blocks, forming part of larger ore bodies. It is quite clear from Figure 9 that the greatest development of pegmatite is in the areas around Oernoep and in the Pegmatite Valley near Henkries. When considering all pegmatite bodies larger than 8,000 m^3 (20 x 20 x 20 m, i.e. 20,800 t), then the total global resource in the outlined area amounts to 531,957,500 m^3 (1,383.1 Mt). Not all of this is mineable, due to limited sizes of deposits. If some of the larger bodies are considered, ore of up to 50 Mt can be delineated for individual deposits. All these figures however, have only academic meaning until proper field investigations can be conducted. The uncertainty surrounding the mineability of the homogenous pegmatites further reduces the significance of these figures. What is certain is that if any of these are to be mined, modern bulk mining techniques and the installation of a beneficiation plant, will be a necessity. For this, the markets should be receptive; the demand from the current domestic market does not justify such development.

5.2 Investigated and exploited pegmatites

It should be noted that the study of Schutte was conducted before 1972. Production figures available from the Department of Minerals and Energy for Blesberg, Witkop and Swartberg date back to 1980 (Appendix 4). Thus, no production figures are available for most of the investigated deposits since 1972 and for Blesberg, Witkop and Swartberg, seven years' (1973 – 1979) of figures are missing. A brief discussion of each of the investigated deposits is provided to update the information. None of these pegmatites were exploited with the intention to mine feldspar as primary commodity (Refer to Table 1).

The Frankie pegmatite is too small to justify a feldspar mining operation. Of the Groendoorn pegmatites Schutte (1972) mentions that the intergrown nature of the feldspar with quartz, makes it unsuitable for the extraction of feldspar by means of hand sorting (again a matter for beneficiation). Currently the Groendoorn pegmatites are considered too isolated and inaccessible to put them high on a priority list for investigation as a source of feldspar. The Groenhoekies pegmatite is known to have been mined on a sporadic basis during the recent pass and since no production figures are available, it is next to impossible to say what resources are left. It would be a viable target for investigation, however, its measured volume restricts it to a very small scale operation. The same can be said for the Kokerboomrand pegmatite. The Norrabees pegmatites represent interesting targets for studying, also in the academic sense, since they are lithium-rich. They too have been mined sporadically during the recent past, again without keeping record of production figures, but on a much smaller scale than the Groenhoekies and Kokerboomrand pegmatites, and mainly for the production of the lithium ores lepidolite and spodumene and for the value of watermelon tourmalines as an income from the selling to tourists. The Noumas I pegmatite (Blesberg Mine) is currently being exploited and discussed elsewhere (see **3.4 local geology and mineralogy of selected deposits** as well as **6.** FINANCIAL ANALYSIS). From its measured outcrop an original volume down to 30 m of 750,000 m^3 (1,905,000 t) of pegmatite was to be expected. In 1972 Schutte predicted a potential feldspar production of 200,000 t. Since 1980, a total of 6,798 t of feldspar has been produced. If the production during the years of unknown production rates (1973 – 1979) is neglected, then by far the most of this ore is still available (193,202 t). The current production rate varies between 500 – 3,000 t per month giving it at least a five year life of mine. The Noumas II pegmatite is very flat-lying and any study on this body would require drilling. Spodumene Kop I is too small to justify investigation into its feldspar potential. Spodumene Kop II is again flat-lying, making its investigation without the aid of drilling, problematic. Swartberg is currently considered to be mined out. It was mined during the past two decades mainly for feldspar and sporadically producing mica, supplying the largest part of South Africa’s glass and ceramic industries as well as some mica-consuming industries such as manufacturers of paint, welding rods and brake pads. Since 1980 (i.e. the past 24 years) it produced a total of 314,358 t feldspar at an average production rate of 1,091 t per month. The size of the Uranoop pegmatite does not warrant an investigation into its feldspar potential. The resources at Witkop was estimated recently by Hansen *et* *al.* (2004) at 1,200,000 t of pegmatite ore. The study of the Zebrakop pegmatite (Agenbacht *et al.*, 2003) is interesting in that it represents the only study so far into the economic potential of a homogeneous pegmatite. A total of 14,200,000 t of pegmatite ore was delineated.

5.3 Market review

5.3.1 Introduction

The primary pegmatite minerals feldspar, mica and quartz are low-priced commodities (referred to as industrial minerals) when compared with the metals and are sold in bulk, making their economic exploitation highly dependent on beneficiation and transport costs and therefore, distance to the markets.

Feldspar is the cornerstone commodity for pegmatite mining in this area not only because of its relative abundance in the ore body, but also because of market conditions in South Africa. The international market for pegmatite minerals is largely supplied by the larger producers especially in Italy and Turkey. The scope for pegmatite mining in South Africa is therefore limited by the capacity of the local consuming industries and calls for the addition of value to the product in order to make it more attractive to the export market.

South African policy (in line with the World Trade Organisation) does not favour direct subsidies. Instead indirect support for exporters is provided via the Export Marketing Assistance (EMA) scheme, which offers financial assistance for the development of new export markets though the financing of trade missions and market research. The recently implemented export finance guarantee scheme for small exporters is the government’s latest means of promoting small and medium exporters through credit guarantees with participating financial organisations.
South Africa has trade agreements with Botswana, Lesotho, Namibia and Swaziland through the South African Customs Union (SACU) to maintain free interchange of goods between these countries. Furthermore, the Southern African Development Community (SADC) has formed a free-trade agreement which has been operational since September 2001. Also in 2001, South Africa concluded the Trade Development

and Cooperation Agreement, which will lead to the discontinuance of tariffs on more than 90% of trade between South Africa and the European Union within the next decade (Mokaila, 2003).

5.3.2 Feldspar

Feldspar is mainly consumed in the glass and ceramics industries. In the glass industry it is used as a source of alkalis and alumina. Industrial specifications require a Fe_2O_3 content within the feldspar of less than 0.1% for the manufacture of colourless, high grade glass and 0.3% for lower grade products, i.e. bottle and container glass (Hansen *et al.*, 2004). Because of a variety of alumina sources, the glass industry may change its alumina source depending on the lowest delivered price (Boelema, 1998). Feldspar is also used as a flux and as a source of alumina in the production of porcelain enamel as well as in ceramic products including pottery, plumbing fixtures, electrical porcelain, ceramic tiles and dinner ware. The requirements vary according to the products in which the feldspar is used. Generally the ceramics industry requires alkali feldspar with a K_2O content no more than 10%, the Fe_2O_3 content should not exceed 0.1% and the CaO content should be lower than 0.5%. In the case of plagioclase (albite), which is mainly used for glazes in the ceramics industry because of its greater whiteness compared to the alkali feldspars, the Na_2O content may not be less than 10%, however, the mines in the study area have never produced plagioclase feldspars, but only K-feldspar, viz. microcline-perthite. Cape Feldspar (Pty) Ltd gives the following analyses for potassium feldspar from Swartberg Mine (from the Specification Sheet, DME):

	Used in the manufacture of high grade porcelain and paint filler	**Used in the manufacture of glass (when milled further also used for high grade porcelain)**
SiO_2	65.3 – 65.8	65.2 – 65.9
Al_2O_3	18.3 – 18.9	18.2 – 18.7
Fe_2O_3	0.03 – 0.06	0.04 – 0.08
TiO_2	0.01	0.01
CaO	0.11	0.11
MgO	0.06	0.06
K_2O	11.8 – 12.7	11.7 – 12.4

Na_2O	2.5 – 3.4	2.5 – 3.4
LOI	0.24	0.28

Feldspar may also be finely ground and used as a filler in latex, paint, urethane and acrylics.

Figure 10 shows the leading international feldspar producers in 2004.

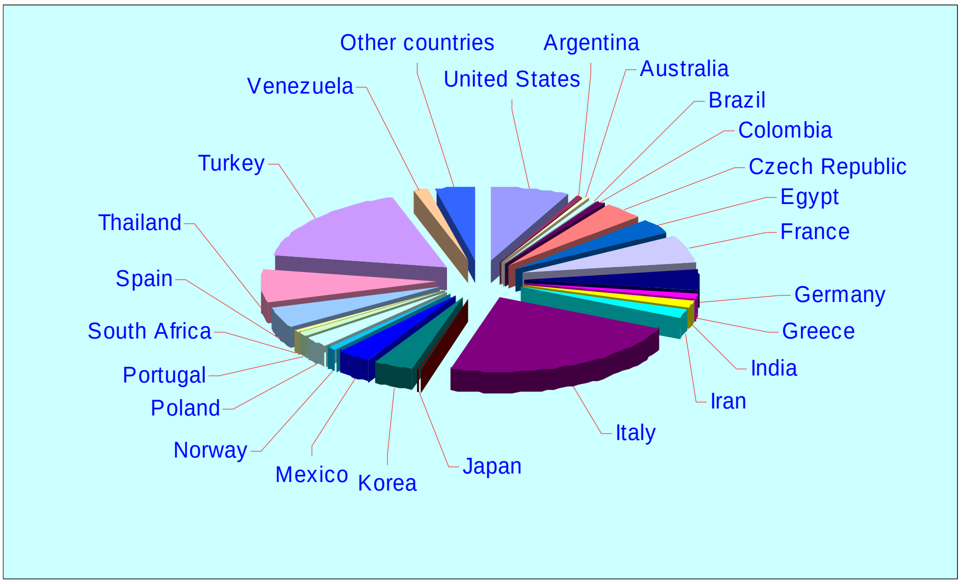


Figure 10: Leading international feldspar producers in 2004. [Source: United States Geological Survey – www.usgs.gov]

Countries like Italy and Turkey largely supply the international feldspar market, denying South African producers access to a vast array of feldspar-consuming industries. In South Africa the demand for feldspar is limited to the glass and ceramics industries which are located in Gauteng and the Cape peninsula. Transport costs currently amount to R 160 / ton (bulk road transport) from the pegmatite area to Cape Town; these costs are paid by the industries. The Gauteng markets are currently supplied from sources in the Northern Province and not from the study area.

Appendix 5 lists the potential feldspar producers in South Africa, their operations, products and specifications, as in 2004 (Agnello, 2004). Swartberg Mine, at the time Appendix 5 was compiled, was the only full-time active producer in the country. The operation has since moved to Blesberg Mine. Feldspar exports in the past came from the producers in the Northern Province. These companies are not currently exporting due to restructuring and other financial factors. Figure 11 shows the mass of feldspar sold on the local and international markets during the period 1984 – 2004.

Exports was at its highest during the nineties, dropping again towards the end of the decade. Exports increased slightly from 2000 onwards mainly as a result of cross-border trade to Indian Ocean islands and SADC countries (Mokaila, 2003). No feldspar is currently exported.

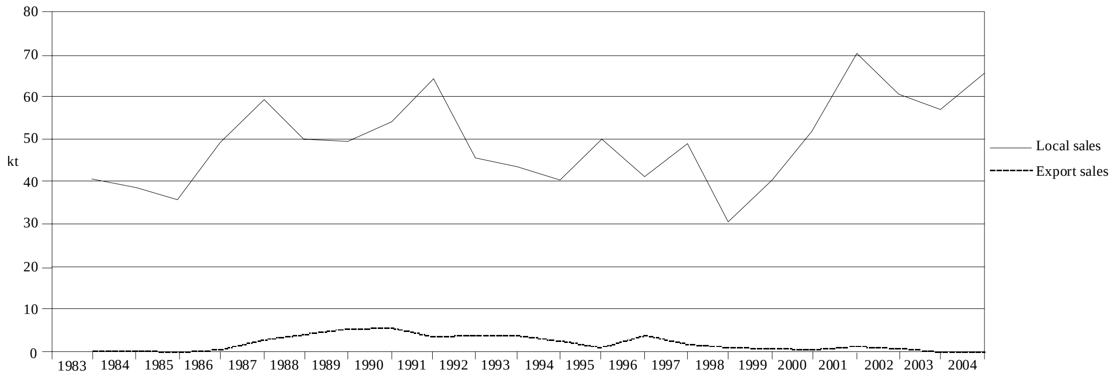


Figure 11: Mass of feldspar sold on the local and international markets for the period 1984 – 2004. [Source: South Africa's Mineral Industry Yearbooks 82/83 - 03/04]

Figure 12 shows the price indicators for feldspar in the past. Four indicators are shown:

a) The prices for ceramic grade feldspar (R / t) sold on the local market for the period 1984 – 2004. These prices have risen on average but coupled with relatively large fluctuations.

b) An indicator of the international ceramic grade feldspar price ($ / t). These prices have been much more stable than the prices on the local market.

c) Prices fetched on the international market ($ / t) for South African ceramic grade feldspar in the days when South Africa was exporting. It can be seen that these prices were higher than the average price of ceramic grade feldspar from other countries. This indicates an opportunity for renewed export of this commodity, if the raw ore can be milled.

d) Prices for micronised ore are even higher and offers another export opportunity if value can be added.

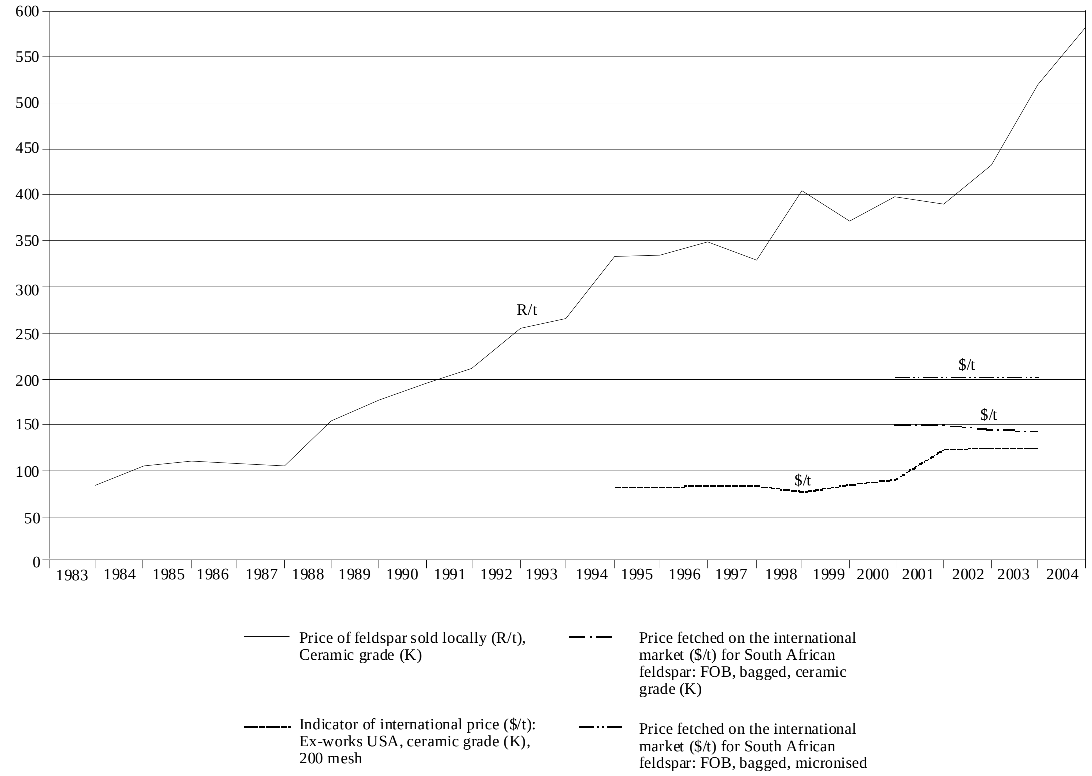


Figure 12: Indicators of feldspar prices. [Sources: South Africa's Mineral Industry Yearbooks 82/83 - 03/04; Industrial Minerals, monthly issues Jan. 95 – Feb. 04]

5.3.3 Mica

Muscovite is the only mica that has been economically extracted from pegmatites in the study area. At certain stages in the past it constituted the primary pegmatite commodity and led to selective mining on many of the pegmatites, resulting in trench-like quarries (see plate 1), often deep ones and in some cases leading to unstable and dangerous working areas.

The physical properties of mica which render it useful to industry are its platy crystal habit, high degree of flexibility and elasticity, poor electrical conductivity and hence good isolation properties, low heat conductivity, and chemical and thermal stability. As such it finds many uses, e.g. as diaphragms in breathing apparatus, high-temperature gauge linings, compass cards, missile battery insulators, beam splitters in lasers, and as electrical capacitors and insulators (all as sheet mica); in paints, drill fluids, plasters and coatings, fillers in plastics and rubber, fluxes in welding rods, and as a pearlescent pigment (as flake and ground mica). The agricultural and cosmetics industries also utilize subordinate amounts of flake mica. There is a growing demand for mica in the manufacture of brake pads, plastics and composites in the automobile industry and this industry also constitutes the largest mica-consumer in South Africa.

The classification of mica in the commercial sector is dependant on the size and thickness of the mica with sheet mica and ground mica being the two end members. Sheet mica is found as a primary constituent in irregular pockets sometimes contained in pegmatites (plate 4). To be used as sheet mica the mica books should be up to 15 cm in diameter and free of staining and inclusions. It should further be suitable for grinding, a factor related to its internal structure. None of the pegmatites in the study area have proven to be a producer of sheet mica. India and Russia together produce more than 96% of the world's sheet mica. Flake mica is produced by crushing and screening the host rock, while scrap mica results from the mining and trimming of sheet mica. Dry grinding, wet grinding or micronising of scrap and flake mica produces ground mica.

Figure 13 shows the leading international flake and scrap mica producers in 2004.

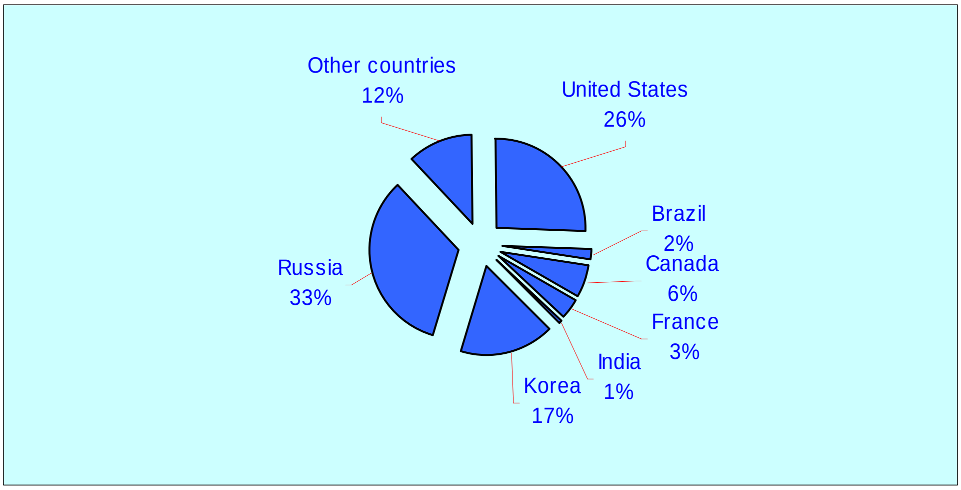


Figure 13: Leading international producers of flake and scrap mica in 2004. [Source: United States Geological Survey – www.usgs.gov]

South Africa's export mica is mainly sold to the USA, suppliers are based in the Northern Province. None of the pegmatites in the study area are currently supplying mica to either the international nor the local market.

Up to 1997 South Africa has been one of the top producers of mainly scrap mica. Russia, the USA and Korea are now dominating the international market. Figure 14 shows the tonnage of flake mica sold on the local and international markets for the period 1984 – 2003.

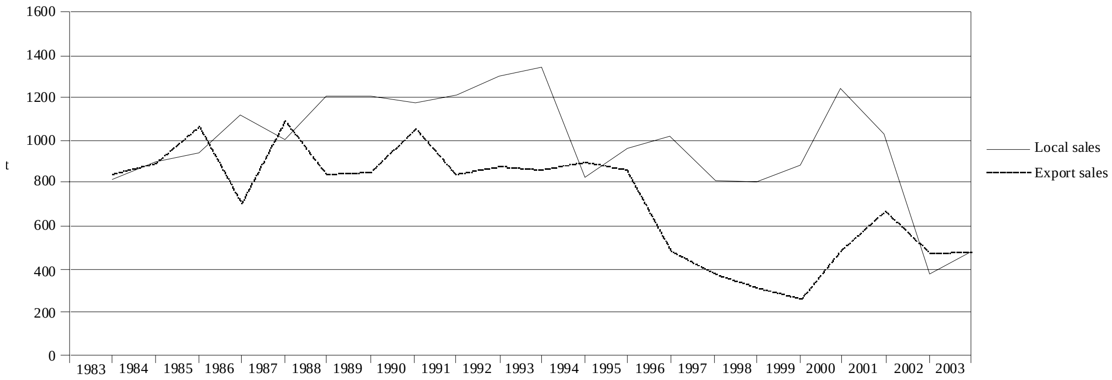


Figure 14: Mass of flake mica sold on the local and international markets for the period 1984 – 2003. [Source: South Africa's Mineral Industry Yearbooks 82/83 – 02/03]

Sales volumes have declined since 2001. If this figure is compared to the price (R / ton) for locally sold mica (Figure 15) it is clear that the drop in production can be interpreted to be the result of depletion of known easily accessible resources rather than a drop in demand, as deduced from the inverse relationship, i.e. an increase in price coupled with a decrease in production.

Figure 15 shows three mica price indicators:

a) Local prices (R / t) for flake mica. This price has risen coupled with a few large fluctuations in the past.

b) An indicator of the prices fetched on average on the international markets ($ / t). These prices have been much more stable.

c) Prices fetched on the international market for South African dry ground mica over recent years. Although the international prices are more stable, with the exchange rate at R 7-30 to the dollar (as at the end of 2003), the local markets do seem to offer better opportunities. If exports are to be considered in the future, a plant is needed for the milling to produce wet and dry ground mica.

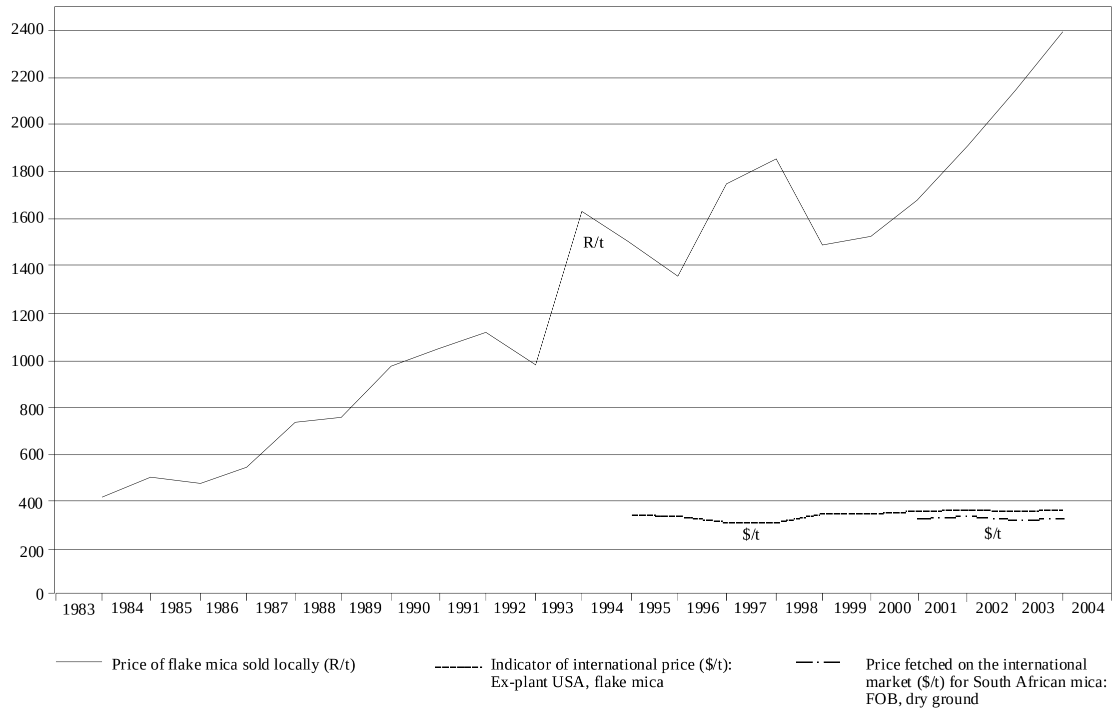


Figure 15: Price indicators for mica. [Sources: South Africa's Mineral Industry Yearbooks 82/83 - 03/04; Industrial Minerals, monthly issues Jan. 95 – Feb. 04]

5.3.4 Quartz

Quartz has never been economically extracted from pegmatites in the study area. The silicon market is located mainly in four industries, i.e. the glass, chemical, metallurgical, and electronic industries. Silicon is classified on the basis of the industry it serves into metallurgical grade, chemical grade, and high grade. For the electronic industry naturally occurring quartz is converted to a halide or halosilane after which it is reduced to high grade silicon metal. The requirements for this process is 99.5% SiO_2 and not more than 0.04 - 0.08% Fe_2O_3 (Oosterhuis, 1998).

The main problems for mining quartz from the pegmatites in the study area, even if testing would prove them suitable, are the distance to the markets and the nearest plant for the reduction of the ore (Witkop Silicon Smelter, Polokwane), as well as the limited local market.

The total mass of quartz produced in South Africa in 2002 was 2,248,000 ton. Of this 2,239,000 ton was sold locally at R 68 / ton and 1,038 ton was exported at R 1,679 / ton. In 2001 quartz imports amounted to 1,000,000 ton - the value of R 20 million - mainly from Zimbabwe, Tanzania and Germany (Mokaila, 2003). The bulk of the local sales was consumed in the bottle glass industry which is more tolerant to impurities but also pays a lower price.

None of the above figures, of course, come from the study area and though it may be worth the while to test some of the quartz occurring in the cores of zoned pegmatites, it is not currently regarded as a viable resource.

5.3.5 Accessory minerals

The pegmatites are hosts to a wide variety of accessory minerals, some of which offer economic potential. Especially tantalite is currently in demand on international markets. Tantalite is a strategic mineral and although the world trade industry in tantalum is relatively small, it finds applications in a variety of specialized industries mainly because of two unique properties, viz. its excellent capacity to store and release electrical charge and its exceptional resistance to corrosion. As such it is utilized in the manufacture of wire, metal, alloys, capacitors, electronic parts, telecommunication equipment, aerospace, turbines and military equipment. Currently the demand for tantalum capacitors, especially in cellular telephones, represents the largest contributor to total global tantalum demand. The combined electronics industry accounts for 55% of tantalum demand.

The largest tantalum reserves are located in Australia and this country is the world's leading producer. In addition to known reserves, considerable potential resources exist in operating and developing mines primarily in western Australia, the Rift Valley region of Africa, Greenland, Canada, South America and Asia.

As a strategic metal, tantalum is not traded on the London Metal Exchange. The price of tantalum-bearing minerals is generally based on negotiations between the seller and the buyer and is either contractually fixed, offered sporadically using the tantalite spot price as a criterion, or sold by bids. Fixed contracts exist among the world's largest production and processing companies and the only realistic way for a smaller producer to sell tantalum on the market, is through a broker. Most brokers will be willing to conclude a transaction for a shipment of 1,000 pounds (approximately 450 kg) or more.

The tantalum price has been relatively stable except for the period during the second half of 2000 and the first half of 2001, where it peaked. This price hike was the consequence of the booming telecommunications and information technology industries and their demand for electrolytic capacitors. The subsequent downturn in the price was mainly due to the fact that many new producers entered the market and existing producers increased capacity, with the result that supply soon exceeded demand.

Other pegmatite minerals which currently offer economic potential include beryl and spodumene.

The sporadic occurrence of the accessory minerals, often occurring in nuggets at totally unpredictable locations in the ore body, means that these minerals have to be collected during mining operations until enough of it is gathered to be sold on the market. This again calls for a bulk mining method. It furthermore means that it would not make any sense to include revenue from sales of these minerals, in a financial analysis.

Chapter 6. Financial analysis

6.1 Introduction

For the purpose of this study feldspar is regarded as the primary commodity and for the most part of the financial analysis it will be assumed that only feldspar will be mined. Export will not be considered in this analysis as this will call for the addition of value through the use of plant and additional machinery and since this is nowhere currently in practice, there is no precedent to follow. However, the possibilities of such development will now briefly be discussed:

For bulk mining methods of larger scale, the hand-picking separation methods currently employed, will not suffice. Directly related to this issue is that of value addition by means of purifying and grain size reduction - the local market alone does not justify the high volumes produced by these methods. A separation plant at or near the site of mining will not only handle higher volumes of raw material and add value to it, it will also enable the mining of pegmatites in which the feldspar is not coarse enough to be hand-picked, or complexly intergrown.

Since the 1930's, separation of feldspar from quartz has been achieved by flotation in an acid medium using hydrofluoric acid (HF) as activator (Shehu and Spaziani, 1999). Because of the growing awareness of environmental and health problems, studies have been conducted with the aim to replace HF as modifier in the flotation process. Even the separation of Na-feldspar from K-feldspar is possible by flotation using monovalent salts (Demir *et al.*, 2001) and Dogu and Arol (2004) found that it was possible to separate the dark coloured minerals from the feldspar by flocculation using starch.

The separation of muscovite mica from pegmatite ore may be achieved by electrostatic methods (Iuga *et al.*, 2004).

All these methods, even if one sticks to the most basic, require notable additional expenses as well as logistical considerations. A crushing and milling plant is needed, as is water, electricity and access by road. In Figure 16 the following are shown:

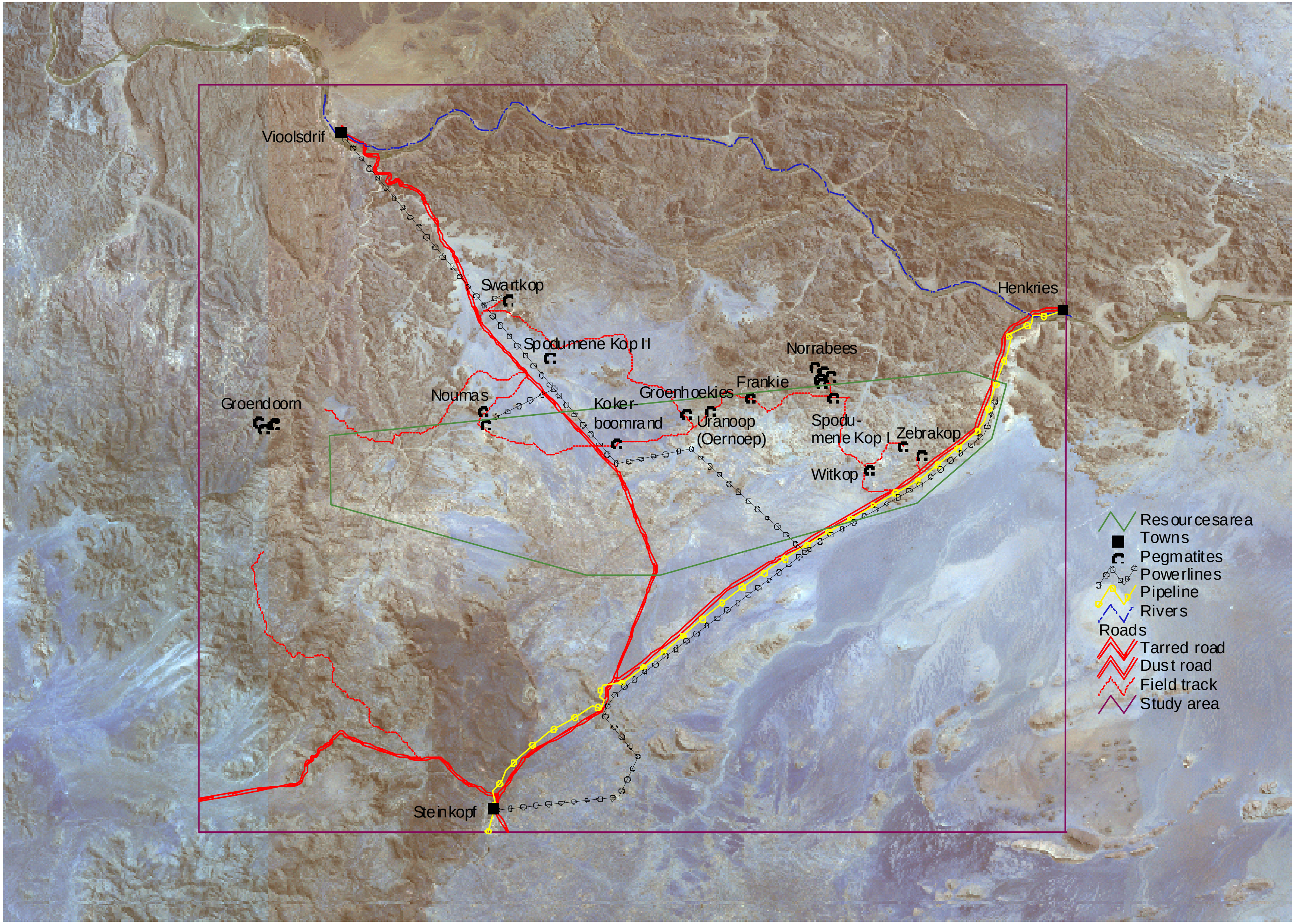


Figure 16: The infrastructure in the study area.

a) There are two reliable sources of water, viz. the Orange River and the Henkries – Springbok pipeline, which supplies the Okiep Copper District with water.

b) High voltage power lines supplying Steinkopf, Vioolsdrif, the main Henkries pump station as well as the support pump station, Blesberg and Swartberg.

c) The N7 national highway, the Steinkopf – Henkries dirt road and some of the field tracks providing access to the pegmatite belt.

In the writer's opinion, the Zebrakop pegmatite, as proposed by Agenbacht *et al*. (2003) would be the proper site for a plant. It is easily accessible, close to all infrastructure, and situated in one of the areas (and close to the other) of greatest pegmatite development.

It can be said that the pegmatite ore bodies in the study area are under-utilized. Only one mine (Blesberg Mine on the Noumas I pegmatite) is currently producing and produces only feldspar, while one or two other pegmatites in the area are producing on a sporadic basis. Furthermore, there are a variety of other commodities contained in some or the other of the pegmatites, which offer potential income, none of which are currently exploited. Of these especially mica and tantalite are currently in demand on international markets. Again, if the main product (feldspar) is upgraded, these by-products will be liberated and concentrated in the process. The main reason for this under-utilization of the pegmatite deposits seems to be the limited market in South Africa. While it is true that the international markets are largely supplied by major producers in foreign countries, the main problems relating to the international market are the troubles and costs involved in value addition and the transport costs from the mine to the port, as well as the FOB costs. Currently the nearest port is situated at Cape Town, a distance of some 700 km. Port Nolloth (approximately 100 km south of Alexander Bay, see Figure 3) is not suited for use as a harbour due to the shallow waters. During the time of initial development of the Sishen iron deposit, Boegoeberg, a few kilometres to the south of Alexander Bay and within 200 km along the road from the study area, was investigated as a possible harbour and was in an advanced stage towards approval. These plans were later changed (for reasons unknown to the author) to the current status with the harbour at Saldanha.

Current mining methods are simple, with ore being drilled and blasted after which the higher grade feldspar (on eye value) is hand-picked and moved to a suitable location where it can be loaded onto a truck as bulk load for transportation to the market. The feldspar is broken into workable sizes by the impact of the explosion or, if necessary, by mechanical means. The mining operation envisaged in this study will cater for the production of up to 3,000 ton feldspar per month which is the maximum currently produced at the Blesberg Mine and in South Africa this can be considered a large small-scale mining operation.

Financial and related data for this study were obtained from the following sources:

a) Consultation with Mr. J. Gagiano, mine manager, Blesberg Mine (operating costs, supply, demand, production, etc.).
b) Consultation with Mr. R. Strauss, Strauss Civil Works, Louisvale (machine costs, machine capacity, etc.).
c) Consultation with Mr. J. Nieuwoudt, Department of Minerals and Energy, Springbok (legal requirements).
d) Consultation with various industries for transport costs, costs of vehicles, housing, officing, etc.

6.2 Costs

6.2.1 Initial costs

The largest initial expenses will be related to:

a) plant and equipment

b) costs related to licensing procedures (legal requirements), which include the costs for rehabilitation, the EIA and EMP.

a) Plant and equipment costs

Start-up costs will come down to the acquisition of the necessary machinery and the establishment of the necessary administrative infrastructure such as offices and housing.

The machinery needed for the required production of up to 3,000 ton feldspar per month and the acquisition costs involved are summarized in Table 2.

Table 2: Costs for the acquisition of machinery for the mining of a pegmatite deposit producing up to 3,000 ton feldspar per month.

Machine	**Quantity**	**Cost per unit (R), Oct. 2004, VAT excl.**	**Cost (R)**
AS1 Atlas Copco compressor	2	142,000	248,000
Bell L1204C loader (1.9 m^3 bucket)	1	792,000	792,000
B18D Articulated Dump Truck (18 t)	1	1,123,000	1,123,000
Truck (8 t)	1	*100,000	100,000
Light Motor Vehicle (1 t bakkie)	2	150,000	300,000
Jackhammers	4	2,000	8,000
		Total	**2,571,000**

Notes:

* Second hand

Costs involved in putting up office and living quarters for the mine manager is summarized in Table 3. Labourers will be commuted to and from the nearest settlement.

Table 3: Costs for putting up offices and housing on the mine premises.

Structure	**Quantity**	**Cost per unit (R), Oct. 2004, VAT excl.**	**Cost**
Wendy house	2	10,000	20,000
House	1	200,000	200,000
		Total	**220,000**

b) Costs related to licensing procedures (legal requirements)

Included in these costs will be those related to exploration for the determination of reserves and grades. It would be possible during this stage to consider the effects of costs related to the upgrading and value addition to the raw material on the budget. In this study only the most basic requirements will be considered in order to make the available data as relevant as possible. It is in the nature of these operations that exploration expenses be kept to a minimum.

A *reconnaissance permit* and *mining permit* need not be considered as a reconnaissance stage is not required and the envisaged operation will occupy a land surface larger than 1.5 ha. As the position currently is under the new law it will not be possible to conduct mining simultaneously with the exploration operations as it is required that the envisaged exploration operations be described accurately in the application, and strictly adhered to during execution. Even the taking of bulk samples will not supply the required production volume for a mining operation. Therefore, costs related to the acquisition of a *prospecting right* and a *mining right* as well as the cost of exploration, are relevant. These costs can be summarized as in Table 4.

Table 4: Costs related to legal requirements and exploration for the envisaged operation.

	Estimated cost (R), Oct. 2004
Exploration	87,000
Desk study (geologist)	12,000
Field work (geologists & field assistants)	35,000
Bulk sampling and analyses (contractor and laboratory)	40,000
Prospecting right	64,500
Application fee	500
Environmental Management Plan (competent person)	9,000
Deposit for rehabilitation (determined by DME)	*50,000
Prospecting Work Programme (competent person)	3,000
Desk study (including maps, financial plan, surface rights, deeds)	2,000
Mining right	859,000
Application fee	1,000
Environmental Impact Assessment (competent person)	50,000
Deposit for rehabilitation (determined by DME)	*800,000
Mining Work Programme (competent person)	3,000

Social and Labour Plan (competent person)	3,000
Desk study (including maps, financial plan, surface rights, deeds)	2,000
Total	**1,010,500**

Notes:

* See discussion under Legal requirements, Licensing, where the Mining Work Programme is discussed. For a mine like Blesberg the amount for a *mining right* could be anything between R 500,000 to R 1 million.

Initial capital costs thus totals R 3,801,500.

6.2.2 Operating costs

Table 5 summarizes the operating costs that are likely to be incurred for the envisaged operation.

Table 5: Operating costs for a pegmatite mine producing up to 3,000 ton of feldspar per month.

Expense	**Description**	**Cost (R) per month, Oct. 2004**
Transport	R 160 / t	*208,000
Labour		105,000
Fuel	Diesel, average 9,000 *l* @ R 3.60 / *l*	33,000
Maintenance	Filters, hydrolic pipes, etc.	**20,000
Explosives	Ampex or Powercord, detonators	12,000
Overheads	Office supplies, etc	5,000
Oil		4,000
Electricity	Including the workshop	3,000
	Total	**390,000**

Notes:

* Production varies between 500 ton and 3,000 ton per month but from experience it can be said that 1,300 ton per month may be taken as an average, which is used for this calculation.

** Varies quite a lot. May be as high as 70,000. On average 20,000. Since the initial capital provides for the acquisition of new equipment, maintenance costs are expected to be a minimum.

Operating costs thus total R 4,680,000 / year.

6.3 Revenue

Factors which will have an influence on revenue include: the commodities that are produced, the value that is added before selling, the decision whether to export or not, amongst others. These issues are related to the scale of the operation and increasing this would require the setting up of a plant in order to handle increasing volumes of ore, mechanise separation techniques, and add value by the purification and milling of the raw product. These issues have been addressed in other sections. For the purpose of this financial analysis, data will rely on the current situation where only feldspar is produced in a small scale mining operation and delivered to the domestic market.

Statistics (Figure 12) shows the feldspar price at approximately R 580 / ton at the end of 2004 and rising. A price of R 550 / ton will be used in the financial analysis and changes in price will be included in a sensitivity analysis. Production varies between 500 ton and 3,000 ton per month but from experience it can be said that 1,300 ton per month may be taken as an average. For the financial analysis, therefore, revenue will be taken as R 8,580,000 / year.

6.4 Discounted Cash Flow (DCF), Payback Period, Net Present Value (NPV), Internal Rate of Return (IRR)

There are a number of incentive schemes available to the small scale mining sector such as the Entrepreneural Mining and Beneficiation Finance scheme of the Department of Trade and Industry. The National Steering Committee of the Department of Minerals and Energy makes available a sum every year to be used on potential development projects in the mining sector. The financing related to these schemes are project-specific and vary from one project to the other. For the purpose of this study it will be assumed that the initial capital will be financed by a commercial bank at prime interest rate which is currently (March 2005) at 11%.

The discount factor is the sum of the country risk as measured for instance in the interest rates of government bonds (8%, March 2005), and a project-related risk factor. The operation as envisaged in the financial analysis is of small scale and similar to existing operations that have been in practise over many decades.

Therefore the envisaged project is not considered especially risky and an additional risk factor of 3% is regarded as sufficient, bringing the discount rate to 11%. As part of the sensitivity analysis the project's robustness will also be tested by applying discount rates of 15 and 20%. For operations aiming to expand the capacity and increase the scale of the operation through the acquisition of a beneficiation plant, the risk factor will increase significantly.

Table 6 represents a Discounted Cash Flow Model over fifteen years for the envisaged mining operation (included on disc at the back of the document). Payback is achieved at the end of year 4, which is still acceptable as the life of mine will be longer than three times the payback period (graph). It shows an Internal Rate of Return (IRR) of 26.07% which is significantly higher than the cost of capital (11%). The NPV at the discount rate of 11% is R 6,490,073.95.

6.5 Risks (sensitivity analysis)

Especially two factors enhance the risks associated with the mining of industrial minerals, viz. the high-volume-low-value nature of the commodity and the threat of substitution (Horn, 1994).

a) High-volume-low-value nature of feldspar

This factor renders a feldspar mining operation (like all industrial minerals) extremely vulnerable to increases in costs like wages and transport. As such, the threat of more economical suppliers closer to the market (for example the producers in the Gravelotte area are closer to the Gauteng markets than those in the study area) also comes into effect. This represents a marketing risk.

Also related to this threat is the possibilities of stricter government controls and regulations and pressures from environmentally conscious organisations (both of which manifested itself in the latest Act), and leading to increases in licensing fees, deposits for rehabilitation, and costs of environmental impact studies. These costs influence initial capital and very often lead to projects being rejected early in the evaluation programme, even before the feasibility study.

b) Substitution

The possible substitution of feldspar as a source of aluminium in the glass industry (by, for example, nephelene) has already been mentioned (Markets). A further threat in this regard (and one that has already became reality) is that of the South African product being replaced on the international market by cheaper and often higher quality, value-added products from foreign producers. This is not only true for the international market but becomes a domestic threat when these materials are imported. These factors influence commodity prices and represent a market risk.

Synthetic materials are becoming a growing threat not only to industrial minerals but also to some of the metals; although with rising fossil fuel costs glass packaging may be seen to stay.

During the recent past it has become apparent that energy sources (as displayed in the price of oil) will not become cheaper in future. This directly influence all costs related to fuel, i.e. the operating fuel costs, and transport costs.

Risks will be addressed here by means of a sensitivity analysis. The following factors will be analysed:

a) The robustness of the project is tested by applying different discount rates, the discount rate being a reflection of the overall risk involved.

b) The risk of increased initial capital will be analysed by including capital costs.

c) Transport and labour costs are included as the most important operating costs.

d) Changes in commodity prices will serve as an indicator of the market risk.

e) Changes in revenue will serve as an indicator of the marketing risk.

f) Changes in the total price of fuel (the sum of operating fuel costs and transport) will be included.

The sensitivity analysis is shown in Table 7 and included on disc at the back of the document.

The NPV at 11% = R 6,490,073.95, at 15% = R 3,829,014.47 and at 20% = R 1,641,044.48.

The commodity price and revenue graphs on the sensitivity chart show very similar trends as revenue in this analysis is dependant on only one commodity (feldspar). These two factors offer the most serious risks to the project as can be deduced from the steep slope on the sensitivity chart.

The project is also relatively sensitive to fuel prices as indicated by the slopes of total fuel and transport costs on the sensitivity chart.

As far as the identified risks are concerned, the project is less sensitive to changes to capital costs, and the least to changes in labour costs.

CHAPTER 7. CONCLUSIONS

The resources of industrial minerals in the Northern Cape are fairly plentiful and to these the pegmatites of the study area contributes significantly. The Northern Cape however, is a vast stretch of country (the largest province in South Africa) and especially the western parts are rather isolated. The sensitivity of industrial mineral mining operations to commodity prices, revenue, transport costs and other costs related to fuel consumption, is confirmed by this study. However, it is shown that such operations are not necessarily rendered unviable by it.

Labour costs do apparently not present a very serious risk. It would be advisable to let the labourers share in ownership through a profit share scheme.

The addition of value by purification and milling of the raw product, the recovery and utilization of by-products, and the exploitation of the export markets should be seriously considered in future. Coupled with this is a necessity for the development of the consuming markets. Zebrakop pegmatite is regarded by the author as a potential target site for such development.

As could be expected the project is the most sensitive for fluctuation in commodity prices. It is therefore recommended that any new producer enter into a product off-take agreement with a consumer for at least the payback period, to reduce this risk.

The pegmatite belt of the Northern Cape has not been properly investigated for the past three decades; besides the fact that data is outdated, the academic understanding of its formation and evolution is lacking in many regards.

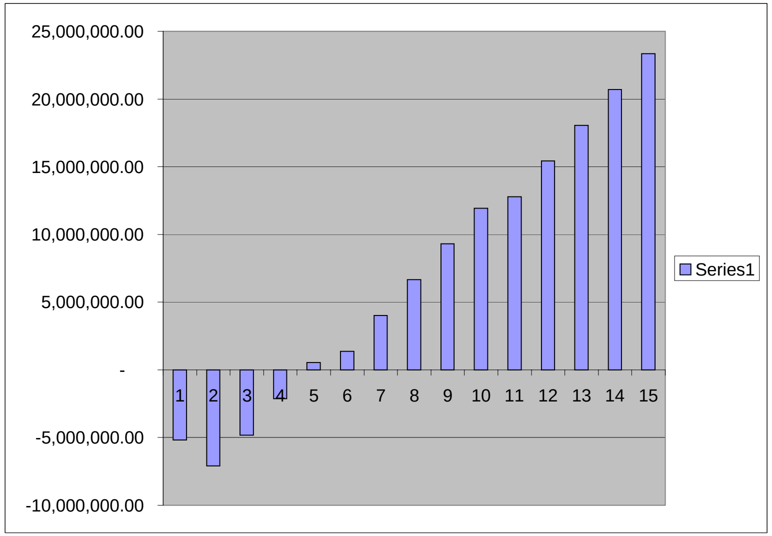
Table 6: Discounted Cash Flow Model of the envisaged project.

Notes				1	2	3	4	5	6	7
A	**Revenue**			**-**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**
	Sales	ton	R/t							
	Feldspar	15,600.00	550.00	-	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00
	Mica			-	-	-	-	-	-	-
	Accessories			-	-	-	-	-	-	-
					865,563.24					
	Expenses			**5,180,465.26**	**5,193,379.44**	**4,891,479.92**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**
B	Capital Costs			4,667,085.82					2,571,000.00	
C	Operating costs									
D	Transport			-	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00
C	Labour			-	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00
C	Fuel			-	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00
C	Maintenance			-	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00
C	Explosives			-	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00
C	Overheads			-	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00
C	Oil			-	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00
C	Electricity			-	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00
E	Interest on loan	11%		513,379.44	513,379.44	211,479.92				
	Profit before tax and levies			-5,180,465.26	-1,409,165.26	3,348,340.17	3,900,000.00	3,900,000.00	1,329,000.00	3,900,000.00
F	**Royalties**	1.5%			128,700.00	128,700.00	128,700.00	128,700.00	128,700.00	128,700.00
	Profit before tax			-5,180,465.26	-1,922,544.70	3,219,640.17	3,771,300.00	3,771,300.00	1,200,300.00	3,771,300.00
G	**Tax**	29%		-	-	933,695.65	1,093,677.00	1,093,677.00	360,090.00	1,131,390.00
	Profit after tax			-5,180,465.26	-1,922,544.70	2,285,944.52	2,677,623.00	2,677,623.00	840,210.00	2,639,910.00
	Cumulative cash flow			-5,180,465.26	-7,103,009.96	-4,817,065.44	-2,139,442.44	538,180.56	1,378,390.56	4,018,300.56
H	**Discounted**	11%		-4,667,085.82	-1,560,380.41	1,671,462.93	1,763,833.21	1,589,038.93	449,210.58	1,271,534.86
	Cumulative discounted cash flow			-4,667,085.82	-6,227,466.23	-4,556,003.30	-2,792,170.09	-1,203,131.17	-753,920.59	517,614.27

Notes		8	9	10	11	12	13	14	15
A	**Revenue**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**	**8,580,000.00**
	Sales								
	Feldspar	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00	8,580,000.00
	Mica	-	-	-	-	-	-	-	-
	Accessories	-	-	-	-	-	-	-	-
	Expenses	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**	**4,680,000.00**
B	Capital Costs				2,571,000.00				
C	Operating costs								
D	Transport	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00	2,496,000.00
C	Labour	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00	1,260,000.00
C	Fuel	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00	396,000.00
C	Maintenance	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00	240,000.00
C	Explosives	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00	144,000.00
C	Overheads	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00
C	Oil	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00	48,000.00
C	Electricity	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00	36,000.00
E	Interest on loan								
	Profit before tax and levies	3,900,000.00	3,900,000.00	3,900,000.00	1,329,000.00	3,900,000.00	3,900,000.00	3,900,000.00	3,900,000.00
F	**Royalties**	128,700.00	128,700.00	128,700.00	128,700.00	128,700.00	128,700.00	128,700.00	128,700.00
	Profit before tax	3,771,300.00	3,771,300.00	3,771,300.00	1,200,300.00	3,771,300.00	3,771,300.00	3,771,300.00	3,771,300.00
G	**Tax**	1,131,390.00	1,131,390.00	1,131,390.00	360,090.00	1,131,390.00	1,131,390.00	1,131,390.00	1,131,390.00
	Profit after tax	2,639,910.00	2,639,910.00	2,639,910.00	840,210.00	2,639,910.00	2,639,910.00	2,639,910.00	2,639,910.00
	Cumulative cash flow	6,658,210.56	9,298,120.56	11,938,030.56	12,778,240.56	15,418,150.56	18,058,060.56	20,697,970.56	23,337,880.56
H	**Discounted**	1,145,526.90	1,032,006.21	929,735.33	266,584.61	754,594.05	679,814.46	612,445.46	551,752.66
	Cumulative discounted cash flow	1,663,141.16	2,695,147.38	3,624,882.70	3,891,467.32	4,646,061.37	5,325,875.82	5,938,321.28	6,490,073.95

IRR: 26.07%

NPV: 11% R 6,490,073.95



NOTES

A Average production of 1,300 t / month = 15,600 t / year @ R 550 / t.
(See discussion under **6.3 Revenue**)

B In year 1:
Initial costs + two months working capital
For initial costs see discussion under 6.2.1 Initial costs
Two months working capital = 1year expenses/6 = 865,585.82
In years 6 and 11:
Replace equipment (see discussion under 6.2.1 *a) Plant and equipment costs*)

C Rate / month x 12 (See discussion under 6.2.2 Operating costs)

D Average production / month (1,300 t) x Transport costs / month (R 160 / t) x 12

E Loan to cover capital costs

F Royaltie based on revenue paid to the Department of Minerals and Energy.

G Current company tax rate (March 2005)

H Value of a government bond at 8% + a risk factor of 3%
(See discussion under **6.4 DCF, Payback Period, NPV, IRR**)

Table 7: Sensitivity analysis of the envisaged project.

IRR (%)

	Transport costs	Labour costs	Commodity prices	Total fuel	Capital costs	Revenue
-30	34.62	30.34	-3.73	36.02	43.97	-4.35
-20	31.73	28.91	7.21	32.65	36.22	6.88
-10	28.88	27.49	16.72	29.33	30.49	16.56
0	26.07	26.07	26.07	26.07	26.07	26.07
10	23.29	24.66	35.73	22.85	22.54	35.90
20	50.52	23.26	45.90	19.65	19.65	46.28
30	17.77	21.86	55.99	16.46	17.22	56.55

NPV (R)

At 11% discount rate

	Transport costs	Labour costs	Commodity prices	Total fuel	Capital costs	Revenue
-30	10,069,720.31	8,297,106.97	-5,610,340.68	10,637,644.97	9,471,667.10	-5,814,960.42
-20	8,876,504.86	7,694,762.63	-1,576,869.14	9,255,121.30	8,477,802.71	-1,713,282.30
-10	7,683,289.40	7,092,418.29	2,456,602.40	7,872,597.62	7,483,938.33	2,388,395.82
0	6,490,073.95	6,490,073.95	6,490,073.95	6,490,073.95	6,490,073.95	6,490,073.95
10	5,296,858.49	5,887,729.61	10,523,545.49	5,107,550.27	5,496,209.56	10,591,752.07
20	4,103,643.04	5,285,385.27	14,557,017.04	3,725,026.60	4,502,345.18	14,693,430.19
30	2,910,427.59	4,683,040.93	18,450,499.89	2,342,502.92	3,508,480.80	18,646,300.17

At 15% discount rate

	Transport costs	Labour costs	Commodity prices	Total fuel	Capital costs	Revenue
-30	6,697,873.20	5,277,236.42	-5,866,737.33	7,153,028.67	6,647,483.82	-6,032,687.42
-20	5,741,586.96	4,794,495.77	-2,634,820.07	6,045,023.94	5,707,994.04	-2,745,453.46
-10	4,785,300.71	4,311,755.12	597,097.20	4,937,019.20	4,768,504.25	541,780.51
0	3,829,014.47	3,829,014.47	3,829,014.47	3,829,014.47	3,829,014.47	3,829,014.47
10	2,872,728.22	3,346,273.82	7,060,931.74	2,721,009.73	2,889,524.68	7,116,248.43
20	1,916,441.98	2,863,533.16	10,292,849.00	1,613,005.00	1,950,034.90	10,403,482.39
30	960,155.74	2,380,792.51	13.398882.90	505,000.27	1,010,545.12	13,556,902.18

At 20% discount rate

	Transport costs	Labour costs	Commodity prices	Total fuel	Capital costs	Revenue
-30	3,889,580.59	2,776,122.80	-5,956,494.20	4,246,319.49	4,276,784.44	-6,088,298.40
-20	3,140,068.55	2,397,763.36	-3,423,981.31	3,378,894.49	3,398,204.45	-3,511,850.78
-10	2,390,556.51	2,019,403.92	-891,468.41	2,509,469.48	2,519,624.46	-935,403.15
0	1,641,044.48	1,641,044.48	1,641,044.48	1,641,044.48	1,641,044.48	1,641,044.48
10	891,532.44	1,262,685.04	4,173,557.37	772,619.47	762,464.49	4,217,492.10
20	142,020.40	884,325.59	6,706,070.26	-95,805.53	-116,115.49	6,793,939.73
30	-607,491.63	505,966.15	9,127,788.67	-964,230.54	-994,695.48	9,252,612.68

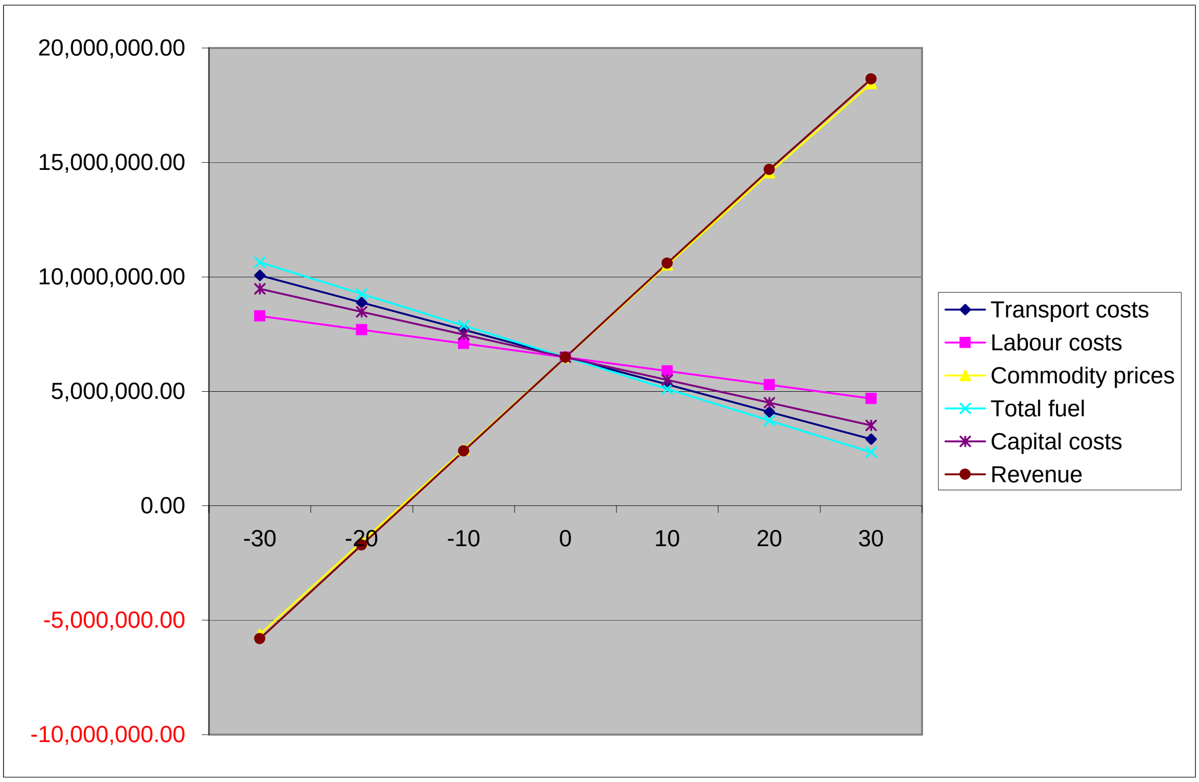


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Plate 1: Part of the zoned Witkop pegmatite. In the left of the photo, the quartz core is visible; in the middle, the mica-rich intermediate zone has been mined out; in the right of the photo, the wall zone (feldspar, plagioclase, quartz), is visible.

Plate 2: Homogeneous pegmatite at Uranoop.

Plate 3: Pegmatite swarm in the Henkries Valley.

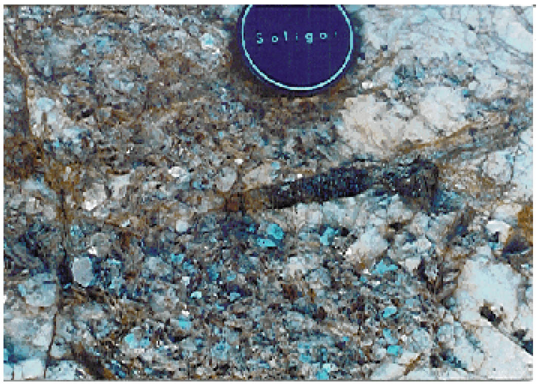

Plate 4: Part of a mica-rich pocket. These pockets occur in an irregular fashion throughout the pegmatite body.