The exploitability of pegmatite deposits in the lower Orange River area (Vioolsdrif - Henkries - Steinkopf)

H. Minnaar
Department of Geology, University of Pretoria, Pretoria, South Africa.
Current address: Council for Geoscience, P.O. Box 775, Upington, 8800, South Africa
e-mail: hminnaar@lantic.net

H.F.J. Theart
Department of Geology, University of Pretoria, Pretoria, South Africa.
e-mail: htheart@postino.up.ac.za

ABSTRACT

The pegmatite deposits situated in the centre of a triangular area between the settlements of Vioolsdrif, Henkries and Steinkopf in the lower Orange River region constitute the westernmost extension of the Northern Cape pegmatite belt. Aspects regarding the resource classification, geology, and the economic viability of these pegmatite deposits are considered here. Current ore deposit models are reviewed and the deposits are classified according to recognised classification schemes. Feldspar is regarded as the primary economic mineral for exploitation based on its abundance and the consistency in the demand for this product. A financial analysis demonstrates the exploitability of the deposits, based on the resources quantified and the analysis of the feldspar market. Other potentially economic mineral constituents, occurring in the pegmatite body, could only be considered when more information on their distribution and abundance is available.

Pegmatites of the study area belong to lithium-caesium-tantalum enriched group of rare element bearing granitic pegmatites (Ginsburg *et al.*, 1979). Both homogenous and zoned varieties are present. The currently prevailing ore deposit model for the formation of these pegmatites regards the pegmatite body as the final stage of crystallization of a cooling granitic magma (Cerny, 1998a). Recent studies suggest that crystallization of the pegmatite body happens at unexpectedly fast rates during under-cooling conditions, in which the rate of cooling exceeds the rate of crystallization (London, 2005).

The pegmatites of the study area are mostly developed in granites and granodiorites of the Vioolsdrif Suite, in a late- to post-orogenic tectonic setting. An apparent age discrepancy makes it improbable that the source of the pegmatite-forming liquids was the Vioolsdrif Suite. It is proposed that the pegmatites were derived from a younger suite of plutonic granitic intrusions, currently located largely beneath the surface, and that the late magmatic fluids derived from these crystallizing granites in depth, were injected into shear related tension fissures.

It is estimated that the larger pegmatite bodies in the study area host a global resource of approximately 50 million tons of pegmatite ore, belonging to a resource category referred to as resources of undetermined economic significance. The markets for feldspar currently display an increasing price tendency and there exists a positive outlook for the future demand for this mineral product. The financial analysis suggests that, although mining operations on pegmatite bodies are highly sensitive to changes in commodity prices, revenue, and costs related to fuel consumption (including transport), their exploitation is feasible under the current market conditions.

Introduction

Ever since the introduction of the Australasian JORC Code in 1989, international acceptance grew of a standardized regulatory framework for the public reporting on mineral resources and reserves. Various countries have since followed with similar reporting standards and a good example of this is the South African SAMREC Code released in 2000. In general, these codes, collectively referred to as the JORC family of codes, display a large degree of synergy, and with the release of revisions the initial discrepancies are rapidly disappearing. The JORC family of codes sets out minimum standards, recommendations and guidelines to be followed by private industry in public reporting to investors in the mining industry. In considering the need to have international guidelines, this became known as the reporting of economic and potentially economic mineralization. Nonetheless, at this level it is also important to recognize the need for guidance of governmental and international agencies in reporting on mineral resources and reserves, and since there are no currently accepted standards regulating such reporting, great confusion exists in the terminology and numbers used. Such reporting is required amongst other reasons for national and international inventory documentation, policy and land utilization decisions. At a recent meeting in Johannesburg (16 to 18 May 2006), of the Joint United Nations Economic Commission for Europe (UNECE) and the Combined Reserves International Reporting Standards Committee (CRIRSCO), a draft document for an international framework on the reporting of exploration results, mineral resources, mineral reserves and additional non-economic mineralization was tabled. At this meeting there were general consensus on the acceptance of the first part (Part A) of the international framework classification, dealing with the reporting of economic and potentially economic mineralization, by following the terminology and conceptual principals set out in the JORC family of codes. Part B of this document addresses the reporting of what is unfortunately referred to as additional non-economic mineralization. The latter category would probably be better referred to as mineralization of an *undetermined* economic significance.

In this paper, the authors intend to demonstrate how estimates could be made at a pre-feasibility level, of mineral resources belonging to the undetermined economic significance category, and that these estimates could be important in providing guidance for policy decisions on regional poverty alleviation strategy and community based mining operations (government strategy decisions) and for inclusion in national inventory tabulations. Such estimates do not need to be based on the same class of information required for the reporting of economic and potentially economic mineral resources and reserves as required by the JORC family of codes. In arriving at these estimates, it is important to appreciate the fact that confidence in the estimated numbers provided lies in a fundamental understanding of the geology and classification of the ore deposit type and the regional geology, rather than in the information specifically related to an individual project. Numbers indicative of the financial value are therefore of an illustrative nature and can not be used to obtain funding from a financial institution, but are intended to demonstrate potential economic value both to government and to attract exploration interest from the private industry. Similarly financial risk could not be addressed comprehensively, as this would require a far greater degree of confidence in the underlying information. It is however intended to demonstrate by using simplistic sensitivity analyses, which aspects could most likely pose a thread to the viability of such a project in this region so as to highlight those aspects that would require the most attention prior to the commissioning of a new operation. Furthermore we wish to demonstrate that even when reporting resources of an undetermined economic significance it is important to at least be able to demonstrate its potential economic significance before using it in national mineral inventories or basing policy decisions on it.

Pegmatites are attractive exploration targets as they offer potential for the simultaneous extraction of a variety of ore and industrial minerals Furthermore, the presence of, and abundance of minerals containing rare elements that are currently demanded in advanced technological applications has increased the interest in these bodies (Cerny, 1998a). Nonetheless, the irregular distribution and scarcity of such minerals, combined with the variable shape and internal structure of the pegmatite bodies, complicates the effective evaluation of such resources. McGill and Theart (in print) discuss the treatment of risk related to small scale mining ventures such as the one envisaged here.

A number of the pegmatites in the Vioolsdrif – Steinkopf – Henkries area have historically provided sources of income to small-scale miners on a sporadic basis. 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 in the 1920's (Gevers *et al.*, 1937).

The sporadic nature of mining activities on these pegmatites is caused by a variety of factors such as: highly variable commodity prices, variations in the demand for specific pegmatite minerals, the influence of transport costs, the unpredictability of the yield for the accessory minerals, and the overall low yield due to inefficient small scale mining methods. Minnaar (2006) recently reinvestigated the pegmatites of this area, and this paper is largely based on the finding of the latter investigation.

The sporadic nature of mining activities on these pegmatites in the past was caused by a variety of factors such as: highly variable commodity prices, variations in the demand for specific pegmatite minerals, the influence of transport costs, the unpredictability of the yield for the accessory minerals, and the overall low yield due to inefficient small scale mining methods. It is suggested here that previous failure of small-scale pegmatite mining efforts in this region could be ascribed to such ventures directed at the scarcer pegmatite minerals.

It is recommended here that initial exploitation planning should be based on the production of feldspar as the primary commodity, as there is a consistent and growing demand for this mineral from the South African ceramic and glass industries. A significant section of these industries are currently dependent on supply from the pegmatites in the study area. The upside potential for highly lucrative revenue that could be derived from by-product minerals such as muscovite, tantalite-columbite, spodumene and beryl, should not be allowed to influence the initial evaluation decisions, due to unacceptably high risk factors related to their geological distribution, price and marketing. However, it is foreseen that future extraction of these minerals will provide a significant source of income; even if this could be done during the reprocessing of the proposed operation's waste dumps. 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 current investigation

Available literature related to the pegmatites of the study area was reviewed and this desk study was supplemented with field investigations. An attempt was made to reconcile the pegmatites of the study area with currently prevailing ore deposit models and classification schemes, and to further our understanding of their formation. For the financial analysis, feldspar is considered to be the commodity of interest and this is indeed currently the practice at the Blesberg Mine, which was the only operational pegmatite mine in the area during the time this study was executed (June to December 2004).

To obtain an estimate of the global resources in the study area, the exposed pegmatite bodies were outlined on aerial photographs of 1: 20,000 scale and the surface area of the exposed pegmatite bodies were calculated and an estimation of the depth extension was done. These volumetric calculations were then used in the estimation of the total resources in the area.

A survey was made of all costs related to an envisaged mining operation. The markets for feldspar were evaluated. Finally a financial analysis was done envisioning a venture similar to the existing mine at Blesberg. In doing this, a discounted cash flow model (DCF model) was created in which the variables can be accounted for and the project's sensitivity to various risks can be determined.

General ore deposit model and classification

Many models have been proposed for the formation of rare element bearing granitic pegmatite bodies. These include: multiphase injection (*e.g.* Nikitin, 1957), metasomatic origin of extensive albitic and micaceous units (*e.g.* Ginsburg, 1960), recrystallization plus metasomatism of granitoid rocks (*e.g.* Schaller, 1925), open-system syndilational crystallization from streaming vapour (Kretz *et al.*, 1989), or exsolution of immiscible liquid (*e.g.* Melentyev and Delitsyn, 1969). However, the currently favoured model is that of late-magmatic crystallization in a restricted system (Cerny 1998a & b). Internal pegmatite consolidation occurs by crystallization under decreasing temperature (and variable pressure) in a volatile-rich, highly hydrous granitic melt, complemented by precipitation from an aqueous fluid (Cerny, 1998a). London (2005) concluded that crystallization occurs at unexpectedly high cooling rates under the influence of under-cooling in the presence of volatiles such as H_2O, B, F and P, acting as fluxing components.

The pegmatite-forming melts are currently generally accepted to be derived from the fractionation of granitic igneous intrusions. The abundance of lithophile rare elements in pegmatites is the result of classic crystal-chemical selection of compatible versus incompatible trace elements and not as result of anomalously enriched source rocks from which the pegmatitic melt formed as result of eutectic melting (Cherny 1998a).

Pegmatite emplacement is governed by the same controls affecting any small-scale igneous intrusion, namely: melt pressure, rheologic state of the host rock, lithostatic pressure, deviatoric stress, and strength anisotropies in the host rock (Cerny, 1998b).

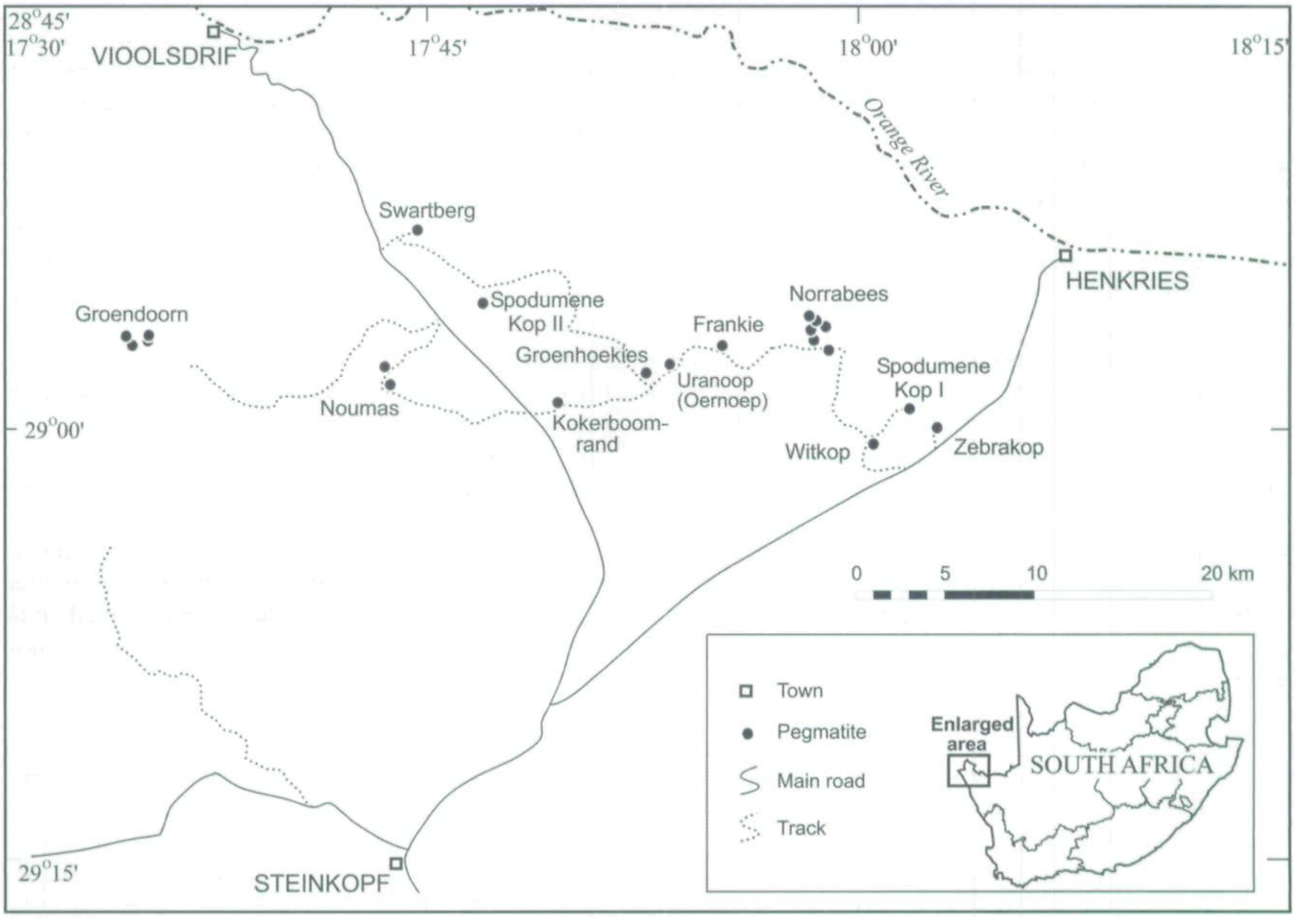

Figure 1. Location of the study area and investigated pegmatites.

Pegmatite bodies related to the same evolutionary event occur in pegmatite fields, belts and provinces and commonly display compositional zoning on a local and regional scale (Cerny, 1998b).

Pegmatites have been classified by Cameron *et al.* (1949), based on their internal zoning, into homogeneous and inhomogeneous (zoned) pegmatites, and by Ginsburg *et al.* (1979) based on their depth of formation (crustal setting), mineralisation and their relationship to the igneous process and metamorphic environment, into abyssal, muscovite, rare-element, and miarolitic classes (Ginsburg *et al.*, 1979; Cerny, 1990).

The study area

Some of the more important, previously exploited pegmatites in the study area are indicated in Figure 1. They include from west to east: Groendoorn I, II, III and IV; Noumas I (Blesberg Mine) and II; Swartberg; Spodumene Kop II; Kokerboomrand; Groenhoekies; Uranoop; Frankie; Norrabees I, II, III, IV, V and VI; Witkop; and Spodumene Kop I. All of the above pegmatites represent zoned bodies (according to the scheme of Cameron *et al.*, 1949) and previous studies on them include those of Gevers *et al.* (1937), Hugo (1970), Schutte (1972) and Hansen *et al.* (2004). Zebrakop is the only homogeneous pegmatite in the study area that was investigated (Agenbacht *et al.*, 2003).

The climate in the area is arid with both vegetation and wildlife being sparse. The relief becomes progressively more mountainous as the Orange River gorge is approached. All the above-mentioned pegmatites, with the exception of the Groendoorn pegmatites, are situated on flat land and are easily accessible by means of field tracks. Distances along the road from the study area to the domestic consumer markets are approximately 1,300 km to Gauteng, and 700 km to Cape Town. The study area extends over parts of the Steinkopf and Vioolsdrif communal land and the surface rights are owned by the state.

Previous work, historical background and the current situation

The Noumas I pegmatite (Blesberg Mine) was the first pegmatite to be exploited in the area where mining already commenced in 1925. Shortly thereafter the demand and price for beryl increased and this, in Namaqualand, led to the beryl-boom of the early 1930's. During this time the Geological Survey investigated the area between Steinkopf, Vioolsdrif and Goodhouse and this lead to extensive government-sponsored prospecting from1935 to 1936. Gevers *et al.* (1937) reported the results of these activities.

After the outbreak of the Second World War, the Geological Survey embarked on a programme of exploration for strategic minerals along the Orange River valley west of Upington. During the 1940's, resources of reactor minerals also became important with the advent of the nuclear era. With pegmatites being the main source of some of the minerals containing these elements, they were studied in detail. The results of these studies were the reports by Hugo (1970) and Schutte (1972).

The Blesberg Mine, at the time this study was executed, exploits the Noumas I pegmatite and some of the other bodies such as those at Groenhoekies and Kokerboomrand are being mined sporadically. Blesberg provides for the demand of a large proportion 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, viz. resource evaluations executed on Zebrakop (Agenbacht *et al.*, 2003), and Witkop (Hansen *et al.*, 2004). An indicated resource of 14.2 million ton of raw ore was estimated for Zebrakop (a homogeneous body) and 400,900 ton for the Witkop main body (a zoned body).

The results obtained from these two studies are interesting as they deal with two different types of pegmatite – homogenous and inhomogeneous. The homogeneous bodies are generally much larger than the zoned bodies. However, traditionally only zoned bodies were exploited because of the concentrated manner (so-called 'pockets') in which rare minerals occur within the body such as native bismuth, beryl, tantalite, etc., which were then considered to be the primary minerals of interest. Later mica became more important and mining activities were concentrated on the mica-rich zones. In recent years however, feldspar replaced all other commodities as the primary economic mineral in the pegmatites. If the mineral abundance profiles in the above two studies 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 pegmatites and the viability of the homogeneous pegmatites. Four important factors call for the application of a bulk mining method:

a. The primary commodity, feldspar, 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, lead to unstable high walls and unsafe working conditions, while a bulk mining method may allow for the reopening of mines which might have been closed for this reason.
d. Bulk mining will allow for larger volumes of ore to be mined and in practice this will necessitate the erection of a beneficiation plant. It will also enable expansion to the international market, as the South African domestic feldspar consuming markets do not support high production rates. These possibilities are not considered in any further detail here, as the necessary financial data is not readily available

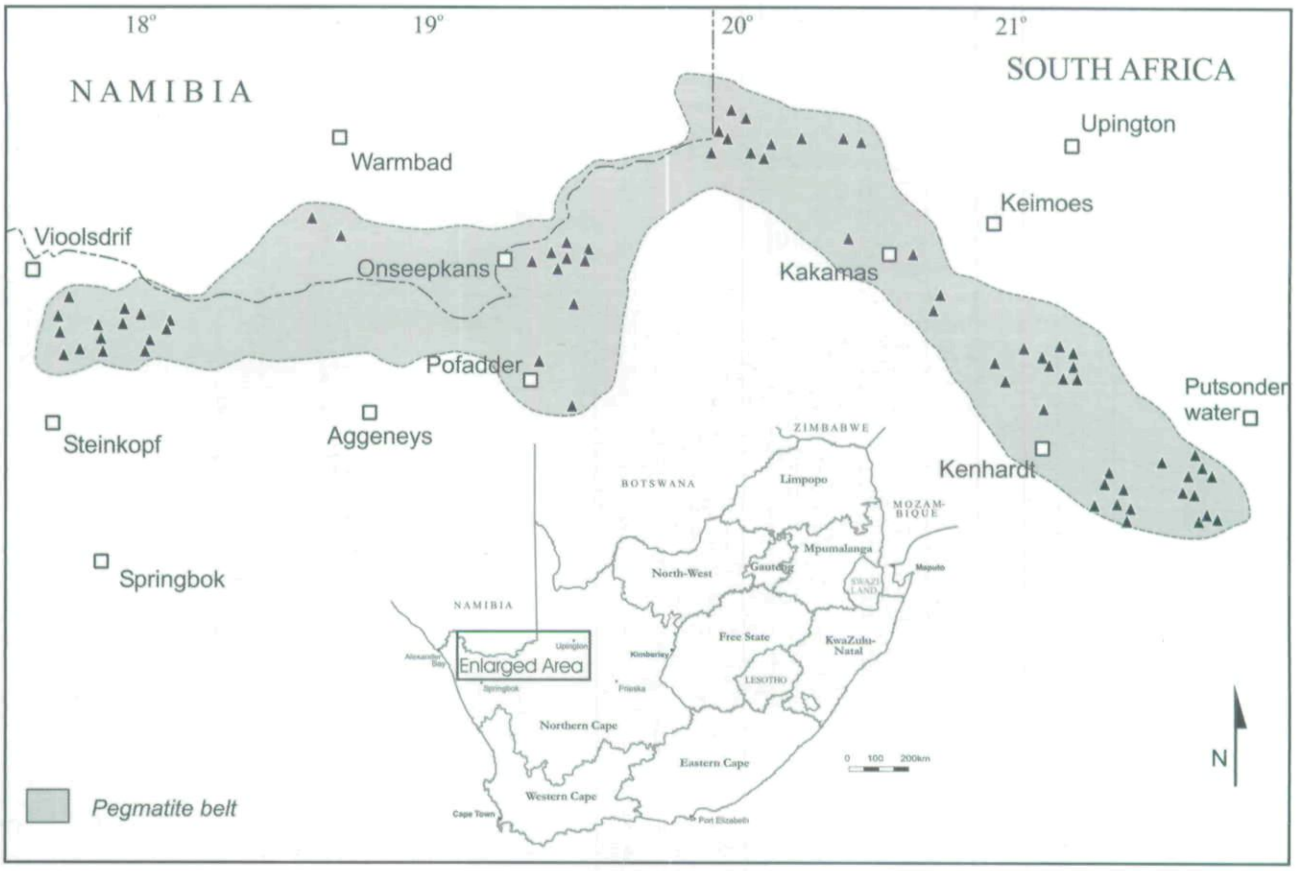

Figure 2. The Northern Cape pegmatite belt.

Geology and mineralogy of the pegmatites

The pegmatites of the study area form the westernmost extension of the Northern Cape pegmatite belt which stretches from the study area eastward along the Orange River, occurring in both South Africa and Namibia with an average width of 60 km, turning south-eastward in the vicinity of Riemvasmaak and reaching the Kenhardt district, over a total length along strike of ~400 km (Figure 2).

In the study area, the pegmatites are hosted by granitoids (mostly granites and granodiorites) of the Vioolsdrif Suite. A general northwest strike for the bulk of the exposed pegmatite bodies is evident on aerial photographs. It should be noted that a significant proportion of the area (~25%, Figure 3) is sand covered. A minor proportion of these bodies show no preferred orientation, striking in every possible direction. The pegmatites range from bodies measuring only a few centimetres to >3 km in length and ~100 m wide. They also vary in shape from thin veins or dykes to irregular discordant masses. While most of the bodies are markedly discordant, many strike parallel to the foliation in the country rock. Gradational contacts between pegmatite and country rock are also sometimes observed. The great irregularities in dimensions and shape make their continuation in depth difficult to predict.

Compositionally two types can be recognised in the field, namely homogeneous and zoned pegmatites (after Cameron *et al.*, 1949). The homogeneous pegmatites are simple aggregates of quartz, feldspar, mica, and accessory minerals, and cannot be divided into units of contrasting mineralogy and texture. The zoned pegmatites can, on grounds of mineral assemblages and textures, be divided into more or less concentric zones which most often include a core comprising massive quartz and perthite, an intermediate zone, a wall zone, and a border zone. Zonation may be simpler or more complex in different bodies. The investigated pegmatites conform to the rare-element granitic class of the Ginsburg *et al.* (1979) classification scheme. Along with the major constituents (quartz, feldspar and mica), they also host an array of accessory minerals such as native bismuth, columbite-tantalite, beryl, spodumene, garnet, tourmaline and uranium-bearing minerals.

The pegmatites of the study area are situated in a intensely foliated transitional zone between two tectonic domains, referred to as the unfoliated to weakly foliated Richtersveld Subprovince to the north, and the pervasively and intensely foliated Bushmanland Subprovince to the south (Kröner and Blignault, 1976). This transition is gradational and although most of the pegmatites occur within the foliated gneisses of the Bushmanland Subprovince to the south, some also occur in the unfoliated granites of the Richtersveld Subprovince to the north. The foliation is related to the Namaqua orogeny, which reached its peak at ~1.2 Ga (*e.g.* Joubert, 1986). During its termination at ~1.1 Ga, easterly trending shear zones were formed on regional scale (Colliston and Schoch, 2003).

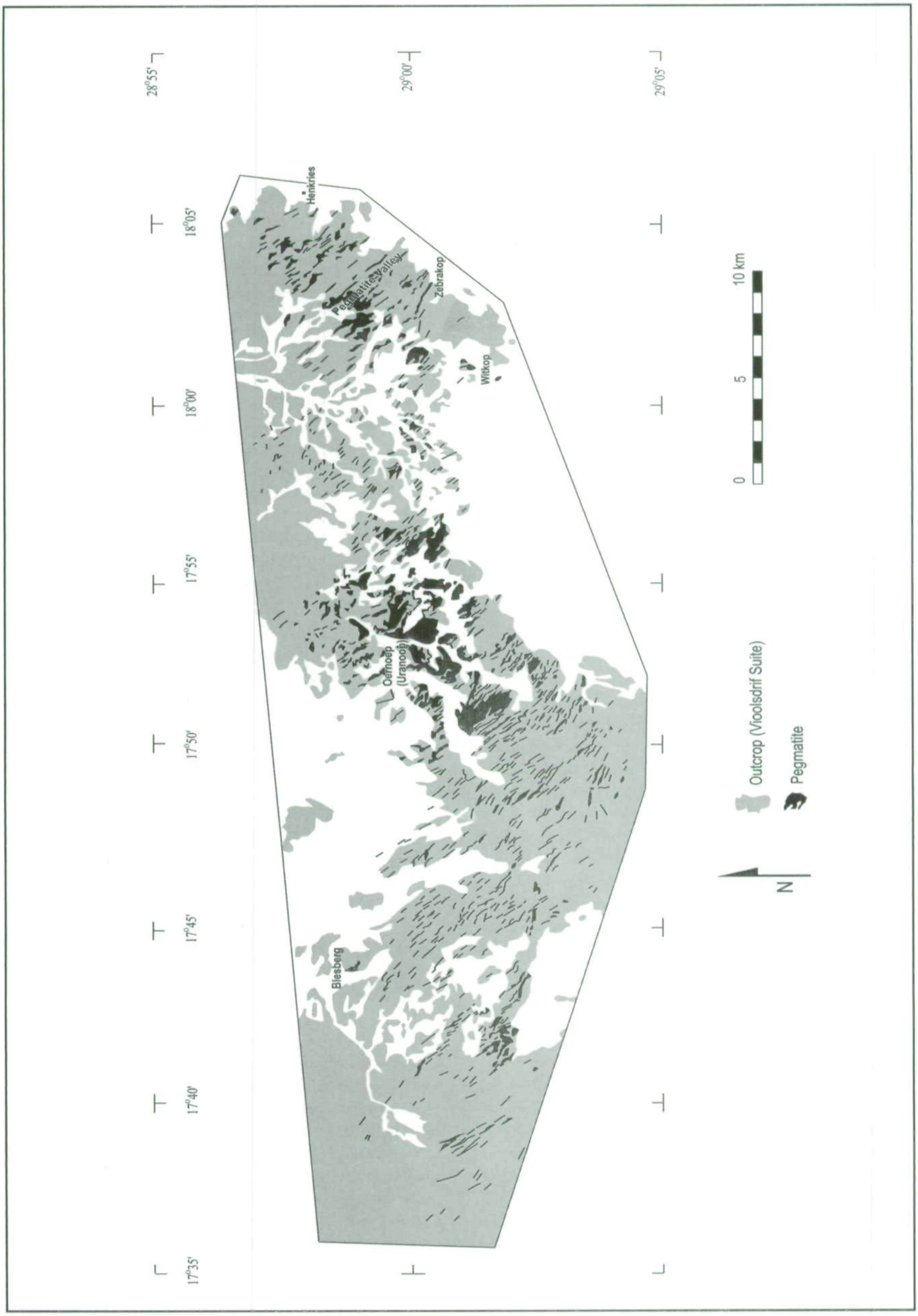

Figure 3. A delineated part of the study area showing pegmatite development (reduced from 1 : 20,000 scale).

Table 1. Chemical analyses for feldspar from Noumas I pegmatite (Blesberg Mine).

	1	2	3
Major elements (%)			
SiO_2	65.87	65.96	63.70
TiO_2	<0.02	<0.02	0.02
Al_2O_3	18.58	18.53	18.96
Fe_2O_3 (t)	0.26	0.29	0.02
MnO	<0.02	<0.02	0.00
MgO	<0.02	<0.02	0.00
CaO	0.1	0.11	0.00
Na_2O	1.86	1.97	2.43
K_2O	12.89	12.68	12.65
P_2O_5	0.27	0.24	0.46
Cr_2O_3	<0.02	<0.02	0.00
LOI	0.01	<0.02	0.24
Total	99.83	99.77	98.49
Trace elements (ppm)			
As	<10	<10	3
Ba	60	68	90
Ce	<5	<5	5
Co	<5	6	37
Cr	7	41	11
Cu	21	18	12
Ga	20	17	18
Mo	<2	3	1
Nb	<2	<2	5
Ni	16	11	25
Pb	25	27	3
Rb	4201	2531	9786
Sc	<3	<3	1
Sr	14	25	67
Th	<5	<5	63
U	<3	<3	70
V	<5	<5	17
W	<3	<3	276
Y	10	5	3
Zn	3	<3	11
Zr	<5	<5	10

1 and 2 Council for Geoscience laboratories

3 University of Pretoria, Geology Department

The Vioolsdrif Suite intruded the ~2.0 Ga Orange River Group during the interval ~1.9 Ga (mafic members) to ~1.73 Ga (felsic members) (Reid, 1977). The Orange River Group is a succession dominated by volcanic rock types representing the extrusive component of the same magmatic event, giving rise to the Vioolsdrif Suite (Reid, 1977).

Two phases of pegmatite intrusion are recognised. The first of these have been dated at approximately ~1.0 Ga and a younger phase at ~950 Ma (Hugo, 1970). This means that the emplacement of the pegmatites followed the closing stages of the Namaqua orogeny, during which time east-west trending shear zones developed with predominantly sinistral displacement. These shear zones may have been responsible for the formation of the regionally northwest-striking extensional fractures controlling the emplacement of most of the pegmatites. These extensional fractures resemble those described for shear zone hosted gold deposits by Roberts (1998).

The source of the pegmatite-forming liquids is problematic. The age difference between the last phases of the Vioolsdrif Suite (~1.73 Ga) and the formation of the pegmatites (~1.0 Ga) makes it highly unlikely that the magmas of this suite provided the pegmatite-forming liquids, unless the ages are in error. However, ages for the Vioolsdrif Suite have been tested thoroughly subsequent to the study of Reid (1977) and are widely accepted. Cerny (1998a) points out that radiogenic isotope systems in granitic pegmatites are notorious for being disturbed, particularly in geologically old localities. However, field observations show no influence from the Namaqua orogeny on the pegmatites, supporting the post-orogenic formation age, *i.e.* younger than ~1.0 Ga. One possible alternative is that the pegmatite-forming liquids were derived from younger plutonic granitic intrusions, which are currently largely situated in depth, beneath the surface. One such younger intrusion may be represented by the peraluminous, garnet-bearing Wyepoort Granite (Theart, 1980) of which a small body is exposed within the study area, in the transitional zone between the Bushmanland Subprovince and the Richtersveld Subprovince. This possibility highlights the need for dating the Wyepoort Granite. However, this does not provide a solution for the regional distribution of the entire Northern Cape pegmatite belt.

An important observation to take into consideration is the fact that the Northern Cape pegmatite belt, although sharing a common age of formation, straddles a wide variety of rock units, differing vastly in ages, and various tectonic terrains differing in structural fabric. The belt may in fact be considered as a "stitching" event providing an approximation for the age of the finalization of the accretionary processes in the Namaqua Province. The fact that most of the pegmatites represent exterior bodies, of which the pegmatite-forming liquid was transported from its source granite to its place of intrusion, complicates the identification of their source granites. The common age implies a common source, or at least contemporary sources, for all the pegmatites in the belt. This calls for a rather extensive geochronological study of all granitic suites associated with the belt.

Lastly it should be noted that certain field observations speak clearly in favour of a metamorphic origin for at least some of the pegmatites especially the much smaller ptygmatic pegmatite veins in the foliated gneisses of the Bushmanland Subprovince. The more important of these observations are gradational contacts between the pegmatite and the host rock, and certain primary textures in the host rock, which are preserved in the pegmatite. Hugo (1970) associated the larger homogeneous pegmatites with formation through

Table 2. Costs for the acquisition of machinery.

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 truck)	2	150,000	300,000
Jackhammers	4	2,000	8,000
Total	2,571,000		

Notes: * Second hand

Table 3. Costs for the erection of temporary offices and housing on the mine premises.

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

migmatization and partial melting under high-grade metamorphism, and the zoned pegmatites with granitic intrusions. More recent investigations have ruled out a metamorphic origin for these larger rare element bearing granitic pegmatites (Cherny 1998a).

Resources and markets

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. Although some of the investigated pegmatites fall outside of the area, it does incorporate by far the majority of pegmatites in the study area and also comprise the part in which the concentration of pegmatites is the highest. The most prominent pegmatite bodies in this area were delineated on aerial photographs of 1 : 20,000 scale (Figure 3).

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 dimensions it was assumed that the body retains its shape in depth and its extension is taken as equal to the width. The specific gravity of pegmatite is taken as 2.60, determined on the basis of a ration 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.

It is estimated that the larger pegmatite bodies in the study area host a global resource of approximately 50 million tons of pegmatite ore containing 60% feldspar, belonging to a resource category referred to as resources of undetermined economic significance. The term global is used here to indicate that this estimate apply to the entire area considered and not to any smaller part of the area. This corresponds to a global resource of 30 million ton feldspar contained in both the homogeneous and zoned pegmatites.

The effectiveness of this method should be considered bearing the following in mind:

a. No distinction is made between zoned and homogeneous pegmatites. Exploitation of the homogeneous pegmatites will inevitably necessitate the introduction of bulk mining methods, the erection of a beneficiation plant, and expansion to the international market, as the current South African domestic feldspar consuming markets do not justify such developments.

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: * For a mine like Blesberg the amount related to a *mining right* could be anything between R 500,000 to R 1 million.

Table 5. Operating costs for the envisaged operation.

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, hydraulic 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.

b. The highly irregular shapes of pegmatite bodies, 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 feldspar, all require more attention. These factors have implications on the volumes, metallurgical processes and acceptibility to the market and as such, on the mineability of individual bodies.
c. Only the most prominent exposed bodies on the aerial photographs that were used, were included and the resultant Figure 3 should therefore not be seen as an accurate indication of the ratio of pegmatite: wall rock in the area. Various factors play a role in the prominence of the bodies on the aerial photographs, most notably the size of the body, the colour contrast between the body and its wall rock (leucocratic wall rock such as the acid granitoids render the pegmatite less prominent than mesocratic wall rock such as intermediate granitoids), and the brightness of the photograph itself.

Nevertheless, from Figure 3 a number of ore blocks were identified. It is quite clear that the greatest development of pegmatite is in the areas around Oernoep and the Pegmatite Valley near Henkries. If some of the larger bodies are considered, it is evident that pegmatite bodies of up to 50 million tons can be delineated for individual deposits.

Feldspar currently forms the basis of all pegmatite-mining operations. The two regions in South Africa where pegmatite-mining operations are conducted are the Northern Cape pegmatite belt and the Limpopo pegmatite field. These operations are of relatively small scale and mostly sporadic in nature. Feldspar is consumed in the glass and ceramic industries of South Africa. Both these industries are currently being supplied by the pegmatite operations, as well as from the Franspoort alkaline Complex at the Mamelodi Quarries, where feldspar is produced from syenite. No feldspar from pegmatites is currently being exported. The South African glass and ceramics industries are relatively small. Average production at Blesberg is 1,300 ton per month and is limited by demand from the markets. The scope for pegmatite mining in South Africa is therefore limited by the capacity of the local consuming industries and calls for value addition to the raw product in order to make it more attractive to the export market. The South African industries are, however, growing along with the country's economy and a steady increase in demand is expected.

Three recent chemical analyses are available for feldspar from Blesberg Mine (Noumas I pegmatite) (Table 1). This material meets the standards of both the local glass and ceramic industries. Feldspar from the study area is in good repute with these industries as it is relatively free of impurities such as iron. Prices for

Table 6. Internal Rate of return and Net Present value at different discount rates.

IRR:	26.07%	
	Discount Rate	
NPV:	11%	R 6,490,073.95
	15%	R 3,829,014.47
	20%	R 1,641,044.48

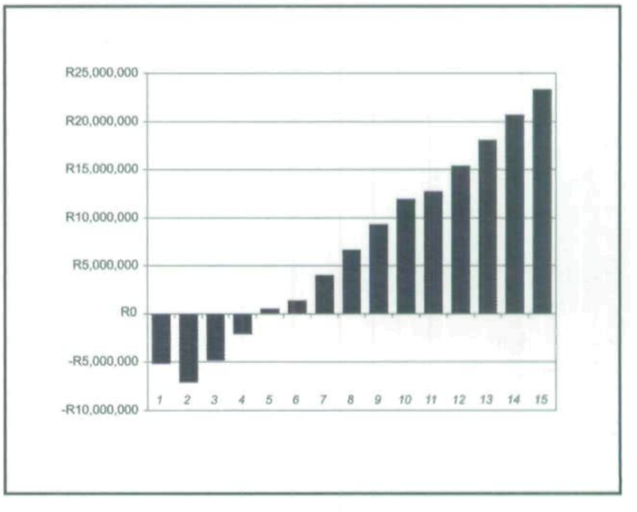

Figure 4. Cumulative cash flow in Rand, derived from the discounted cash flow model for the base case scenario of the pegmatite project with a fifteen year life of mine.

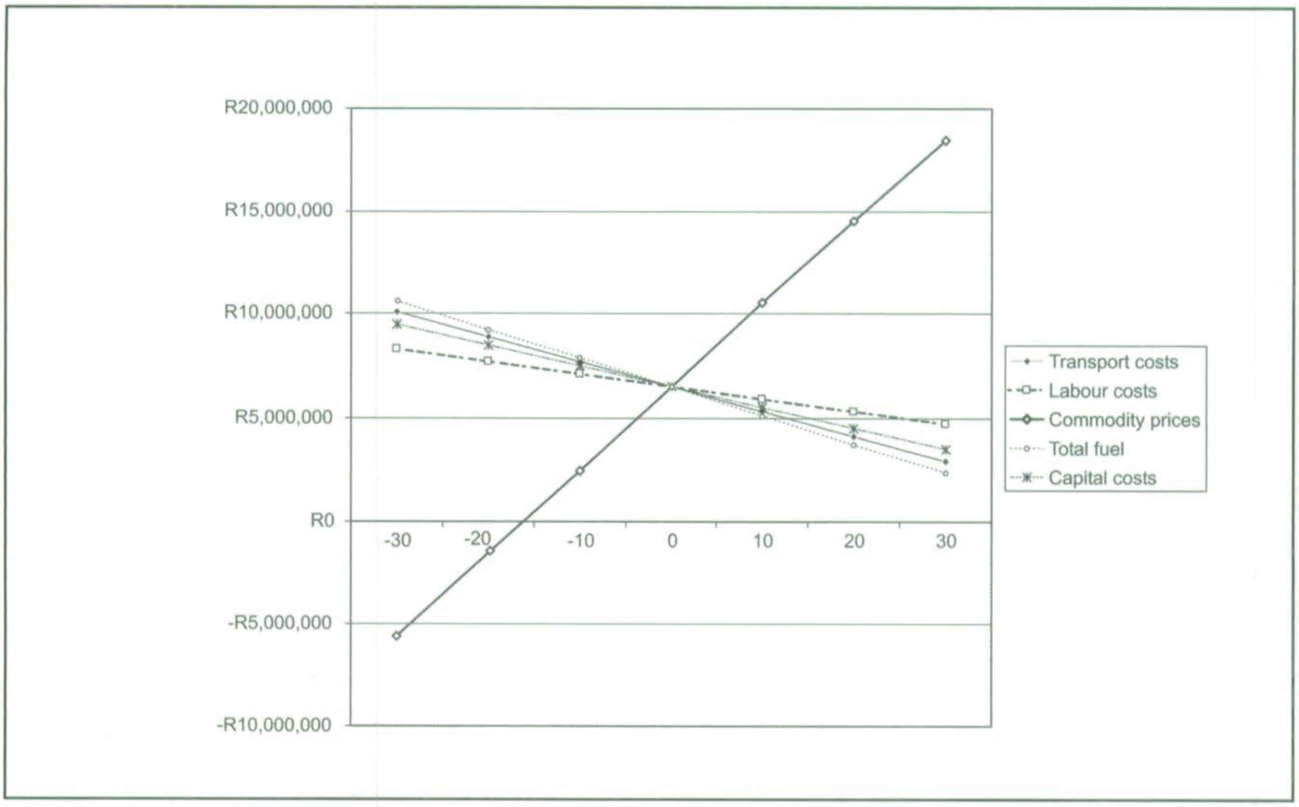

Figure 5. Results of a sensitivity analysis of the envisaged project.

feldspar on the local markets have risen sharply over recent years (R 390 / t in 2002 to R 580 / t in 2005). Export opportunities at higher prices exist for milled ($ 150 / t) and micronised ($ 200 / t) ceramic grade feldspar. These prices are much more stable than the local markets and have remained constant over the past five years.

Financial analysis

The financial analysis presented here is based on the existing operation at the Blesberg Mine (June to December 2004). Financial data needed for the analysis include initial costs, operating costs, supply, demand, production figures, costs related to licensing and exploration, *etc*. The mine manager of Blesberg, the Department of Minerals and Energy, and various industries generously provided these figures.

Initial costs related to the envisaged mining operation are summarized in Tables 2, 3 and 4.

The initial capital requirement thus totals R 3,801,500.

Operating costs related to the envisaged operation are summarized in Table 5.

The operating costs for the envisaged operation are estimated to total R 4,680,000 / year.

A hypothetical production rate of 1,300 t / month of feldspar is selected, based on the precedence at the Blesberg operation. It is assumed that this relatively low production rate would not have a negative impact on the local market conditions, as it can potentially be absorbed by a growing industry. Furthermore this mining rate is appropriate for extraction by handpicking, a practice that would result in maximum job creation. Job creation would attract favourable incentives from the local and national authorities. This aspect would need to be revisited if a larger production rate, geared for the export market, is envisaged.

The last published local price for feldspar is R580 for 2004 (Agnello *et al.*, 2006). Notwithstanding an expectation that the feldspar price would steadily rise in future borne out by discussions with some of the principal local buyers (messrs. P. Durrheim and J. Polasek, personal communication, 2006) it was decided that the financially prudent approach would be to fix the revenue at R 550 / t in the DCF model.

All the feldspar from the study area is currently consumed in the South African ceramics and glass industries. Feldspar is currently being produced in South Africa from the Northern Cape and Gravelotte – Mica pegmatite field (Boelema, 1998). Information provided in the latest figures from the DME (South African Minerals Industry 2004 to 2005) indicate that South African production and sale of feldspar has shown a steady decline from 68.1kt in 1997 to only 53.0 kt in 2004 (Agnello *et al.*, 2006), this is not as result of a shrinking local demand, but indicative of a decline in South African production, with mines coming to the end of their reserves and closing, combined with the strength of the local currency, which affected the export market negatively. In fact, the local glass industry is currently committed to expansions that would double local production capacity as result of a phenomenal growth in the local demand (messrs. P. Durrheim and J. Polasek, personal communication, 2006).It is expected that the ceramic industry are experiencing the same growth.

The high-volume-low-value nature of the commodity and the threat of substitution are the two most important factors that enhance the risk associated with the mining of industrial minerals (Horn, 1994). In addition, further risk elements are related to increases in capital costs (such as rising legislative costs), rising operating costs (especially transport and labour), a market risk (changes in commodity prices) and a marketing risk (changes in revenue). Included in this is the risk of rising fuel prices (the sum of operating fuel consumption and transport). Off-take agreements regarding the feldspar product could be considered to ameliorate some of these risk elements.

The discounted cash flow model for the envisaged operation at a base case discount rate of 11% is shown in Table 6. The discount rate of the base case is based on an estimated project risk factor of 3% (as the project is considered to represent a relatively low risk venture) added to the overall financial risk factor of 8 % (based on current government bond rates). The influence of higher risk factors on the net present value (NPV) is also shown in Table 6 (discount rates of 15% and 20% were selected for this purpose).

The project (base case) has an internal rate of return (IRR) of 26.07%, which is significantly higher than the estimated cost of capital (11%). The NPV at the discount rate of 11% is approximately R 6,500,000. At a discount rate of 15% the NPV is approximately R 3,800,000 and at 20%, it is about R 1,600,000. The cumulative cash flow for the project at the base case discount rate of 11% over a 15-year life of mine is shown in Figure 4. Payback is achieved at the end of year four, with the maximum debt reaching R 7 million.

Figure 5 shows the sensitivity of the project (base case) to variation in capital costs, transport costs, labour costs, commodity prices, revenue, and total fuel prices as indicators. Commodity prices and revenue are closely related as revenue for the envisaged project is derived solely from the sales of feldspar. The project is most sensitive to these two factors and would fail if the average commodity price achieved over the life of mine fall by more than 15%. The project is much less sensitive to the other factors investigated.

Recommendations

This study is based on a financially prudent, but conservative approach, where the viability of a small operation is demonstrated. Such an operation would satisfy the need for the establishment of sustainable business enterprises in the small-scale mining sector in this area that would be particularly suitable to new entrants from the historically disadvantaged communities. As such, it addresses and meets the intention of the South African Minerals and Petroleum Resources Development Act, Act 28 of 2002 and would provide employment opportunities in a region where this is greatly needed. It should be stressed that this study is based on a realistic, but hypothetical, case at the pre-feasibility level of confidence, to demonstrate the presence of a feldspar resource in the area, belonging to the undetermined economic significance category, which may be included in the national minerals inventory. However, the study has also shown that there exists much greater potential for the exploitation of feldspar from the pegmatites of this area at a larger scale. It is therefore strongly recommended that funds be made available for further studies to demonstrate the financial viability of a larger operation in this area. Such a study would require additional information on aspects such as exploration, metallurgical test work and plant design, and a marketing study.

The objective of the additional geological exploration would be to upgrade the resource information from the inferred to the indicated and measured category with a carefully designed drilling and sampling programme. This information can then be used to generate estimates of the probable and proved reserves in terms of the SAMREC Code, a prerequisite for project funding. Metallurgical test work should be done to demonstrate, at pilot plant level, the ability to concentrate the feldspar from the homogeneous variety of pegmatites and to produce a product of consistent and high grade. Test work may also be done to determine the viability of extracting some of the other rarer mineral commodities. This aspect may however be delayed till after a feldspar-based operation has been successfully brought into production. The marketing study envisaged should investigate the suitability of the feldspar product for the export market, identify the most likely buyers, and predict realistic commodity price forecasts.

Conclusions

The pegmatite belt of the Northern Cape has not been properly investigated during the past three decades and many aspects related to a better understanding of the pegmatite geology and that of their potential source rocks are still lacking. The resources of industrial minerals in the Northern Cape are poorly defined and it is intended that this study on the pegmatites of the study area highlights the potential of this largely ignored driver for future development The Northern Cape however, is a vast stretch of country (the largest province in South Africa) and especially the western parts are rather isolated. Utilizing available information, the Zebrakop pegmatite locality (Figure 3) has been identified as the most suitable place to establish a new feldspar mining operation.

The sensitivity of industrial mineral mining operations to changes in commodity prices, revenue, transport and overall fuel prices, are confirmed by this study, but it has been demonstrated that such operations are not necessarily rendered unviable by these risks.

The area represents a definite target for a small-scale feldspar mining operation and offers potential for larger projects. The addition of value by purification and milling of the raw product, the recovery and utilization of by-products, and further penetration into export markets should be seriously considered.

Acknowledgements

The writers are grateful to Mr J. Gagiano, the mine manager at Blesberg Mine, who kindheartedly shared his extensive knowledge on pegmatite mining and also provided reliable operational cost data. We appreciate the comments by the two reviewers Jac Genis and Dick Minnett.

References

Agenbacht, A.L.D., Minnaar, H. And Wipplinger, P.E. (2003). An investigation of the Zebrakop pegmatite, Henkries area, Northern Cape, Project 5501. *Open file report, Council for Geoscience of South Africa*, **2004-0096**, 5pp.

Agnello, V.N., Naidoo, D., and Tshabalala N. (2006). Statistics for other industrial minerals. *In:* Robinson, I., N Van Averbeke, N., Harding, A .J., Duval J. A. G., Mwape P., and Perold J. W. (Editors). South Africa's mineral industry 2004/2006. *Director: Mineral Economics, Pretoria, South Africa*, 163-171.

Boelema R. (1998). Feldspar. In: Wilson M.G.C. and Anhaeuusser C.R. (Editors) The mineral resources of South Africa. *Handbook of the Council for Geoscience*, **16**. 267-268.

Cameron, E.N., Jahns, R.H., McNair, A. and Page, L.R. (1949). Internal structure of granitic pegmatites. *Economic Geology Monograph*, **2**, 115pp.

Cherny, P. (1990). Distribution, affiliation and derivation of rare- element granitic pegmatites in the Canadian Shield. *Geologische Rundschau*, **79**, 183-226.

Cerny, P. (1998a). Rare-element granitic pegmatites. Part I: Anatomy and internal evolution of pegmatite deposits. Ore Deposit Models V. II, *Geoscience Canada Reprint Series*, **6**, 29-47.

Cerny, P. (1998b). Rare-element granitic pegmatites. Part II: Regional to global environments and petrogenesis. Ore Deposit Models V. II, *Geoscience Canada Reprint Series*, **6**, 49-62.

Colliston, W.P. and Scoch, A. E. (2003). A mid-Proterozoic volcano-sedimentary sequence in the Aggeneys Hills Duplex, Namaqua Metamorphic Complex. *South Africa Journal of Geology*, **106**, 343-360.

Gevers, T.W., Partridge, F.C. and Joubert, G.K. (1937). The pegmatite area south of the Orange River in Namaqualand. *Memoir of the Geological Survey of South Africa*, **31**, 180pp.

Ginsburg, A.I. (1960) Specific geochemical features of the pegmatitic process. *International Geological Congress, 21st Session Norden, Report*, **17**, 111-121.

Ginsburg, A.I., Timofeyev, I.N. and Feldman, L.G. (1979). Principles of geology in the granitic pegmatites. *Nedra, Moscow*, 296 p. [In Russian]

Hansen, R.N., Minnaar, H. And Wipplinger, P. (2004). Geological report on mapping and sampling of Witkop pegmatite, Steinkopf. *Open file report, Council for Geoscience of South Africa*, **2004-0126,** 20pp.

Horn, G.F.J. (1994). Optimizing the exploration for and the exploitation of industrial mineral resources. *Fifteenth CMMI Congress, South African Institute of Mining and Metallurgy*, **3**, 215-224.

Hugo, P.J. (1970). The pegmatites of the Kenhardt and Gordonia districts, Cape Province. *Memoir of Geological Survey of South Africa*, **58**, 94pp.

JORC Code (1989). Australasian Code for Reporting of Mineral Resources and Ore Reserves (The JORC Code) Prepared by the Joint Ore Reserves Committee of The Australasian Institute of Mining and Metallurgy, *Australian Institute of Geoscientists and Minerals Council of Australia (JORC)*, http://www.jorc.org/main.php

Joubert, P. (1986). The Namaqualand Metamorphic Complex — A summary. *In:* C.R. Anhaeusser and S. Maske (Editors), Mineral Deposits of South Africa, *Geological Society of South Africa*, **2**, 1395-1420.

Kretz, R., Loop, J. and Hartree, R. (1989). Petrology and Li-Be-B geochemistry of muscovite-biotite granite and associated pegmatite near Yellowknife, Canada. *Contributions to Mineralogy and Petrology*, **102**, 174-190.

Kröner, A. and Blignault, H.J. (1976). Towards a definition of some tectonic and igneous provinces in western South Africa and southern South West Africa. *Transactions of the Geological Society of South Africa*, **79**, 232-238.

London, D. (2005). Granitic pegmatites: an assessment of current concepts and directions for the future. *Lithos*, **80**, 281-303.

McGill, J.E. and Theart, H.F.J. (2006). Technical risk assessment techniques and practice in Mineral Resource Management with special reference to the junior and small-scale mining sectors. *The South African Institute for Mining and Metallurgy Journal Transactions*, **106**, 561-568.

Melentyev, G.B. and Delitsyn, L.M. (1969). Problem of liquation in magma. *Academy of Sciences of the USSR, Doklady, Earth Sciences Series, American Geological Institute*, **186**, 215-217.

Minnaar, H. (2006). The exploitability of pegmatite deposits in the lower Orange River area (Vioolsdrif – Henkries – Steinkopf). *Unpublished MSc (Earth Science Practice and Management) thesis, University of Pretoria, Pretoria, South Africa*, 64pp.

Nikitin, V.D. (1957). Characteristics of rare-metal mineralization in pegmatite veins. *Zapski Vsesoyuznogo Mineralogicheskogo Obshtchestva*, **86**, 18-29. [In Russian]

Reid, D.L. (1977). Geochemistry of Precambrian igneous rocks in the lower Orange River region. *Bulletin of the Precambrian Research Unit, University of Cape Town, South Africa*, **22**, 397pp.

Roberts, R.G., (1998). Archean Lode Gold Deposits. *In:* Roberts R. G. and Sheahan P.A., (Editors) Ore deposit models. *Geological Association of Canada*, 1-19.

SAMREC Code (2000). South African code for reporting of mineral resources and mineral reserves (the SAMREC code). *Prepared by the South African Mineral Resources Committee (SAMREC) under the auspices of the South African Institute of Mining and Metallurgy*, 38pp. http://www.saimm.co.za/codes/samrec.asp

Schaller, W.T. (1925). The genesis of lithium pegmatites. *American Journal of Science, 5th Series*, **10**, 269-279.

Schutte, I.C. (1972). The main pegmatites of the area between Steinkopf, Vioolsdrif and Goodhouse. *Memoir of the Geological Survey of South Africa*, **60**, 19pp.

Theart, H.F.J. (1980). The geology of the Precambrian terrane in parts of western Namaqaland. *Bulletin of the Precambrian Research Unit, University of Cape Town, South Africa*, **30**, 103pp.

Editorial handling: J. M. Barton Jr.