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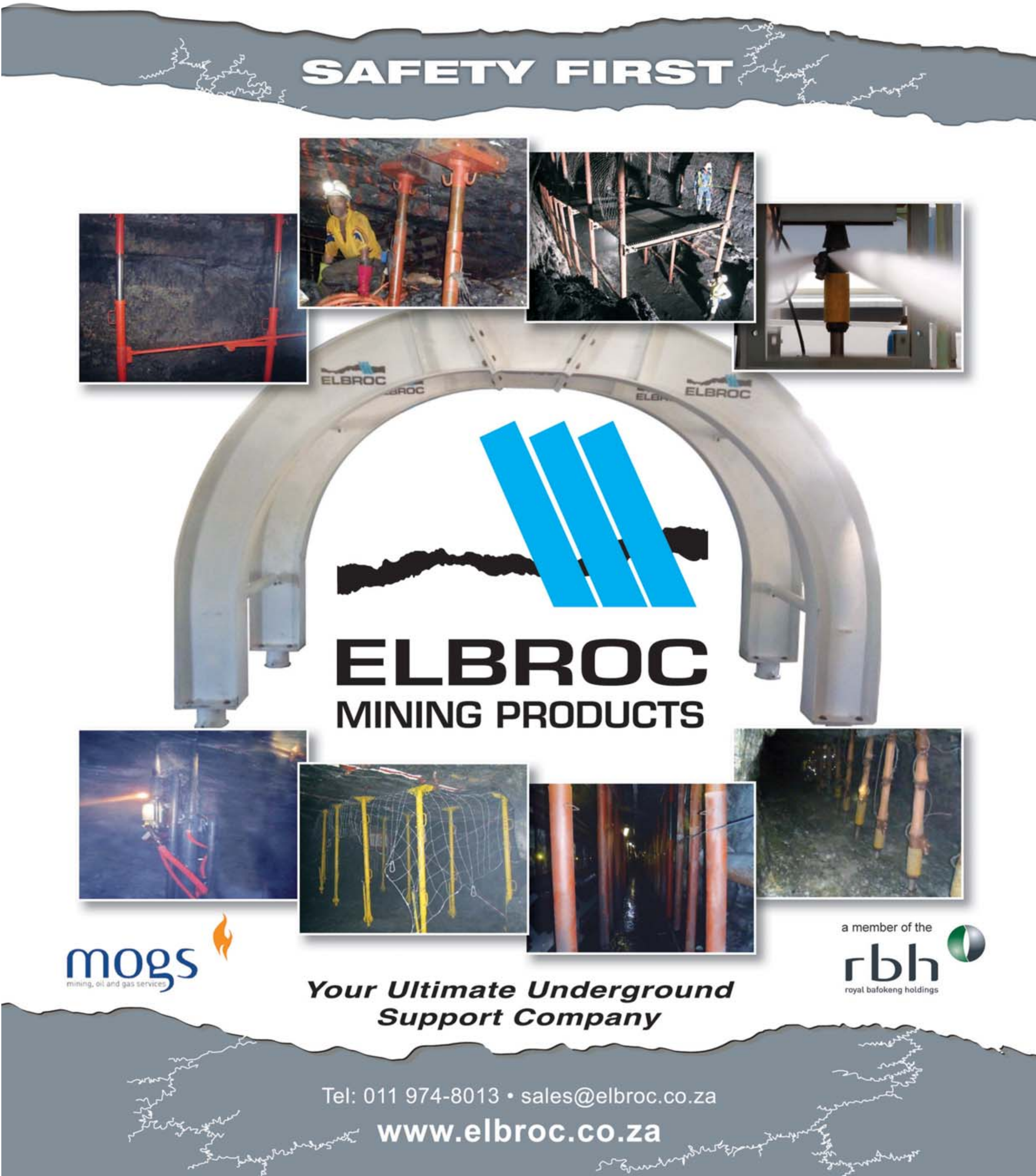

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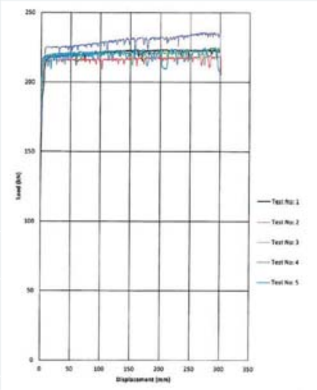

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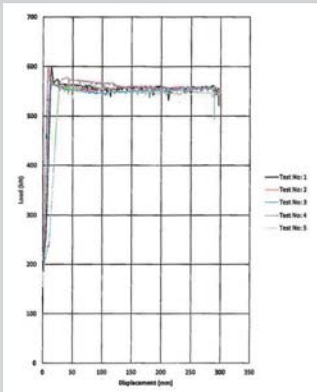
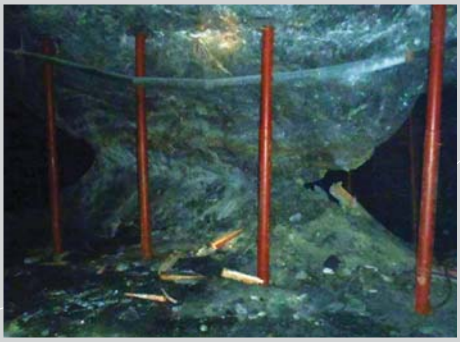


Omni 150 CSIR Graph
55 Ton Props



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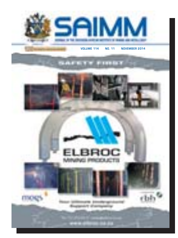

Journal Comment

The SAIMM held its first Mining, the Environment and Society conference in November 2013. The theme of this conference was 'Issues and Responses'. Over the two days, 21 papers highlighted the range of social and environmental issues associated with mining and how the sector is responding, or could respond, to them. A number of papers in this edition of the Journal have been selected from the conference.

The two papers on small-scale tiger's eye (Ledwaba) and marble mining and beneficiation (Mahumapelo and Magaseng) in the Northern Cape highlight how small-scale mining has the potential to make a significant contribution to poverty alleviation and local socio-economic development. However, this opportunity is hindered by the illegality of many operations, the lack of technical skills, and limited support for these miners. Similarly, across Africa, where artisanal and small-scale mining (ASM) provides a livelihood for millions of people, a lack of understanding and detailed information on this sector, together with the absence of a supportive legal framework, limits its contribution as discussed in the paper by Debrah *et al.* with reference to Ghana's and South Africa's ASM sectors. All three papers provide suggestions and recommendations for improving this situation so as to enable ASM to make a more significant contribution to sustainable development.

Perhaps the greatest environmental and social impacts of mining occur when a mine opens and closes, respectively. Building a mine requires the clearing of vegetation, extensive earthmoving, and the establishment of infrastructure. It is during this time that rare and endangered species may be threatened. The paper by Harris *et al.* documents the successful translocation of an endangered succulent ; an important mitigation option, especially where entire habitats are threatened. Communities may be economically devastated by the closure of a mine, especially in remote locations. Establishing a sustainable post-mining land use programme is therefore critical. From an environmental perspective the norm is to return the land to its pre-mining land cover. Apart from not always being possible, this may not always be a desirable outcome for the community. Limpitlaw and Briel's paper argues that some mining infrastructure has value, and re-using this may aid in mitigating the loss of mining employment.

There is an awareness among business in general, and mining in particular, of the importance of the 'triple bottom line' – people, planet, and the traditional focus on profit. In his paper Mostert develops a methodology to assist mining companies to make choices between different corporate social responsibility projects, using this approach. Stacey and Stacey investigate how the three elements of the triple bottom line rank among company directors, based on their research through the Institute of Directors of Southern Africa. As would be expected, financial capital is ranked most important, followed by social and then environmental issues. Although not surprising, this perspective is, however, short-sighted, especially when considered in the context of the South African mining sector. Recent research by Franks *et al.*[1] illustrates how social and environmental issues in the extractive sector can translate, through disputes, into business costs and reduced profit.

The research found that environmental issues were central to disputes with communities. These related to the pollution of, competition for, and access to natural resources. Disputes with communities resulted in lost productivity due to delays, the inability to pursue projects, and additional staff time needed to address disputes. The researchers cite an example of a major, world-class mining project with capital expenditure of US$3–5 billion suffering roughly US$20 million per week of delayed production, in net present value terms, as a result of community conflict. These findings highlight the significance of good environmental performance throughout the life cycle of a mine. They also underline the short-sightedness of directors who rank environmental issues last.

Conflict with communities threatens the social license to operate. The social license to operate refers to the tacit consent from local communities for mining companies to operate in an area. It is based on trust and acceptance, and has to be earned. Supporting the findings by Franks *et al.*, the recently released EY Business Risks Facing Mining and Metals 2014-2015 report include social licence as one of the top risks (no. 3) facing mining companies. The EY report also lists the sharing of benefits (no. 8), access to water and energy (no. 10), competing demands for land use (no. 15), and climate change concerns (no.16) as risks facing the industry. What is interesting is how the focus has shifted from how mining activities impact the environment and communities to how these issues constrain how and where mines operate. This calls for a different approach, and an objective of the second Mining, the Environment and Society conference is to re-invigorate the debate on this and consider ways of building resilient socio-ecological systems that include mining. The theme for the conference, which will take place on 12 and 13 May 2015 is 'Beyond Sustainability—Building Resilience'. Come and join the conversation!

[1]Franks, D.M., Davis, R., Bebbington, A.J., Alia, S.H., Kempa, D., and Scurrah, M. 2014. Conflict translates environmental and social risk into business costs. Proceedings of the National Academy of Sciences, vol. 111, no. 21. pp. 7576–7581.

I. Watson

ECSA, GDID, and UJ sign a Memorandum of Agreement

The Engineering Council of South Africa (ECSA), the Gauteng Department of Infrastructure Development (GDID), and the University of Johannesburg (UJ), have entered into a memorandum of understanding aimed at supporting and coaching engineering students at UJ who are recipients of the GDID bursaries.

This tripartite initiative follows GDID's recognition of the need to mentor first- and second-year students, the majority of whom fail to complete their qualifications as they are unprepared for the level of academic commitment required when studying engineering. This has been linked back to the need for stronger life-skills support, and ECSA, as the custodian of the engineering profession in South Africa, has designed the pilot model for the support of students in partnership with both the GDID and UJ.

Professor Angina Parekh, Deputy Academic Vice-Chancellor at UJ, emphasized that the likelihood of students remaining within a tertiary institution's system depends on their success during the first year of study. 'The UJ has introduced a national First Year Experience (FYE) programme, as a student's overall success is linked to how well they adjust academically and socially within the university environment,' she said. This FYE has increased the success rate for students to 83%.

The Honourable Nandi Mayathula-Khoza, Member of the Executive Council (MEC) of the GDID, lauded the partnership as marking an important milestone in addressing the broader needs of Gauteng Province. 'The GDID is committed to creating and sustaining partnerships with universities in the Province as it provides an opportunity to actively support first-year students through life-skills training, mentoring, and coaching in study techniques,' she said. The support for students from the GDID will extend to grade 10 learners, who, through Sci-Bono, will receive assistance in maths and science subjects.

Mr Cyril Gamede, President of ECSA, pointed out that this initiative will allow ECSA to play a significant role in social development in South Africa.

Mr Sipho Madonsela, CEO of ECSA, expanded on this theme by emphasizing that the launch marks a proudly South African moment, and that the 'Pipeline Model' utilized in this programme is based on the Thuthuka Model, which was founded by the South African Institute of Chartered Accountants (SAICA) and which has proven to be very effective.

The priority focus areas for ECSA are:

- Improving the 'talent pipeline' and talent schools feeding into the University of Johannesburg on a pilot project basis
- Improving the poor pass rates at undergraduate level among previously disadvantaged students
- Transforming the profession by delivering high-level engineering skills with a specific focus on previously disadvantaged engineering practitioners
- Facilitating mentorship for engineering graduates.

This partnership is a true demonstration of organizations that are aimed at addressing problems that are undeniably visible in the academic environment. As ECSA, we are obliged to go beyond the regulatory function and add value to the society' Gamede concluded.

The GDID will oversee the funding and sponsorship of this project, as well as the provision of bursaries and practical experience for the students, while the UJ will be responsible for providing a healthy learning environment for the bursary recipients and meeting facilities for the engineering students.

The MEC further gave her committment that the programme would later be extended to other universities in the province, namely the University of Pretoria and Wits University.

C. Mogoeng
On behalf of: T. Machimane

Committed to caring enough to make a difference

The University of the Witwatersrand

The University of the Witwatersrand has received a R12. 5 million donation from Sibanye Gold Limited towards mining and engineering education.

At a handover ceremony held on 25 July 2014 at the Sibanye Gold Academy on the West Rand, Professor Beatrys Lacquet, Deputy Vice-Chancellor: Knowledge, Information and Management at the University of the Witwatersrand, received the donation on behalf of the University from Sibanye Gold Chief Executive Officer Neal Froneman.

Said Lacquet: 'This generous donation provides the opportunity for Wits to offer additional student support with respect to needy and deserving students. It will also enable us to further progress our Digital Mine Research Project, while also affording us the much-needed funds to extend the laboratory facilities in the Richard Ward building for the chemical and metallurgical engineering students.'

'It is commendable to have a company like Sibanye Gold investing in our people, and this partnership will go a long way to assist us in moving forward as we continue to strive to support the South African mining industry in a meaningful way,' she said.

Speaking at the handover, Neal Froneman commented that Sibanye remains resolute that mining should benefit all stakeholders and create a legacy that can endure long after the existing mines have reached the end of their productive lives. 'Our dream is to facilitate the emergence of engineers from communities around our mines such as Bekkersadal, Khutsong, and Matjhabeng, because we know that education will not only give us future employees but will help us break the cycle of poverty and thereby eliminate all the social ills associated with it.'

Sibanye Gold has supported the University in various ways over a number of years. 'Wits is extremely grateful for the sustained contribution made by Sibanye Gold in enabling us to graduate students into the industry. We are committed to South Africa, the industry, and this partnership,' concluded Lacquet.

In the words of Nelson Mandela: 'Education is the most powerful weapon which you can use to change the world' ... one student at a time.

Seen at the handover ceremony were (left to right): Professor Beatrys Lacquet, Deputy Vice-Chancellor: Knowledge, Information and Management at the University of the Witwatersrand; Neal Froneman, CEO of Sibanye Gold; and Professor Fred Cawood, Head of the School of Mining Engineering, University of the Witwatersrand

President's Corner

In terms of the SAIMM Charter and in order to fulfill its obligations to the various communities making up the broader SAIMM membership, the Institute has established, over a long period of time, a series of portfolios and sub-committees. One of these portfolios is Career Guidance, executed through the very successful Career Guidance and Education Committee. Starting some six years ago, various initiatives were taken to develop this portfolio to focus more closely on how to encourage the younger SAIMM members to become more involved in SAIMM activities. The Young Professionals Conference held in March of this year provided an excellent example of some of our younger members in the Technical Programme Committees taking ownership of the event.

More recently, in the annual strategy review session, office bearers and Council members of the Institute have been considering issues relating to demographics and the longer term development of capacity and succession within the SAIMM – especially within the context of southern Africa. In this regard it was decided that the concept of a 'Youth Council' should be explored, with a clear objective of proposing structures within the SAIMM that would establish a more formal representation and role of young professional people within the Institute.

On 3 October 2014 I was invited to attend the second workshop of the Youth Council, held at the Ditsong Military Museum in Johannesburg. I ended up staying much longer than anticipated, as I was drawn in to the enthusiastic discussion and was caught up in the spirit and excitement of the process. There was a real sense that something new was being created, and this was summed up in the consensus statement that: 'they want to be considered as young professionals, not youth'.

The Young Professionals Council (YPC) of the SAIMM is made up of energetic and immensely enthusiastic young professionals willing and looking forward to participate in this initiative to provide active leadership and bring about positive influence in the mining industry – not only in South Africa, but also in the SADC region.

They want to be involved in creating awareness, influencing key legislation and professional and regulating entities, identifying and nurturing promising and talented individuals, and encouraging the development of coaching and mentoring systems in the mining and metallurgical industry.

In summing up the workshop, Office Bearer Portfolio holder Professor Sehliselo Ndlovu says:

> '*They see the challenges more clearly than we ever did, and most of them are quite eager and looking forward to coming up with potential solutions; they clearly have quite a few ideas on what can be done better*.'

It is envisaged that the YPC will be fundamental in the development of new leadership in terms of succession planning. There will be mirror roles in the YPC of the portfolios held in the SAIMM Council such as Treasurer, Interest of Members, etc. Some members of the YPC have already identified the portfolios that they want to be involved in, showing their eagerness to be involved. They do not want this to be considered as an elitist initiative, but a council that will represent the needs of everyone involved in the mining and metallurgical industry, from school through university up to the young professional level.

To date there has been overwhelming support for this initiative from most of the host companies/ employers of these young Council members. I would personally like to thank those companies that allowed their young professionals to attend the workshops. This initiative is developing capacity and potential not only for the SAIMM, but also for the employer companies. Involvement in voluntary organizations is an important part of building leadership skills.

The interim YPC members are currently developing the necessary documentation to be tabled to the SAIMM Council for approval. Thereafter, the members of the YPC will be elected through a process administered by the SAIMM office.

It has been a great privilege to see this initiative develop. It is embryonic and will still require mentorship from key members of Council – how important it is going to be for our future that this bright new flame is kept burning.

J.L. Porter
President, SAIMM

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These papers have been refereed and edited according to internationally accepted standards and are accredited for rating purposes by the South African Department of Higher Education and Training

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Tiger's eye in the Northern Cape Province – potential for employment creation and poverty alleviation

by P.F. Ledwaba*

Synopsis

South Africa's Northern Cape Province houses a variety of gemstone minerals. Diamonds remain the primary gemstone in the province, but there are also tiger's eye, sugilite, rose quartz, jasper, amethyst, amazonite, tourmaline, and topaz deposits. This paper gives an overview of the tiger's eye (TE) mining sector in the Northern Cape, with the objective of assessing the potential of TE to contribute to job creation and poverty alleviation in the province. Mining of TE started in 1803, but gained momentum during the 1960s. Mining is conducted on a small-scale basis, and in most cases without any legal framework. The majority of the residents are not benefiting from TE. It has been reported that an estimated R700 000 to R800 000 worth of TE is leaving the country every week through illegal trading. The potential for TE mining to contribute to socio-economic development is hindered by illegal operations, lack of technical skills and knowledge, exploitation by dealers, lack of market information, community rivalries, and absence of value addition. A multi-stakeholder approach is needed to formalize the sector and reap the benefits. Mintek is spearheading a TE project in the Prieska area of the Northern Cape, which aims to establish a gemmological centre where TE can be beneficiated into saleable and high-value products..

Keywords
Northern Cape, small-scale mining, tiger's eye, socio-economic development, multi-stakeholder approach

Introduction

South Africa is well endowed with mineral resources. The country's mineral endowment includes precious metals and minerals, energy minerals, non-ferrous metals and minerals, ferrous minerals, industrial minerals, and semi-precious minerals, with a total estimated worth of 2.5 trillion US dollars (Department of Mineral Resources, 2011). Semi-precious minerals have been neglected because of their low economic value compared to the traditional gold and diamonds. Semi-precious minerals are also referred to as gemstones. The UN Standard International Classification System defines gemstones as 'all precious and semi-precious stones (whether or not they have been worked or graded) excluding: all categories of diamonds, all precious stones composed of non-minerals and all precious stones made of synthetic or reconstructed material' (Cross, Van der Wal, and De Haan, 2010). Examples of gemstones include (but are not limited to) tiger's eye, sugilite, rose quartz, jasper, amethyst, amazonite, tourmaline, and topaz. This paper focuses specifically on tiger's eye (TE).

The Northern Cape Province houses significant TE resources, which are among the few in the world with economic potential. TE mining in the province started as early as 1803 (Loo, 1998), and has been conducted since then on a small-scale basis. The small-scale mining (SSM) sector in South Africa has been identified as having potential to address triple developmental challenges, namely job creation, poverty alleviation, and inequality reduction. The sector provides a platform for the historically disadvantaged South Africans (HDSAs) to participate in and benefit from the minerals and mining industry. The objective of this paper is to assess the potential of TE to contribute to job creation and poverty alleviation in the province. This is done by assessing the mine value chain of TE and hence identifying challenges and opportunities present in the sector.

Study area

TE deposits occur in the banded iron formations in the Northern Cape Province. Significant deposits are located in the Niekerkshoop, Prieska, Griekwastad, and Hay areas of the province (Northern Cape Province Mineral Sector Strategy, 2004), and there are extensive mining activities in the Prieska and Niekerkshoop areas. Most miners are dependent on mining for their livelihoods.

* *Small-Scale Mining and Beneficiation Division, Mintek.*

Tiger's eye in the Northern Cape Province

Overview of the TE sector

TE is a form of asbestos that has been silicified by iron-bearing quartz, leaving the fibrous appearance intact. The attractive cat's eye effect, called the chatoyant effect or chatoyancy, is caused by the reflection of lightfrom the fibres. TE comes in a variety of colours, which depend on slight differences in the oxidation state of the iron (Rocksandminerals4u, n.d.). The common colours include gold, yellow, and brown; red and blue/grey are rarer. Figure 1 shows a TE sample from Prieska.

Mining of TE

TE is mined on a small scale using rudimentary tools to extract and dress the stone. The process involves the removal of the overburden to expose the TE, which is hosted in the banded ironstone, also referred to as 'dead stones' by the miners. In areas where the host rocks are too hard to remove, miners burn wood and old tyres on top of the rock mass to crack the rocks. This allows the TE to be extracted using chisels and hammers. Some miners make use of hydraulic jacks to separate the rocks. Mining is done haphazardly using trial-and-error methods. The miners use colour to prospect and identify mining sites. Once the TE is removed, it is sent for dressing. This is usually conducted by women as it is less labour-intensive than the mining. Dressing involves the removal of the 'dead stone' from the TE.

TE mining in the Northern Cape occurs on both communal land and private farms. Communal land in the Prieska and Niekerkshoop districts covers an area of approximately 32 000 hectares, with private farms occupying about 5 000 hectares (Basson, 2013). Mining on communal land is not regulated, and most miners continue to operate without any legal framework. The Department of Mineral Resources (DMR) has records of 15 mining permits, all of which are located on private farms (Mahala, 2012). There appear to be over 100 miners exploiting TE on communal land. It is difficult to quantify the number of unlicensed operations, because most miners work as individuals, although some have formed groups. Moreover, the numbers fluctuate from time to time because anyone seems to be able to enter the area and mine.

Value addition

South Africa had a local TE processing industry prior to 1996. In 1971, the government introduced the Tiger's Eye Control Act, which banned the export of unprocessed TE. The objective of the export restriction was to develop the stone cutting and polishing industry and hence increase the country's benefits from TE. Unfortunately, the provision was not able to deliver on the set objectives. According to Loo (1998), it gave rise to illegal mining and illegal trading. This led to the closure of the TE processing facilities. Local manufacturers decreased from 15 in 1990 to 5 in 1995. At present all known manufacturers have closed down (Loo, 1998). The export of raw TE is still banned. However, due to the lack of government capacity to enforce the ban, raw TE continues to be exported.

TE grades and pricing

The miners produce six grades of TE: grade A, grade B, grade C, grade X, variegated, and blue. The thickness of the seam (or 'reef') and chatoyancy are used to grade the stones (Cornelissen, 2013). The different grades are shown in Table I. The prices are those paid to the miners by the dealers.

Grade A is high-quality stone. Stones with thickness of 15 mm or greater are graded A. The price for grade A material ranges from R10.00 to R18.00 per kilogram. The price is usually dictated by the buyers and because TE mining

Table I

Tiger's eye grades and selling prices

Tiger's eye type	Yellow TE	
Quality/grade	Seam thickness	Price per kilogram*
AT (A – Top)	+54 mm	R18.00
A medium	32 – 54mm	R16.00
A3	+35 mm	R14.00
A2	25 – 32 mm	R12.00
A (plain A)	15 – 25 mm	R10.00
B	Price varies by thickness	R6.00
X	Any thickness	R0.50–R1.00

* Prices are indicative only, and vary between buyers

Figure 1—Tiger's eye sample from Prieska, Northern Cape

is poverty-driven, it constitutes a 'buyer's market'. Grade X is the lowest quality. It contains inclusions which are often regarded as 'dead stones', and sells for between R0.50 and R 1.00 per kilogram.

Table II summarizes selling prices for variegated and blue TE. Variegate is TE with two colours, usually a mixture of yellow and blue. It sells for R2.50 to R3.00 per kilogram.

There is no conclusive information on TE export prices. A study conducted by the Northern Cape Provincial Government (2004) reported TE export prices in the range US$0.50 to US$12 per kilogram, depending on the quality of the stone.

Supply and demand

There are currently no production figures available for TE. Production figures were last recorded in 1996 by the Minerals Bureau. Daily production is dependent on the areas being mined and the number of miners working together. It is difficult to estimate production rates because some miners work in groups and some as individuals. However, most of the miners sell their stone to one buyer/dealer. It is reported that at least two to three containers leave Prieska every week. A container can take approximately 420 bags, each weighing 50 kg. This equates to 21 t per container. If three containers leave the area weekly, then monthly production will amount to 252 t. (Please note that this calculation is not conclusive: it was informed by the data obtained from the miners during field work.)

The containers are transported to Cape Town for export. There is very limited information on the TE export market. However, literature reports that main markets are the USA, Japan, and China, with China constituting the largest share of the market. The local market is small, almost non-existent.

Table II

Selling price for variegated and blue TE

Tiger's eye type	Blue TE	
Quality/grade	Seam thickness	Price per kilogram
Medium	30–40 mm	R 9.50
B	30 mm	R4.50–R5.50
Variegated TE		
Any grade	Any thickness	R2.50–R3.00

TE is widely used in ornamental jewellery. It is also used to make pendants, beads for jewellery, and other small items.

Market structure

Figure 2 illustrates the market structure of the TE industry in Prieska.

The miners sell their stones to the primary dealers. A dealer is defined as a person or a firm that is involved in the buying and selling. There are two dealers operating in the Prieska; that is the primary and secondary dealers. The primary dealer buys directly from the miners, and the secondary dealer is the gateway to the export market. Secondary dealers have knowledge of the export market.

Legislation governing the TE industry

Tiger's eye mining in South Africa started as early as 1803. During the 1960s, mining activities increased considerably. This led to the introduction of the Tiger's Eye Control Act of 1977, which banned the export of unprocessed TE. This was done to develop the local cutting industry and hence increase jobs and government revenue. However, because of inadequate capacity (infrastructure, skills, high cost of consumables, access to markets etc.), many processing factories closed. This resulted in the smuggling and illegal selling of TE. To date, the government has not been able to control illegal trading of unprocessed TE.

In 1994, after the major political change in South frica, the new government rationalized minerals and energy legislation. Past laws were reviewed and Tiger's Eye Control Act was repealed and replaced by the Minerals Act (Act 50 of 1991). This in turn was later replaced by the Mineral and Petroleum Resources Development Act (MPRDA) in 2004, which currently governs all mining activities, including TE. There are no special provisions for TE mining and benefi-ciation in the MPRDA. However, the MPRDA supports the development of a mineral beneficiation industry in the country (Government Gazette, 2002). Mineral-rich countries are prioritizing value addition and are looking at different mechanisms to develop mineral beneficiation industries. South Africa has placed export restrictions on several minerals, including TE, under the International Trade Administration Act No. 71 of 2002 (Government Gazette, 2003). According to the Act; 'Tiger's eye shall not be

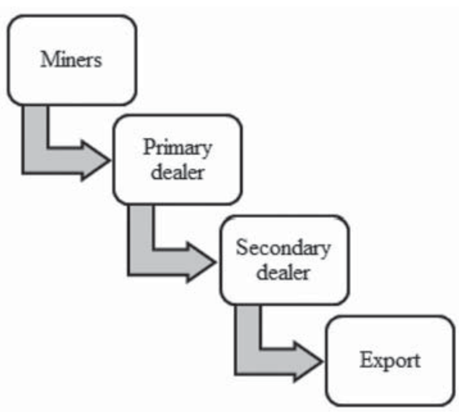

Figure 2—Tiger's eye market structure

exported from the Republic of South Africa, except by virtue of an export permit issued in terms of Section 6 of the Act'. TE is defined in the Act as follows: '*Tiger's eye including its related varieties and also any articles consisting wholly or partly of tiger's eye or its related varieties but excluding properly finished and finally and completely polished cabochons, beads, eggs, spheres, tumbled stone and carvings cut there from or otherwise processed or tumbled*' (Government Gazette, 2012).

Other legislations governing mining activities include the National Environmental Management Act, National Water Act, Mine Health and Safety Act, National Heritage Resource Act, Waste Act, Biodiversity Act, and Air Quality Act. At present, none of the applicable legislations are followed and adhered to in the TE sector.

Potential of TE sector

The TE resources of the Northern Cape Province are among the few in the world with economic value. There are currently no resource estimations, although it is reported that there still exist large deposit of TE. An estimated 37 000 hectares of land in Prieska and Niekerkshoop holds significant TE deposits. The depth of TE mining is limited by the mining methods, which involve the use of primary tools to remove TE from the ground. Hence there may still significant TE resources at greater depths.

Mining of TE is relatively a simple process, and does not require expensive equipment. At present, the industry employs over 100 miners. A substantial number of these are women and youths. However, because the miners are being exploited, mining has little visible impact in their lives. They are mining for day-to-day survival. The main hurdle in the sector is the lack of supervision and action by government to enforce legislation. The DMR is currently assisting miners in Prieska to obtain a mining license. This is a positive step towards addressing the ills in the sector.

Mineral beneficiation has been identified as one of the drivers for job creation. Jewellery fabrication has been earmarked as one of the strategic value chains in South Africa's beneficiation strategy, which proposes the establishment of integrated jewellery hubs across the country (Department of Mineral Resources (2011). The current focus is on gold and platinum. However, there are notable interventions directed to other minerals used in jewellery manufacture, such as semi-precious minerals. The establishment of a TE beneficiation centre will generate additional jobs.

Profitability

TE miners are not making significant amounts of money. The returns from mining range from R500 to R1500 per week, depending mainly on production rates and the quality of the stone. Typical weekly production varies from 50 kg to 100 kg. This applies to miners who work in groups (usually a group of four or five). Miners who work as individuals produce less and hence make very little money. However, it has been reported that significant amounts of TE leave the country every week. The local market is controlled by a few individuals who have export connections. The value of the industry is currently unknown. However, an estimated R700 000 to R 800 000 worth of TE is reported to leave the country every week through smuggling (Spicer, 2003). If that is the case, then the total value of TE leaving South Africa per month is over R3 million. These figures indicate that there is a substantial market for TE, which South Africa is not benefiting from.

Marketability

The issue of marketability is linked to long-term sustainability. Marketability remains a gap in the sector. Current demand is dominated by the international market. Local interest is not established. TE should be marketed both locally and internationally to build a solid market. TE is rarer than most semi-precious stones, and is among the gemstones that are regarded as attractive, owing to its unique chatoyancy and lustre. Marketability is affected by the issues of illegal mining and smuggling. The miners allege that the TE that is exported from the country is stockpiled overseas, although this has neither been proved nor disproved. However, if this is the case, it will impact on the TE marketability, and could place the country's comparative advantage at a risk.

SWOT analysis

Table III summarizes the strengths, weaknesses, opportunities, and threats of the TE sector.

There are a number of issues in the TE sector. However, the key issues that need the most attention are: (1) government capacity (2) resource information, (3) market information, (4) beneficiation, and (5) community rivalries. In relation to the key issues, it is proposed that the following activities be undertaken:

- Increase government participation and involvement
- Invest in research and development (R&D)
- Marketing should take the lead in R&D
- Increase collaboration between government structures and other relevant stakeholders.

Mintek TE project

The Northern Cape Province has been identified as a priority area for socio-economic development by the South African Treasury under the Medium Term Expenditure Framework (MTEF). The province is home to significant semi-precious mineral deposits, most of which are exploited on a small-scale level and informally in most areas, resulting in very little socio-economic benefit.

The objective of Mintek's TE project is to establish a gemmological centre where semi-precious minerals can be beneficiated into saleable and high-value end-products. Mintek is spearheading the project, which is funded by the MTEF. This is a three-year project and is divided into two phases. The first phase consisted essentially of research and development to identify and locate all potential deposits of semi-precious minerals. The second phase is the implementation phase, in which beneficiation centres will be established in the province. The first phase has been completed and TE in the Prieska region has been selected as a priority area because it holds potential socio-economic benefits. Mintek is working with the Department of Mineral Resources and communities and stakeholders from the Siyathemba Local Municipality to set up the beneficiation

Table III

SWOT analysis for TE industry

Strengths	Weaknesses
• South Africa holds the comparative advantage • Increased government interest and interventions • Local government support	• Lack of government regulation and capacity • Illegal mining • Smuggling • No resource information • Lack of proper market structure • Lack of technical skills • Community rivalries
Opportunities	*Threats*
• TE is attractive and unique • Rarity compared with most semi-precious stones • Mining of TE is a simple process • There are currently no known substitutes • Government is promoting mineral beneficiation • Semi-precious minerals have been earmarked for mineral beneficiation by local government • Mintek's MTEF project as one of the initiatives	• TE continues to be exported internationally • It is alleged that TE is stockpiled overseas • TE is perceived as low value gemstone (perception) • Well-established markets for final jewellery products (competitive products on the market)

centre in Prieska. The potential benefits from the project are: (1) job creation, (2) skills development and transfer, (3) development of small, micro, and medium enterprises (SMMEs), and (4) promotion of local beneficiation.

Conclusion

Since mining commenced during 1803, socio-economic benefits from tiger's eye have not been realized. The majority of the people in the Northern Cape are not benefiting. To date, mining of TE has constituted a means to livelihoods. The biggest hurdle in the sector is the lack of effective government regulation. Although legislation exists, government lacks the capacity to enforce and monitor legislation. It is important for government to recognize the potential of TE. This is a socio-economic imperative, not only for the Northern Cape Province, but for the national mainstream economy. The contribution of the TE industry to socio-economic development is hindered by illegal operations, lack of technical skills and knowledge, exploitation by dealers, lack of market information, community rivalries, and the absence of a beneficiation industry. Because of the nature of these challenges, a multi-stakeholder approach is needed. However, it should be the responsibility of government to spearhead the initiative. Government should identify and facilitate all relevant stakeholders.

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A quantitative method for selecting renewable energy projects in the mining industry based on sustainability

by M. Mostert*

Synopsis

Mining companies sponsor a range of non-core, corporate social responsibility projects to adhere to social and labour plans and environmental management prerequisites that form part of a mining licence application. Some companies go above and beyond such projects, sponsoring initiatives that generate renewable energy through solar power, wind energy, natural gas, *etc*. The challenge for these companies is to choose between a variety of projects to ensure maximum value, especially in times when the economic climate might be less favourable for such projects. The focus of this research was to analyse the concept of sustainability as it exists today, and to apply that to the triple bottom line accounting method in an attempt to quantify the sustainability of a project. Research was done on the methane burn-off project at Sibanye Gold's Beatrix Mine to establish how such projects are planned and financed, and what impact they have on the triple bottom line of a company. The financial bottom line is, by definition, one that executives understand. This paper also proposes a quantitative method for defining the social and environmental bottom lines as well. By considering the financial, social, and environmental values, the study attempts to determine a monetary value for a sustainable renewable energy project. This monetary value can be compared to similar values obtained for other sustainable renewable energy projects under consideration. The research suggests that monetary value alone is not enough to base a sustainable decision on, and qualitative measures are suggested for use in conjunction with quantitative methods. The selection method proposed should assist the board of a mining company to choose the most sustainable option and the project that will add the greatest value to the company across all three bottom lines. It will also provide increased justification for such renewable energy projects, even in periods of harsh or uncertain economic climates.

Keywords
renewable energy, sustainability, project evaluation, triple bottom line.

Introduction

Mining companies are well versed in the quantitative methods of evaluating and selecting mining projects that will give the most competitive return on investment. However, when the project under review is a sustainable, socially responsible project there are additional factors that should be considered in combination with the net present value (NPV) and internal rate of return (IRR). The social and environmental impacts of the project play an equally large role in the viability of the project as the financial parameters. Gold Fields, for instance, has many socially responsible, sustainable projects globally. This paper focuses on one of the renewable energy technology (RET) projects that Gold Fields had decided to implement. The methane burn-off project is situated at Beatrix Gold Mine, which currently belongs to Sibanye Gold after the unbundling of some of Gold Fields' South African operations into the new company. However, since the project was initiated by Gold Fields, this paper refers to that company as the owner of the project. The justification for the investment and the criteria that are used to decide on a specific project competing for funding are discussed. Additionally, other factors are considered that should be a part of the decision-making process. Finally, a decision checklist is proposed to assist mining companies in choosing between these types of projects. The checklist is based on the overarching concept of sustainability to ensure that all three of the bottom lines are duly considered. It is suggested that a quantitative approach alone would not do the process justice, due largely to the qualitative nature of the social and environmental factors. The proposed checklist makes provision for a qualitative evaluation of projects in addition to the quantitative aspects for the sake of substance over form and in the interest of integrated reporting.

The triple bottom line (TBL) reporting framework is used to derive three basic criteria against which to evaluate a project:

- Financial – Is the RET project financially viable?
- Financial capital – Is the technology proven? (Manufactured capital)
- Social – Is it good for the community? (Social and human capital).

* *SRK Consulting, Johannesburg, South Africa.*

Moral responsibility

A large part of the reason mining companies undertake sustainable, non-mining projects is to demonstrate moral and social responsibility. Demonstrating this responsibility is vital in obtaining a 'social license' to mine, *i.e*. the agreement with society to allow a mining project to go ahead. Echenique (2012) states that Aristotle (384–323 BC) was the first to draw up a theory on moral responsibility

According to Eshleman (2009), moral responsibility entails being worthy of a particular kind of reaction, whether it be praise or blame, for having performed a certain action. He argues that judgement of responsibility requires that the behaviour or deed of the protagonist is governed by an 'interpersonal normative standard of conduct that creates expectations between members of the shared community', and that moral responsibility is an inherently social notion. Thus, holding someone responsible means addressing a fellow member of a certain moral community (Stern, 1974).

Considering the literature on the nature of moral responsibility, the reader could be at risk of oversimplifying the nature of corporate social responsibility and the investment required in this regard as simply the reaction to potential consequences of negative social impact. In other words, companies will only do good out of fear of negative social reaction, *i.e.* of obtaining bad publicity and losing the social license to mine.

The reason that drives companies to increase their moral responsibility is not the question here. The fact remains that, through social pressure, the mining industry has taken moral responsibility for its actions. Industry is responsible and accountable to society.

Sustainability as a value

It is challenging to find some sort of socially acceptable and understood value for a company's social responsibility and investment, and its environmental impact, taking into consideration the risk of oversimplification when a monetary value is assigned to unknown quantities such as social and environmental capital.

The value by which RET projects will be measured in this paper is 'sustainability'. This sustainability value is a hard–to-define value that takes into consideration all three of the bottom lines (People, Profit, Planet) as well as the Five Capitals (Financial, Manufactured, Social, Human, and Natural) to compare different RET projects with one another. By finding a way to value social, environmental, and human capital in terms of financial capital it may be possible to persuade the investor that sustainability is not just the domain of the philanthropist, but also of the hard-core businessman.

Understanding sustainability: the triple bottom line

In the mid-1990s Elkington (1994) strove to measure sustainability in a framework of his design. This framework incorporated social and environmental factors in the typical dimensions of business success (Taylor *et al*., 2006). By focusing on comprehensive investment results with respect to performance along the interrelated dimensions of profits, people, and the planet, TBL line reporting can be an important tool to support sustainability goals.

The TBL approach can be defined as an accounting framework that incorporates three dimensions of performance: social, environmental, and financial. This differs from traditional reporting frameworks since it includes ecological (or environmental) and social measures, to which it can be difficult to assign appropriate means of measurement (Slaper and Hall, 2011). The TBL principles are also commonly referred to as the 'three Ps': Profit, People, and Planet. Savitz (2006) defines TBL as '[capturing] the essence of sustainability by measuring the impact of an organization's activities on the world ... including both its profitability and shareholder values and its social, human and environmental capital'.

For the purposes of this paper the TBL approach is used as the foundation. The TBL approach leads to the three main questions:

- Is the RET project financially viable? (Profit)
- Is it good for the community? (People)
- How will it impact the environment? (Planet).

The three matrices of the TBL do not have a unit of measure in common. Some commentators (Rogers and Hudson, 2011; Roe, 1984; Laszlo, 2008) argue that there are harmonies along the TBL elements and that an impact or investment in a specific bottom line may influence the others. When profits are measured in dollars, how can social capital and environmental or ecological health be measured? Finding a common unit of measurement is challenging. Accountants might advocate monetizing the dimensions, which are, after all, sometimes referred to as types of capital. It can be argued that a cost can be allocated to factors like social welfare or environmental damage. Many try putting a dollar value on 'green' or social factors. Another challenge is to find a way to assign an objective value to aspects such as lost wetlands or extinct species. Human emotion, like with so many other things, seems to add intrinsic value to these dimensions even before the balance sheet is completed.

Another solution might be to calculate the three Ps in terms of an index. As long as there is a universally accepted accounting method allowing for comparison between entities, this could be a way of reporting on 'People' and 'Planet'. Slaper and Hall (2011) refer to the Indiana Business Review's 'Innovation Index', but the authors admit that there is some subjectivity to the process, which presents itself especially in the weighting of the indexes. They comment: 'Would each "P" get equal weighting? What about the sub-components within each "P"? Do they each get equal weighting? Is the people category more important than the planet? Who decides?'

Five Capitals model

The idea of using capitals other than financial capital was first explored by Forum for the Future (2012). The premise is that there are five types of sustainable capital from which the goods and services we need to improve the quality of our lives are derived. Figure 1 shows a diagram of the Five Capitals model of sustainability.

This model shows that there are five main capitals, or values, to consider in a sustainable society. If the manufactured and financial capitals were to be removed, the social, human, and natural capitals would continue to exist. However, if the natural capital was to be removed (*i.e.*

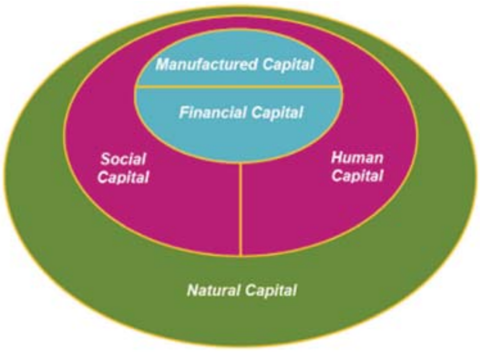

Figure 1—Five Capitals model

destroyed), the other capitals would cease to exist. As such it is necessary to view the entire system holistically when a decision is made that affects mankind.

Porritt (2007) argues that capitalism is, and will for the foreseeable future be, the world's driving economic principle. He maintains that rather than fighting this, it is better to harness the power and momentum of capitalism to secure a sustainable future. It follows that the mining industry should apply some of its wealth to create a sustainable future.

Question 1: Is the project good for the bottom line?

Financial capital

The financial capital criterion has traditionally been the test of whether a project is viable. Evaluating a project's future cash flows and its promise of growth against the company's internal hurdle rates determines whether a project is viable. New techniques for capital budgeting have been developed. These are, *inter alia*: strategic options (Kester, 1986), scoring methods (Nelson, 1986), fuzzy logic approaches (Zimmermann, 1991), and discounted cash flow (DCF) modified methods (Azzone and Bertele, 1991). Traditionally, however, the two main criteria for financial viability have been net present value (NPV) and its counterpart, the internal rate of return (IRR) as part of the DCF process (Maccarrone, 1996).

The essence of sustainable development and the accounting thereof lies not in financial viability alone, but also in its impact on society (its social capital), as well as it impact on the environment (Burritt and Schaltegger, 2010). If we accept that capitalism is currently the main driving force in our society, then we have to accept that it is the financial viability of a project that will make a board of directors view it in a favourable light. The aim of this paper is not to argue for a change in the nature of capitalism, but to find a way of adding to it to ensure that sustainability becomes a major focus of the mining industry and inherent in decision-making processes for RET projects.

Hence the first question revolves around the financial viability of a project: does the project add value to the bottom line?

Answering question 1 – Is the project financially viable?

A full NPV and IRR calculation must be done in order to compare the project with others vying for funding. The IRR is the initial hurdle. Only if the IRR of a project is above the internal hurdle rate of a company should the project's NPV be measured against that of another to find the most valuable project.

For RET projects, however, the impact on the other four capitals should be considered. RET projects might not show profitable returns when financial capital is considered. When the other two bottom lines are considered, the true value of the project in terms of a sustainability value is considered and this value might make the project viable.

Manufactured capital

The concept of manufactured capital has been defined by the Forum for the Future (2012) as the physical, built machinery and infrastructure related to a project. The value of manufactured capital lies in its efficiency and effectiveness. It is in this area that the expertise of various players is needed to ensure that the project is successful.

Mining, electrical, mechanical, and civil engineers are all part of the array of engineering expertise that is found on a mine. It is only through collaboration between these disciplines and the hard work of artisans that a large mining project can be sustained. When venturing into the realm of sustainability projects, this engineering expertise needs to be complemented and amplified by the pure sciences, especially where the project is ground-breaking or new to the mining environment. In the case of the methane burn-off project it quickly became clear that the applicable manufactured capital was assured of viability and value only in close collaboration with various science disciplines.

Manufactured capital adds a new dimension to the concept of the TBL. The sustainability of a project depends not only on the financial viability, but also on the value and quality of the manufactured capital. It is in this sense that the Forum for the Future expands on the concept of the TBL. Instead of the first bottom line being purely a financial question, this is now expanded to incorporate manufactured capital.

The data for the methane burn-off project at the Beatrix gold mine was supplied by Gold Fields.

The Beatrix methane burn-off project

Beatrix gold mine is an intermediate-level mine in the Free State Province of South Africa. The mine has the highest methane emission rate of any gold mine in the country (Du Plessis and Van Greuning, 2011). Mining operations liberate this methane from underground sources, from where it dissipates in the atmosphere. The total methane emission rate for the entire mine is reported to be in the order of 1600 l/s. Beatrix has a history of gas accumulation that has led to a number of underground explosions. Following the last explosion in 2001, a number of recommendations were made. One of these was to consider extracting the methane from the mine in order to render the mine atmosphere safe. This is the crux of a project that has resulted in a method for not only improving safety at Beatrix, but also for generating electricity.

The contribution of methane gas to global warming and climate change is estimated at 20 times that of carbon dioxide. The Beatrix methane burn-off project is in fact a carbon project under the Clean Development Mechanism (CDM) of the Kyoto Protocol.

Technical aspects of the methane burn-off project

The aim of the project is to capture and extract the underground gas and use it in a sustainable manner by generating electricity. Through this process the atmospheric conditions underground will be vastly improved, as will the financial bottom line of the mine owing to the generation of cheap electricity.

Beatrix gold mine is situated 40 km south of the city of Welkom and 280 km south of Johannesburg (Figure 2).

Production from stoping operations amounts to 225 000 t/month. An air flow rate of 1 826 kg/s and 60 MW of refrigeration are required to maintain acceptable environmental conditions. The methane gas emits from deep-seated sources through geological features such as faults, fissures, and dykes. The concentration of methane emitted varies from 82% of the atmosphere, but can be as much as 90% (Du Plessis and Van Greuning, 2011).

It is impossible to extract all the methane because of the layout of the stoping operations and the widely spread methane intersections. It was therefore decided to target high-emission areas. The project has two phases, the first one being the capture of methane emitting from the mining operations and piping it to the surface, where it is flared. The second phase is the installation of Jenbacher electrical generation plants (Figure 3) that will convert the methane gas to electricity. Any excess methane is flared.

Financial capital – Following the money

The technical viability of the project was proven in concept by means of a technical feasibility study and underpinned the solid performance record of the Jenbacher generators.

If a project is technologically viable it will need funding. It is vital then that the methods of financial viability testing are understood and applied to the project. The financial model consisted of two phases, both of which were dependent on the revenue received from carbon emission reduction (CER) sales. Carbon emission reduction units, also known as carbon credits, are traded as commodities through the CDM. The United Nations Framework for Climate Change [UNFCC] approved the project design document for registration under the CDM in October 2008 (Du Plessis and Van Greuning, 2011).

Gold Fields was fortunate enough to find a buyer for the CERs very early on in the project design. The value of the CERs makes up an invaluable part of the financial bottom line of the project. The carbon credits are hedged. The buyer pays Gold Fields for the carbon credits at the beginning of the year. Until 2016, Gold Fields plans to sell 1.7 million CERs to the European energy trading company Mercuria Energy Trading SA under forward contracts.

Phase one of the project – flaring only

The first phase of the project consisted only of methane burn-off through flaring. Net cash generation for the project ramps up to R31 million per annum, resulting in a NPV of R229 million over 21 years. An IRR of 45.66% is generated in the

Figure 3—Jenbacher generator

Figure 2—Geographical location of Beatrix gold mine

first phase. Bearing in mind that this project does not necessarily carry the same risks as a long-term mining project, the IRR is comparatively high.

Phase two of the project – electricity generation

The second phase of the project consists of electricity generation through the Jenbacher plants. The emission reductions in this phase are not as high as in phase one of the project, with the result that the carbon emission sales are lower and CER revenue is less. However, there is a cost saving on Eskom electricity, which is added to project revenues. Electricity revenues are calculated at R27 million per annum. Added to the R20 million revenue from carbon credits sales, total project revenues exceed R47 million per annum.

This results in an NPV of R325 million over 21 years, with an IRR of 54.12%. This is 10% higher than the phase one IRR and proves the financial feasibility of the phase two addition.

Concluding question 1 – Financial and manufactured capital

A crucial part of financial viability is the technical viability of the RET technology. An in-depth study and thorough research must be undertaken to ascertain whether the technology employed in the project will actually work as planned. Only when the viability of the manufactured capital (the effectiveness of the technology) is considered in addition to the financial viability of the project (in terms of IRR and NPV) can the first question truly be answered.

An RET project is good for the bottom line of the company when the technology works, the IRR is above the internal hurdle rate, and the NPV favourable.

Question 2: Is the project good for the community?

Corporate social investment and responsibility

Corporate social investment (CSI) can be seen as encompassing all projects that are external to the normal business activities of a company and not directly for the purpose of increasing profit. CSR projects utilize company resources to benefit and uplift communities and are not primarily driven as marketing initiatives.

CSI value is widely recognized, *i.e.* reputation improvement, compliance with government regulations, competitive advantage, stakeholder appeasement (Hall and Vredenburg, 2004; Kassinis and Vafeas, 2006). CSR is an umbrella concept that refers to an organization's total responsibility towards the business environment in which it operates (Moir, 2001). However, there is no consensus on the value added to shareholders by CSR/CSI initiatives.

A report by McKinsey and Company (2009) states clearly that 'no consensus has emerged to define whether and how such programs create shareholder value, how to measure that value, or how to benchmark financial performance from company to company'. The report remarks that there are notable differences in opinion between chief financial officers (CFOs) and investors as to how much value these programmes create, which specific environmental, social, and governance activities create value, and whether such programmes are a proxy for good management. It is anticipated that environmental, social, and governance programmes will create more and more value over time. This potential highlights the importance of developing a better matrix and resolving the gap in understanding between CFOs and investors.

The problem with the CSR/CSI approach is that measuring the value of a project in terms of its social value is highly subjective. '*When doing a valuation, CFOs and investors alike say they count the effects on some stakeholders much more than effects on others; further, different stakeholders matter to the two groups. Most CFOs and investment professionals who don't integrate environmental, social, and governance considerations into their evaluations of corporate projects – or who don't do so fully – agree that the contributions are either too indirect to value or that the available data are insufficient. Indeed, few CFOs or investment professionals found value in external rating, ranking, or reporting standards or guidelines to assess the effects of environmental, social, and governance programs, with the exception of certain certification or accreditation standards*' (McKinsey, 2009).

Especially in Africa, with its wide range of cultures and peoples, a project's value is in the eye of the beholder. A concentrated solar power plant supplied by a new investor may, for example, generate enough electricity to supply the community as a whole, but the loss of grazing land for the project's footprint may represent a greater loss to the community than the gain in electricity.

Porter and Kramer (2011) provide an interesting example. They start their report by stating that the capitalist system, in its current form, is under siege. Many commentators agree, and the literature abounds with various rethinks of the current capitalist system (Barnes, 2006; Young, 2003; Pirson and Lawrence, 2009; Porritt, 2007). Porter is of the opinion that the legitimacy of business has in recent years fallen to levels not seen previously and that a large part of the problem seems to be an outdated approach to value creation. Companies take a short-term view of value creation and in so doing miss customer needs, overlook the well-being of their customers, and ignore the depletion of natural resources and the economic distress of the communities they operate in.

According to Porter and Kramer (2011), '*Companies must take the lead in bringing business and society back together. Yet we still lack an overall framework for guiding these efforts and most companies remain stuck in a "social responsibility" mind-set in which societal issues are at the periphery, not the core. The solution lies in the principle of shared value, which involves creating economic value in a way that also creates value for society by addressing its needs and challenges.*'

The idea of creating shared value transcends CSR, philanthropy, and even sustainability. It should, in Porter and Kramer's opinion, not be at the periphery of what companies do but at the heart (Porter and Kramer, 2011). They argue that the CSV approach calls for a re-imagining of the lines between society and corporate performance. This is supported by Michelini and Fiorentino (2011) and Yunus (2010, 2008). Porritt feels that '*Capitalism is an unparalleled vehicle for meeting human needs, improving efficiency, creating jobs* *and building wealth. But a narrow conception of capitalism has prevented business from harnessing its full potential to meet society's broader challenges*.'

At the root of creating shared value (CSV) is the idea that the competitiveness of a company and the well-being of the surrounding community are closely intertwined. It should be a symbiotic relationship. According to Porter and Kramer, there are three ways a company can create shared value:

➤ Reconceiving products and markets
➤ Redefining productivity in the value chain
➤ Building supportive industry clusters at the company's locations.

Porter and Kramer are at pains to explain the difference between CSV and CSR, as shown in Figure 4. '*CSV should take precedence over CSR in guiding the investments of companies in their communities. CSR programmes focus mostly on reputation and have only a limited connection to the business, making them hard to justify and maintain over the long run. In contrast, CSV is integral to a company's profitability and competitive positio*n.'

In researching how CSV is valued, it is clear that a hard-line value cannot be put on shared value. Once the CSV concept has been entrenched in a company's ethics and business model it is easy to calculate the shared value retrospectively. In a presentation to the Shared Leadership Summit in 2012, Porter (2012) demonstrated the link between business and social value leading to shared value in the diagram shown in Figure 5. From this illustration it is evident that CSV is created in the overlap between business and social value.

Porter's schematic can be simplified as shown in Figure 6, which clarifies the domain of shared value. Only where business and society both agree on the value of a project can there be shared value.

In attempting to establish shared value a mining company simply has to ask, that is engage with, stakeholders about what is of value.

Gold Fields subscribes to the AA1000 Stakeholder Engagement Standard 2011 (AA1000SES) and uses its principles to recognize the needs of all stakeholders in a specific area.

Figure 4—CSR vs CSV

AA1000 Stakeholder Engagement Standard 2011

Stakeholder engagement is considered crucial to the sustainability and success of an operation (Ayuso *et al*., 2011). Stakeholder engagement can be defined as: 'The process used by an organisation to engage relevant stakeholders for a clear purpose to achieve accepted outcomes' (AccountAbility, 2011).

AccountAbility is a global organization that provides solutions to challenges in corporate responsibility and sustainable development.

In South Africa, as in other parts of the world, stakeholder engagement is a sensitive issue. It is essential that mining operations inform all stakeholders in detail about what it is going on in their operations and how proposed developments may affect stakeholders.

The origin of stakeholder engagement lies in crisis resolution. Companies have come to realize that engagement, transparency and quick responses to stakeholder concerns are vital to address external pressures.

For quality stakeholder engagement to be successful the three accountability principles: namely inclusivity, materiality, and responsiveness, must be honoured.

Inclusivity is defined as 'the participation of stakeholders in developing and achieving an accountable and strategic response to sustainability. It is also a commitment to be accountable to those on whom the organisation has an impact and who have an impact on it, and to enable their participation in identifying issues and finding solutions.' (AccountAbility, 2011)

Materiality is the process that determines the most relevant and significant issues for an organization and its stakeholders. It recognizes that certain issues are stakeholder-specific. What is important to the local community in a South American mining village may not

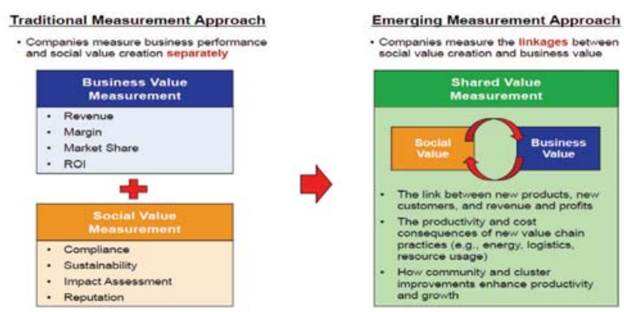

Figure 5—Measuring shared value (Porter, 2012)

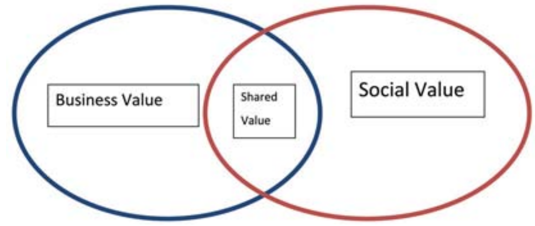

Figure 6—Shared value

necessarily be as important in rural Ghana. AccountAbility (2011) continues: 'Responsiveness is the decisions, actions, performance and communications related to those material issues.' Responsiveness is the company's reaction to materiality.

Before attempting the stakeholder engagement process it is necessary to define the purpose, the scope, and the stakeholders involved.

The stakeholder engagement process consists of four main steps, namely (a) planning, (b) preparing, (c) implementation, and (d) acting, reviewing, and improvement. These four steps form a continuous cycle in order to improve the engagement process.

Brand value

For several decades, a process much like the stakeholder engagement process discussed above has been implemented by the marketing industry to ascertain brand value, which is a measure of stakeholders' perceived value of a product. Testing brand value is exactly the same as testing a project's shared or stakeholder value. If brand value can be viewed as a measure of how much stakeholders 'like' an idea or a company, then it is also a useful measure for ascertaining a company's shared value.

According to Bick and Abratt (2003), 'brands ... makes them [customers] feel confident of their purchase decision. Managers have also become aware of the fact that the brand has become an important company asset, and focus is needed on the creation of brand equity.' Bick and Abratt draw a comparison between shared and brand value: 'As capital becomes less of a constraint on businesses there will be far greater emphasis on how capital is used to creatively differentiate the organisation. The point of differentiation (and the source of shareholder value) will flow from intangible assets'.

Shared value is an intangible asset or 'soft' concept that, like brand value, is difficult to quantify. Also, like brand value, shared value is a concept that has intrinsic stakeholder value and is a long-term asset to the company. If the community sees value in a project then, and only then, is shared value created.

Much work has been done on valuing brands. With the close link between shared value and brand value it is possible to identify a suitable method of brand evaluation and adapt it to quantify shared value.

Bick and Abratt (2003) assert that 'The benefit of ascertaining the correct brand value will ensure that resources are appropriately channelled to where they will deliver the greatest value ...' That is, the crux of the matter for shared value as well: to identify the RET project that will have the most value and in which it will make the most sense to channel available funds.

Measuring brand value

A wide range of methods produce widely varying results. Bick and Abratt (2003) list the following five main methods:

- Cost-based approaches
- Market-based approaches
- Economic use or income-based approaches
- Formulary approaches
- Special situation approaches.

Measuring shared value – a forward-looking approach

The author proposes that, if some measure of shared value can be established through the engagement process (AA1000), a project can be seen as having shared value. There are three possible outcomes to community engagement:

1. The community does not perceive a project to have value. No shared value is established
2. The community considers the project to add value but to be too disruptive. The value of the project is not shared
3. The project is considered advantageous by both the company and the community, a symbiotic relationship exists in which all stakeholders draw value from the project. The project is then in the realm of true shared value, as per the overlapping area in Figure 7.

By applying the cost-based approach for brand evaluation the monetary shared value can be stated as:

Replacement cost of project (if shared value has been established) = Monetary shared value

Concluding question 2 – Human and social capital

If shared value is established, the project with the highest replacement cost, *e.g.* capital expenditure in monetary terms, is the project with the highest shared value. Comparing the cost of one project to that of another gives an unbiased, quantifiable measure of the shared value of that project and leads to a weighting metric.

If the stakeholder engagement process is followed, shareholders are assured when looking at the balance sheet that expenses reported under CSR strategies are creating shared value.

Social hurdle rate

Monetary shared value (MSV) is expressed in terms of money. MSV defines human and social capital through the sustainability value. The company could also set up internal hurdle rates for the required MSV. In other words, a MSV that automatically places projects in one of two categories: either creating sufficient MSV for the company to go ahead with the project, or not. This 'social' hurdle rate should only be a salient metric for comparing projects, because even if a project does not clear the internal hurdle rate set for MSV it might be more valuable than a competing project when the financial and environmental bottom lines are considered. If a certain project's MSV is below the company's internal hurdle rate for MSV the project should be identified as a possible risk and extra care should be taken in comparison with other projects. When MSV is considered in conjunction with financial capital, two of the three bottom lines are accounted for, *i.e.* Profit and People.

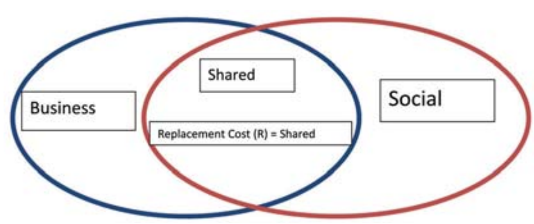

Figure 7—Monetary Shared Value

Question 3: How will the project impact on the environment?

The use of marginal abatement cost (MAC) curves is advocated in conjunction with an environmental impact assessment (EIA) to determine a project's impact on the environment. The fact that other methods of environmental impact assessment are not discussed here does not detract from their validity or importance. The anticipated end result of this work is a decision checklist that is easy to use, not overly onerous to complete, and also comparatively cheap. For this reason only the MAC curve is elaborated on.

Marginal cost curves

A MAC curve shows a schedule of abatement measures ordered by their specific costs per unit of carbon dioxide equivalent abated. Certain abatement measures can be put into action at a lower unit cost than others. The MAC curve is a valuable tool that illustrates either a cost-effectiveness or a cost-benefit assessment of measures where the benefits of avoiding carbon-emission damages are expressed by the shadow price of carbon (Moran *et al.*, 2011).

MAC curve analysis is a method of determining optimized levels of pollution control across a range of environmental media (McKitrick, 1999). MAC curves are one of the favoured instruments for analysing the impacts of the implementation of the Kyoto Protocol and emissions trading (Klepper and Peterson, 2004). The MAC represents either the marginal loss in profits from avoiding the lost unit of emission, or the marginal cost of achieving a certain emission target given some level of output (Klepper and Peterson, 2004). Figure 8 shows a typical MAC curve.

The MAC curve is widely used for climate policy analysis in the context of a general equilibrium framework. An economy, as a whole, can be treated like a production plant. Hence, a MAC curve can be applied to an entire region.

In constructing an MAC curve, the abatement measures are ordered in increasing cost per unit of carbon dioxide abatement. The horizontal axis denotes the actual volumes abated over the period of the implementation of the technology measure. The figures below are examples of MAC curves.

Klepper and Peterson (2004) maintain that 'In a computable general equilibrium (CGE) model the marginal abatement cost is defined as the shadow cost that is produced by a constraint on the carbon emissions for a given region and a given time'. They go on to explain that this shadow cost is equal to the price of an emission permit in the case of emissions trading. This is the same cost that equals the price of one CER as sold by Gold Fields through Mercuria trading on the open market through the CDM of the Kyoto protocol. Through the use of a MAC curve it becomes possible to pin a direct cost to the abatement potential of a project. This abatement potential is in fact what is bartered on the open market. The relatively huge revenue that is generated by Gold Fields' Beatrix methane burn-off project is thus the result of the sale of the carbon abatement potential of that project.

This leads to:

MAC = Net present value/greenhouse gas emissions saved from abatement measures during investment timeframe (Carbon Innovators Network, 2011)

or:

$$MAC = \frac{NPV}{\text{GHG Abateman due to project during time frame}}$$

Clean Development Mechanism

The CDM allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol to implement an emission-reduction project in developing countries. Such projects then earn saleable certified CER credits, each equivalent to 1 t of CO_2, which count towards meeting Kyoto targets.

The CDM is the first global environmental investment and credit scheme of its kind, providing a standardized emissions offset instrument, CER (UNFCC, 2013). The aim of the CDM is to stimulate sustainable development and emission reductions, while at the same time giving industrialized countries a flexible tool with which to meet their emission reductions or carbon limitation targets. The Beatrix methane burn-off project is a typical CDM project.

Final selection of environmental valuation system with criteria

There are various methods of calculating what can only be described as a shadow cost, *i.e.* the intangible cost of what the environment means to the human race. During the

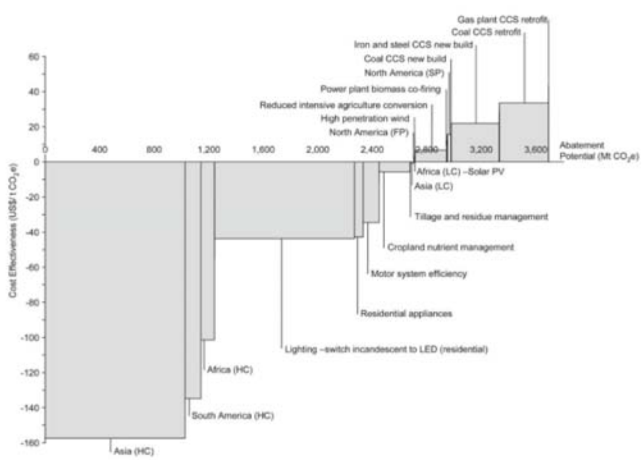

Figure 8—The MAC curve of a range of carbon-abatement technologies and strategies for the world by 2030 (Pratt and Moran, 2010)

feasibility or scoping study stage for a renewable energy project it becomes necessary to choose the most applicable tool. It is inevitable that some of the methods will be used in conjunction with each other, but it is the verifiable audit of the final value that is important.

It is very difficult to find one value that satisfies all commentators, since the value assigned to the environment is highly subjective. It is useful, however, to be able to calculate a value, even if that value is only considered to be the 'at least' value. This 'foundation' value should be seen as the fairest and most logically calculated value that makes sense to all stakeholders and on which there is agreement that more value be added but not decreased.

The South African mining industry is well versed in the use of environmental impact assessments (EIAs), the requirements for which are written into law through NEMA (The National Environmental Management Act, 107 of 1998). An EIA does not result in a final financial value for a project, but is a tool that identifies environmental hazards and the necessary mitigating projects. As such it is important that these projects, as well as the environmental management plan (EMP), are drawn up in such a manner that the cost of possible mitigation measures can be calculated. The EIA is only half of the process as it does not take into account the advantages a RET project can bring to the environment. An EIA should be undertaken in conjunction with at least one other environmental rating tool.

These two values should then be added to give a foundation cost for an RET project.

For any given renewable energy project then:

$$EMP + EIA + MAC = EBL$$

where

EMP = full financial cost of the environmental management plan

EIA = full financial cost of the environmental impact assessment

MAC = the marginal abatement cost of the project

EBL = the full economic cost of the renewable energy project to the environment (Economic Bottom Line).

Concluding question 3 – Natural capital

Expressing environmental impact in monetary value terms does not give a true reflection of the full impact of the project. The challenge lies in trying to place a quantitative value on qualitative measures. The value of animal and plant life, aesthetics, ecosystem services, and clean air *etc.* is subjective and may change over time for each person as personal values change.

Financial capital is a well understood, verifiable, and reproducible metric. By conducting an EIA and calculating the cost of the associated EMP, a financial cost is determined for the rehabilitation of the environment. Calculating the cost of the reduction or gain in ecosystem services likewise gives a financial value to the environmental side of the project. Finally, a MAC curve showing costs for the marginal abatement of carbon gives a cost for that metric as well.

By adding these three costs together a single monetary value is obtained with which to compare one project's environmental impact against another. The NPV calculation does include the cost of the EIA as well as the projected cost of the EMP. The fact that the natural capital calculation, as described above, as well as the NPV calculation both incorporate the EIA and EMP costs does not constitute double accounting. The NPV calculation reports under the Financial Capital 'silo' and the EIA cost calculation reports to the Environmental Capital 'silo', illustrating the fact that the two represent different metrics with which RET projects must be compared. If the EIA costs were to be reported only under the NPV calculation, the risk is that the full impact of the damage to the environment, as illustrated by the magnitude of the EMP+EIA figures, might go unnoticed if the NPV is positive and above the required hurdle rates.

Environmental hurdle rate

As with the financial and social questions, a hurdle rate can be set by the company to rate a project's environmental viability. The environmental hurdle rate should, just like the financial and social hurdle rates, be an indication of the company's appetite for environmental risk. If the EBL is higher than the internally acceptable EBL the company must not consider the project as an option or proceed with extreme caution.

Although the full environmental cost might not be accounted for in the EBL, it is clear that the project with the highest EBL does the most harm to the environment as well as the financial bottom line. The project with the lowest EBL is that project with the smallest impact on the environment and hence, from a purely environmental aspect, should be the favoured project.

The decision checklist

The following checklist is proposed by the author. The aim of this decision checklist is to assist in the choice of the most sustainable RET project.

Is this project good for the bottom line? – Financial and manufactured capital

- ➤ Does the project make engineering sense?
- ➤ Has a complete technical analysis of the project been done to determine its technical feasibility?

The aim of this step is to ensure that the project will work and that the underlying engineering principles are sound.

What are the NPV and IRR of the project? (FBL)

- ➤ Has a complete financial analysis been done to calculate the NPV and the IRR of the project?

This step needs to find the financial bottom line value of the project. This value (FBL) will be used to add to the project's societal value (SBL) as well as its environmental value (EBL). Because of the ambiguity of the IRR calculation, the NPV value will be used in further calculation. The IRR value should be used if a tiebreaker is required to choose between projects.

Is this project good for society? – Social and human capital

- ➤ Have all stakeholders been engaged?
- ➤ Has a recognized engagement standard, like the AA1000 Stakeholder Engagement Standard, been used to ensure that all stakeholders have been consulted properly and systematically?
- ➤ Has shared value been created?

If there is no perceived shared value, *i.e.* the community does not find value in the project, the perceived value applies only to the company and no shared value is created. In this case, it might make economic sense to terminate the project at this point and invest in an alternative project that increases the social investment of the company.

To what extent is the value created truly shared in the community?

What percentage of the sample population agrees to the shared value of the project? People in an area might be divided on the value of a project. Even if the majority finds that shared value is created and are happy with the project to go ahead there might be some that feel the project is not valuable. The percentage of value-finders must be noted in the comments column of the checklist.

If shared value is created, what is the capital expenditure of the company on the project? (SBL)

- ➤ Is this project good for the environment? (Environmental capital)
- ➤ Has an EIA for the project been conducted?
- ➤ What is the financial cost of the environmental impact study?
- ➤ What are the associated impacts of the project?
- ➤ What is the NPV of the EMP and all associated costs?
- ➤ Has a MAC curve been created for the project?
- ➤ What is the full abatement cost of the project?

Calculate the environmental bottom line using:

EMP + EIA + MAC = EBL

- ➤ What is the triple bottom line of the project?

Figure 9 shows a simple diagrammatic workflow for the proposed TBL calculation

Commentary on the findings

Keeping the triple bottom line

There is a temptation to simply add the FBL and the SBL together and then subtract the EBL from that figure to obtain a value for a project that can then be compared to the value for another project that was calculated in the same way. In other words:

Total bottom line = Financial bottom line + Social bottom line – Environmental bottom line

or

TBL = FBL + SBL - EBL

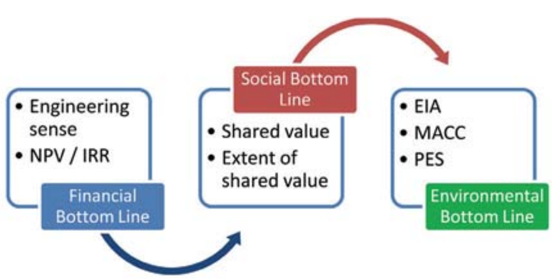

Figure 9—The triple bottom line workflow

Although this function would result in a single monetary bottom line value for the sustainability of the project across all three bottom lines, it has the risk of being skewed by any one of the variables that is much larger than the others. If, for example, the revenue for the project (FBL) is an order of magnitude larger than the environmental impact (EBL), the EBL figure would have a very small impact on the TBL. In this way a project that has a very high environmental impact but an even larger projected revenue will automatically beat a project that has a smaller revenue stream but also has a smaller impact on the environment.

It is necessary to report three separate bottom lines in the decision checklist and not combine the values.

Substance over form

Another risk to the process is the lack of disclosure of information. If the project is simply presented as a list of figures to be compared with one another, the board will not have enough qualitative information to base a decision on. It is necessary that each of the final answers to the three questions has a comments column. These comments will assist with decision-making by ensuring full disclosure but are also essential for the concept of 'substance over form'.

Principle 6.2 of the third King report on corporate governance (King III) states that 'Sustainability reporting should be focused on substance over form and should transparently disclose information that is material, relevant, accessible, understandable and comparable with past performance of the company' (IoDSA, 2009).

Substance over form is described by the International Accounting Standards Board (IASB, 2010) as '*Faithful representation means that financial information represents the substance of an economic phenomenon rather than merely representing its legal form. Representing a legal form that differs from the economic substance of the underlying economic phenomenon could not result in a faithful representation*'.

Qualitative assessment of the EIA

The EIA as described in the checklist is a decision-aiding tool and not a decision-making tool. An EIA is usually used as a tool to decide whether to continue with a project, but in the context of this work it is also used to choose between possible projects based on the impacts those projects might have on the environment. The decision-makers need to assess all three of the bottom lines before a choice between RET projects is made. In the spirit of substance over form it is again important to note qualitative data because the EBL figure alone does represent all the data. The EBL does give an indication of the monetary cost to the environment as a function of the mitigation costs of those impacts. The assessed impacts need to be disclosed in the final report. To ensure fairness and comparability between RET projects, the same ranking system for environmental impacts should be used for all projects under review.

Concluding the commentary

The final answers on the checklist should contain not only the data on the three bottom lines, but all substantive information that is necessary for the final decision-makers to come to an informed conclusion as to which project to fund.

A comments column must be added to all three of the bottom line figures to describe how they were calculated. This approach will ensure a quantitative as well as qualitative approach, thereby satisfying the principle of substance over form.

Application of the checklist

Timing

The author proposes that this checklist be integrated into the various phases of feasibility studies that are conducted in preparation for a RET project. It is common practice for a 'mini EIA' to be carried out before a full scoping study is started. Similarly, the scoping study is usually not as detailed as the full bankable feasibility study. The stakeholder engagement process can also be scaled down to get a preliminary take on stakeholder sentiment. All of this work should be integrated into the checklist as early as possible. These scaled down, early studies are for cost- and time-saving purposes. The same reasons count for a scaled down sustainability study utilizing the checklist.

Fairness, validity, and reproducibility

Some aspects of the checklist have a notable qualitative approach. In order for the process to be fair, valid, and reproducible it is essential that the same team is used to complete the checklist for all projects under review. This will not remove the qualitative aspect from the work but it will ensure that projects are compared fairly. If the team needs to be changed due to operational requirements, it is necessary that the new team members have the same academic qualifications and experience as the original team members. As with all scientific research, it is important to ensure that team members are as neutral and objective towards the outcome as possible.

It is suggested that at least one team member should be chosen each from the financial sciences, engineering sciences, social sciences, and environmental sciences. In this way each of the bottom lines can be represented by its own expert.

Conclusion

Sustainable development has become an integral part of today's business world. Many sustainable projects take the form of renewable energy projects since in a power-hungry industry such as mining these projects can contribute the most. A major challenge lies in valuing sustainable projects. According to value theory, it is necessary to identify some value with which to compare projects. This value was called 'sustainability' for the purposes of this work. Choosing between renewable energy projects would be impossible without identifying one core value as a means of comparison.

The TBL accounting method was the first attempt at finding a common denominator for evaluating sustainability. This method was found to be inadequate to evaluate sustainability on its own. The TBL was then expanded by the work of Jonathon Porritt (2007) and the Forum for the Future (2012). Instead of countering capitalism, Porritt and the Forum for the Future built on the TBL method and identified five capitals – financial, human, social, manufactured, and environmental – on which a sustainable society is built. From the so-called Five Capitals model the idea is derived that a sustainable project should make financial, engineering, social, and environmental sense.

Gold Fields's Beatrix methane burn-off project was used as an example of the sustainability projects of a mining company.

Three questions are used to identify the sustainability of a renewable energy project. The first question concerns the advantages to the financial bottom line. An in-depth look was taken at Beatrix gold mine's methane burn-off project. By studying this example of an RET project, a good understanding is gained of how industry evaluates an RET project financially and technically. The financial evaluation concerns financial capital and the technical aspects concern manufactured capital as, described by the Forum for the Future (2012).

The next question investigated whether an RET project is good for the community. The concept of corporate social responsibility (CSR) was found to be a slightly dated method of determining a company's interaction with the community. Creating shared value is the new norm for attempting to evaluate the social good of a company. Measuring shared value when reviewing a project is a challenging task – a method to forecast the creation of shared value is proposed. The first step in ensuring shared value is to follow a robust stakeholder engagement process. For this the AA1000 Stakeholder Engagement Standard is used. If all the stakeholders find value in a RET project, the capital expenditure on the project should be deemed the monetary or economic value of social value. Shared value is quantified before commencing with a project.

The third question concerns the issue of whether an RET project is good for the environment. The EIA is considered as a longstanding method of auditing a project in terms of its environmental impact. The format and content of the EIA is legislated in NEMA. Unfortunately, however, an EIA is a highly subjective tool and one that does not necessarily lead to a specific economic value for environmental impact. Because the use of an EIA is dictated by law it is necessary to find additional methods of evaluation to obtain a more objective answer. Marginal abatement costs are proposed for use in conjunction with an EIA.

The author advocates the use of hurdle rates for all three questions. The financial hurdle rate is used to gauge the financial risk of the project. The social value, or MSV, is also suggested to have an internal company hurdle rate and gauges the company's appetite for creating shared value with the community through the project. However, even if no MSV is created through the project, it might still be meaningful to go ahead with the project as the other two capitals might create enough value. The environmental hurdle rate gauges the company's appetite for environmental risk. If the project has a higher EBL than the company's hurdle rate, the risk to the environment is too high to continue and the project should not be considered.

It is possible to calculate a monetary value for all three bottom lines, but these values do not necessarily reflect the full cost of that specific capital. These values are particularly useful as a metric to compare one project with another. The three bottom lines should be kept separate but juxtaposed with those of other projects to find the most sustainable RET project.

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Post-mining land use opportunities in developing countries—a review

by D. Limpitlaw* and A. Briel†

Synopsis

The origins of mine closure practice have influenced the way in which it is implemented by companies and regulators. Mine closure practices essentially started developing in the 1970s in countries with advanced economies and mature mining industries. In these settings, the emphasis was justifiably placed on restoration of the landscape and an attempt was made to return to the 'natural' pre-mining land cover. These practices continued to evolve and incorporated socio-economic and cultural aspects, especially after the Brundtland Report in 1987 and the subsequent Earth Summit in 1992.

Today mining is increasingly occurring in remote parts of developing countries where there may be significant need for infrastructure such as roads, clinics, and schools. The costs of returning land to low (economic) value pre-mining use may be far greater than establishing a viable post-mining land use that could potentially add value to the community and take pressure off sites for greenfield development elsewhere. Furthermore, natural resource limitations (such as topsoil availability) may limit the degree to which the historical land cover can be re-established. Establishing post-mining land uses may aid in mitigating the loss of employment that is inevitable when mines close.

Stakeholder participation in establishing post-mining land cover and land use options is critical for long-term success. Similarly, third parties must be identified to support the development of the post-mining land use

This paper draws on the experience of the authors in several developing countries and presents a case for maximizing re-use of mining infrastructure. The paper does not advocate the adoption of poor rehabilitation standards, nor or the wholesale destruction of land capability, but rather leaving key infrastructure in place for post-mining use that may support sustainable development.

Keywords
mine closure, developing countries, Africa, land use, re-use of infrastructure, sustainable development.

Introduction

Mine closure is the process of transforming an active mine into a set of safe and stable landforms that are non-polluting and provide habitat and ecosystem services and/or support economic activities by the new land users. These activities and habitats may be different to those historically present on the site.

Mining is different to most other land uses in that it is temporary and ceases when the orebody is exhausted. Mining may persist in one location for hundreds of years, but modern mines are typically of short duration and many close within a decade of construction. Historically, worked-out mines were simply abandoned, leaving behind sterilized landscapes with limited economic potential that continued to degrade their surroundings through air and water pollution. Today, society expects mining land to be transferred to new productive uses, the pre-mining land use, or to conservation use once mining ceases.

Restoration, a term frequently used in North America, involves attempting to return an affected landscape to its pre-mining state, use, and condition – recreating the original topography and re-establishing previous land capability together with groundwater patterns and faunal/floral assemblages (Bowman and Baker, 1998; Coppin, 2013). Re-establishing pre-existing ecosystems may not be possible in highly degraded mining landscapes. The landscape surrounding the mine site is also commonly subject to secondary development or a population influx (especially in developing countries).

Because of this secondary development, the surrounding areas may be highly degraded at the time of mine closure, reducing the potential value of conservation measures on the mine site itself – there may be little point in attempting to restore an isolated patch of woodland in a deforested landscape.

Reclamation, a term often applied to derelict and abandoned land, requires returning disturbed land to a state where pre-disturbance conditions are not restored but a different condition is established that is appropriate to surrounding land uses and conditions (Bowman and Baker, 1998). The post-reclamation use is not necessarily related to the pre-disturbance use.

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Rehabilitation refers to the transformation of land from its original condition, through mining, to a new and beneficial condition (Coppin, 2013). This process results in the return of land to a stable condition, capable of supporting permanent use as directed by a mine plan. This new, rehabilitated state must allow for alternative land use opportunities, not contribute to environmental deterioration, and must be consistent with surrounding aesthetic values, but can be significantly different to the historical state of the land.

Mine closure practice

Modern mine closure planning and practice preferentially follows and applies established and tested procedures for closure, which are implicitly based on the complete removal of mining infrastructure and the restoration of the pre-mining landscape. This approach is seen as lower risk, even in poor under-developed and populous areas where there is an infrastructure deficit. This perception has a lot to do with the level of control that can be exercised by a company over the closure process – lower levels of control are associated with multi-stakeholder planning where working infrastructure is handed over to a third party on completion of the closure process.

The origins of mine closure practice have also influenced the way in which it is implemented by companies and regulators. Mine closure practices essentially started developing in the late 1960s and early 1970s in countries with advanced economies and mature mining industries. For example, reclamation planning in Canada was entrenched in law in 1969 when British Columbia became one of the first mining jurisdictions to introduce mine reclamation legislation (Bowman and Baker, 1998). In these settings, the emphasis was justifiably placed on restoration of the landscape and an attempt was made to return to the 'natural' pre-mining land cover. These practices continued to evolve and incorporated socio-economic and cultural aspects, especially after the Brundtland Report in 1987 and the subsequent Earth Summit in 1992. In many African countries, as well as in other developing countries, this traditional approach is sub-optimal and reduces the ultimate contribution of a mine to long-term sustainability.

Regulatory authorities have traditionally been reluctant to grant closure. Mining companies are thus more likely to select closure land uses that offer the greatest likelihood of relinquishment, rather than the most sustainable end land use.

Current closure practice

In the past, rehabilitation of mined land was sometimes driven more by public relations considerations than science. Ziemkiewicz (1987, in Bowman and Baker, 1998), for instance, noted that the intensity of reclamation activity in the 1980s was directly related to the public desire to put extremely disturbed landscapes to alternative land uses. Another example is provided by the state of Florida in the USA. For the first five years after the adoption of the reclamation requirements in the Florida Administrative Code in 1975, the emphasis was placed on hiding the evidence of mining activity (Brown, 2005). Consequently, companies were required to level spoil piles and plant trees. State regulation then evolved to include success criteria such as 'no visible evidence of erosion' and 'survival of 400 trees per acre'.

Today, closure planning is a science-driven activity dominated by planning priorities in OECD countries[1] (especially the USA, Canada, and Australia). These priorities are most commonly focused on the restoration of pre-mining landscapes. Brown (2005) states that restoration efforts (with reference to phosphate mining in Florida) should be focused on re-establishing pre-disturbance ecosystem functions. This assertion is supported by Wiegleb *et al.* (2013) who report that in the USA, rehabilitation results have been assessed relative to a natural or reference state that is based on a hypothetical, historically defined state, unaltered by human activity.

Focus on landscape restoration

In Canada, as in Australia, operations are frequently located in remote areas, far from settled communities. In such cases, it is appropriate to completely remove infrastructure as there is little need for mining infrastructure post-closure. Bowman and Baker (1998) report that for the Northwest Territories Diamonds Project, all structures were to be cleared and removed, portals sealed, obtrusive landforms contoured to match surrounding topography, and natural drainage patterns restored. Managed revegetation programmes were to take place in areas of high erosion potential, whereas the rest of the site would be allowed to revegetate naturally.

Another typically 'developed country' approach was adopted for the Mount Polly open pit copper and gold mine in British Columbia. Here the primary objective of the reclamation plan was to return all mine-disturbed land to an equivalent level of capability to that which existed prior to mining (on a property-wide basis). This was to be achieved by preserving water quality, stabilizing engineered structures (such as waste rock dumps, tailings storage facilities, and pits), the removal of roads and equipment, integration of disturbed land into the landscape, and the establishment of self-sustaining vegetation cover (Bowman and Baker, 1998).

Stakeholders in these countries may also prefer conservation-based post-mining land uses to ongoing economic activity. Surveys by the bauxite miner Alcoa found that the general public near their operations in Western Australia favoured restoration of native jarrah forests over the provision of recreational areas such as lakes and grassed picnic sites (Burton *et al.*, 2012). These sites were previously opencast bauxite mines. One of Alcoa's stated rehabilitation objectives was to increase the ecological significance of the rehabilitated site by including all plant species found in an unmined forest and to re-introduce threatened fauna to the site (Burton *et al.*, 2012). This approach is summarized by the Society for Ecological Restoration International, who state that site restoration attempts to return an ecosystem to its historic trajectory, using historic conditions as the starting point for restoration design (SER, 2004).

North American practice stresses the site-specificity of reclamation with emphasis on the testing of vegetative covers on various disturbed surfaces (Bowman and Baker, 1998;

[1]The Organisation for Economic Cooperation and Development, an international economic organisation consisting of developed countries

Wiegleb *et al.*, 2013), the pre-contouring of areas to a planned and stable topography, public safety/hazard issues, and habitat regeneration. It also emphasizes how the reclamation relates to wider systems that surround disturbed areas and how reclamation relates to traditional land uses prior to mining. In the late 1990s, the question of reclamation and its role in community development, including the transfer of the site from the company to the previous or future owners, was shown to be missing in case studies examined by Bowman and Baker (1998).

Developing countries and rehabilitation

In developing countries, in instances where no definite or beneficial land use is identified, areas restored to 'wilderness areas' or 'unused conservation areas' may attract undesirable post-closure land uses. Examples of this include reclaimed tailings footprint sites in the East Rand and West Rand of Gauteng in South Africa, where informal settlements have established as land has become available. These areas are not suitable for housing developments due to the risks posed by residual tailings material.

In South Africa, the area between Roodeplaat and KwaMhlanga is considered a hotspot for sand mining. A common post-closure land use for mined-out sand mines is to restore the area to its pre-mining land use, namely low-intensity grazing. The post-mining topography and soil profile is very difficult to restore and these mines are often located close to watercourses, making erosion a significant problem. When livestock are added to the sparsely vegetated 'rehabilitated' landscape, erosion gullies are quick to set in and the landscape degrades further. Consultation with stakeholders such as surrounding landowners, and conservation and tourism authorities would likely be able to identify more sustainable closure land use options.

Mined-out quarries have successfully been used as adventure tourism facilities. These land uses have a high commercial value and offer employment opportunities, as opposed to derelict quarries. An example of such a facility is Bass Lake near Meyerton in Gauteng.

There is general acceptance that reclamation should not consist of a final set of on-site activities, but rather of a progressive sequence of interventions, starting with the earliest stages of exploration and planning, integrated into the full life of the mine (Dowd and Slight, 2006; Fourie and Brent, 2006; Finucane, 2008; Limpitlaw and Mitchell, 2013). These actions should, however, not be limited to landform re-establishment and revegetation but should include consideration of the post-mining re-use of infrastructure. For example, at a potash project in the Republic of Congo (Congo-Brazzaville, ROC), the mining company decided to locate processing and staff facilities away from the nearby national park, closer to an existing town that would act as a natural node of development over the course of the mine's life. This development would be more likely to be sustainable post-closure and would also reduce pressure on the park as it would have the effect of drawing people away from the park.

Proposed improvements

The practicality of restoration

Bowman and Baker (1998) questioned whether mine reclamation represented a method of mine closure that minimized environmental degradation or an opportunity to enhance and develop the disturbed land base towards an ecologically productive state.

Returning mined land to a state of 'naturalness' is not only often sub-optimal from a post-mining land use perspective, but may not be possible. The goal of rehabilitation of mined land in Australia is typically to restore the pre-mining land use or ecosystem (Queensland DEHP, 2012, in Doley and Audet, 2013), and it is assumed that the rehabilitation process will ensure that landforms, lithology, and soil will closely resemble conditions of the pre-mining environment. This may, however, not be possible at many mine sites where radical landscape changes have occurred and persistent artificial features introduced (Doley and Audet, 2013). Additionally, restoration of the pre-mining environment potentially limits the opportunities for land uses that may be more socially acceptable and ecologically sound (Doll, 1988, in Bowman and Baker, 1998).

Doley and Audet (2013) stress the need to consider the creation of hybrid ecosystems and novel ecosystems post-mining. The former would be slightly different in form and function to the original ecosystem and would share many attributes. The latter would consist of new combinations of physical and biological attributes due to the changed conditions in the post-mining environment. Basically, the work of these authors shows that where biotic and abiotic systems have been significantly and irreversibly changed, the installation of managed ecosystems or novel, unmanaged ecosystems may be achievable and predictable options. This provides opportunities for the incorporation of enhanced land-use value not found within the pre-mining ecosystem. It is critical that all stakeholders (operator, regulator, and the community) are involved in setting and accepting the parameters for decision-making.

The primary goals of rehabilitation identified by Doley and Audet (2013), namely the attainment of the highest achievable standards of biological conservation and ecosystem stewardship, are not incompatible with leaving infrastructure behind, especially when the mine site is not considered in isolation but within a broader regional setting. Re-use of mined land for fuel wood production, for instance, may be less ecologically desirable than the re-establishment of the pre-mining, indigenous woodland. The harvesting of the fuel wood from a plantation, however, is more desirable than the degradation of adjacent, intact woodland ecosystems by fuel wood harvesting.

Doley and Audet (2013) state that meaningful ecosystem recovery may not occur on rehabilitated, highly disturbed mine sites. Instead of focusing on ecosystem development, they argue for the establishment of safe, stable, and non-polluting landforms that support habitat development. They believe that regardless of the final landscape, the post-mining site will always require some intervention. This supports the need for optimizing the value of post-mining land use to ensure that the required management interventions are sustainable.

There is evidence to show that the benefits of sustainable, multi-functional use of natural and semi-natural landscapes exceed the gains from their conversion to single-purpose land-use types (De Groot, 2005). Natural landscapes commonly provide a multitude of functions and are subject to many possible land uses. Closure planning should attempt to create a post-mining landscape in which multiple land uses are possible so that a level of sustainability more closely approximating that of the pre-mining landscape can be achieved. To approach such improved levels of sustainability, multifunctional post-mining landforms are required.

To maximize the benefit derived from post-mining landforms and to ensure optimal use of resources in the rehabilitation programme, the mine lease should be divided into a number of land use precincts. These precincts are typically determined by the existing land use, current and future surrounding land uses, the nature of the topography, and the level of disturbance. A closure options analysis exercise is required to identify closure options and select a preferred option for each precinct. The preferred closure option will inform the direction of the closure strategy and closure cost estimate.

Mine closure and social development

Today, mining increasingly occurs in remote parts of developing countries where there may be significant need for infrastructure such as roads, clinics, and schools. The costs of returning land to low (economic) value pre-mining use may be far greater than establishing a viable post-mining land use. This land use may potentially add value for the community and take pressure off sites for greenfield development elsewhere. In addition, establishing post-mining land uses may aid in mitigating the loss of employment that is inevitable when mines close.

Maximizing the post-mining value of mining infrastructure may contribute substantially to post-mining economies. At a gold producer in a small Pacific island state, the mine's sports facilities are considerably better than those in the nearest regional centre. The rugby fields, golf course, and bowling club have enabled teams from the local community to participate at national and international level in these sports. Part of the challenge of closure planning is finding effective ways of maintaining such facilities once they are handed over to the community on closure. Similarly, in a country with a tourism-focused economy, the establishment of heritage tourism sites using old mine buildings and equipment should be possible. Notable successes in heritage tourism were reported at the site of the former Waihi Gold Mine in New Zealand (Thompson, 2011).

At a copper producer in Katanga, southern Democratic Republic of Congo (DRC), the company's accommodation facilities present an opportunity for re-use post-closure as a training and conference venue as they are within an easy drive of Lubumbashi, the provincial capital. The attractiveness of this land use option is reinforced by looking at ways of maximizing use of the mine's power and water reticulation infrastructure. Light industry is already establishing itself on the outskirts of Lubumbashi, and by the time the mine closes, it is not unlikely that the site could act as an industrial development incubator.

This approach is already being adopted by some multinational mining companies. In the Mine Closure Toolbox, Anglo American states that exploitation of mineral resources should also contribute to the infrastructure base and provide an economic stimulus for sustainable development in the host region (Anglo American, 2013).

Discussion

The use of mining landscapes (including infrastructure) can improve the contribution of mining to sustainable development, but stakeholder participation in establishing post-mining land cover and land use options is critical for long-term success (Limpitlaw and Hoadley, 2006). Similarly, third parties must be identified to support the development of the post-mining land use. Additional stakeholder participation in the closure planning process is required to ensure that any remaining infrastructure can be effectively used after closure.

Should infrastructure remain post-closure, landscapes must still be stable, non-polluting, and non-hazardous. Environmental liabilities should not be carried over to the post-mining land users and site handover should occur only once all risks are mitigated to acceptable levels.

Where the post-mining land use is different to the original land use, it is inevitable that biodiversity may be impaired or agricultural land lost. In such instances, offsets may be required to ensure no net loss of biodiversity or agricultural land. These offsets should be established early on in the life of mine to ensure sustainability post-closure.

The post-closure land use must generate or sustain employment opportunities for local communities and/or redundant mine employees. Exploring new approaches to rehabilitation may present an opportunity to integrate disturbed landscapes and the community. This reduces the risks of socio-economic collapse post-closure and supports the notion of a social licence to operate (for mining companies). Re-use of brownfield sites may save greenfield sites elsewhere (which have higher conservation value) from being developed.

Conclusions

Closure planning should commence during the feasibility stage of a mining development project, as closure should be one of the aspects to consider in deciding whether a project should be developed. If a financially viable, sustainable land use cannot be identified at the feasibility stage, the developer should be aware of the long-term financial implications if relinquishment is not possible.

Closure consultation with affected communities may be an emotive issue, as a mine is often linked to a large portion of their livelihood. Such consultation is, however, essential in order to identify the most viable land use options or redevelopment opportunities.

The risk-averse approach to closure may not always offer the most sustainable solutions and is not guaranteed to ensure relinquishment. Working with reputable development partners during the life of mine is likely to offer ongoing employment opportunities and an alternative source of livelihood to affected communities upon mine closure.

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Translocation of an endangered succulent plant species from sandstone outcrops earmarked for coal mining

by E. Harris*, S.J. Siebert*, J.H.L. Smit†, and J. van den Berg*

Synopsis

Frithia humilis is an endangered succulent plant species. Its distribution range overlaps with the coal fields of Mpumalanga and it is therefore threatened by opencast mining activities in particular. One of the 11 known populations of *F. humilis* was translocated from a licensed coal mining site to three suitable receptor sites within the species' distribution range. A long-term monitoring programme was initiated to track the progress of the newly established populations. Temporal trends in population demography, size classes, and fecundity were recorded. Population numbers of size classes fluctuated annually. However, flower frequency increased over time and seedling recruitment contributed significantly to population growth. Receptor sites with similar geological conditions to the donor site had more persistent cohorts, which suggest that such sites should receive priority during the translocation of endangered edaphic specialists. This study not only confirms that a *Frithia humilis* population can successfully establish after a translocation, but also serves as an important baseline for future comparative purposes to gauge the long-term success of the translocation effort.

Keywords

edaphic specialist, endangered, *Frithia*, mining, relocation, succulent, translocation.

Introduction

During 2008, an ecological survey by De Castro and Brits Ecological Consultants confirmed the presence of *Frithia humilis* Burgoyne, an endangered succulent plant species, at Inyanda Coal Mine (Exxaro) in Mpumalanga, where mining activities had already begun (McCleland, 2009). Mining activities provide the major threat to the persistence of this species, as coal deposits often underlie its rocky habitat (Cairncross, 2001); these sandstone outcrops are typically of the Dwyka and Ecca Groups, Karoo Supergroup (Burgoyne, Smith, and Du Plessis, 2000). Remaining natural populations of this plant species are at imminent risk from complete habitat transformation or loss.

The Inyanda Coal Mine's activities (Figure 1) threatened one of 11 naturally occurring populations of *F. humilis* (Burgoyne and Krynauw, 2005). As the mining license had already been granted before the species was found, translocation to three suitable receptor sites was carried out in 2009 as a mitigation attempt to save the population from extirpation (Figure 2). The translocation was performed by Inyanda Coal Mine, in collaboration with the South African National Biodiversity Institute (SANBI) and the Mpumalanga Tourism and Parks Agency (Burgoyne and Hoffman, 2011).

Translocation is the process whereby a population of living organisms is deliberately moved from one area to another suitable habitat within its existing distribution range (IUCN, 1987, 1998). Most often, such facilitated species movements aim to rescue individuals/populations from extinction, to restore populations, ecosystems, or habitats, or to conduct research on a species (Gordon, 1994).

Translocation can be successful only if a viable, self-sustaining population is established (Griffith *et al.*, 1989). Such a population should be able to reproduce successfully to ensure long-term survival/persistence (Jusaitis, Polomka, and Sorensen, 2004). Certain 'milestones' can be indicative of translocation success: seedling recruitment, plant growth, and plant reproduction (Menges, 2008).

Although translocation is increasingly being viewed as a suitable conservation method for endangered species (Seddon, 2010), the financial and genetic risks undertaken are great (Milton *et al.*, 1999). Translocations are infamous for their low probability of success (Mueck, 2000) and present a significant disturbance to the translocated population (Fahselt, 2007).

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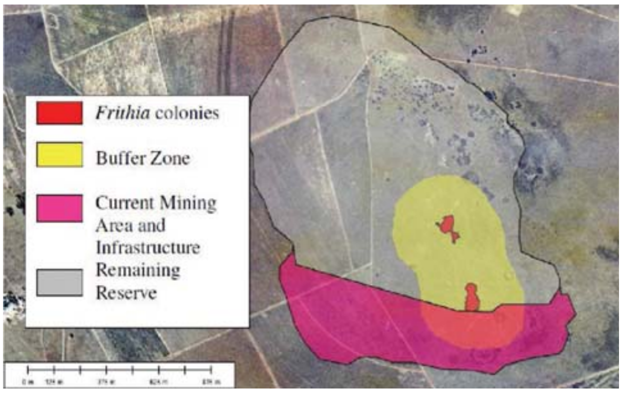

Figure 1—Location of the original donor *Frithia humilis* population *in situ*, prior to translocation in 2009. 'Remaining reserve' refers to the ore reserves (courtesy of De Castro and Brits Ecological Consultants (McCleland, 2009))

Figure 2—Opencast coal mining at Inyanda Coal. Arrow indicates the ridge where *Frithia humilis* plants occurred naturally (Photo: J.H.L. Smit)

Gordon (1994) emphasised that translocation should never be considered as a substitute for the conservation of *in situ* populations and natural habitats. However, as a mitigation measure, as in the case of the imperilled *F. humilis* population, translocation is becoming an essential conservation intervention where no other options are available.

The main aim of the *F. humilis* translocation discussed in this paper was to investigate whether the re-establishment of a threatened population elsewhere could act as mitigation, especially as the threatened species is an edaphic specialist (Burgoyne, Krynauw, and Smith, 2000). Essentially, this study provides a contribution to the evaluation of the viability of translocation as a conservation strategy in the South African conservation context, given that translocation has only been selectively applied nationally (Milton *et al.*, 1999). This study also contributes to scientific knowledge about species translocation.

Methods

Study species

Frithia humilis, commonly referred to as 'fairy elephant's feet', is a rare and endangered (Burgoyne and Krynauw, 2005) window plant (Figure 3A) in the succulent 'vygie' family, namely the Aizoaceae/Mesembryanthemaceae (Burgoyne, Krynauw, and Smith, 2000). This diminutive succulent, rarely protruding more than 30 mm above ground, has retracting leaves, which enables the entire plant to withdraw beneath the soil during the dry winter months (Moore, 1986) (Figure 3B). Consequently, the plant is protected from desiccation and other environmental factors (Burgoyne, Smith, and Du Plessis, 2000). It is therefore considered a cryptic species and becomes conspicuous only when in flower during the summer months, from November to March (Figure 3C).

The species is restricted to the Rand Highveld grassland of Gauteng and Mpumalanga (Figure 4; Mucina and Rutherford, 2006) and is regarded as endemic to this region (Burgoyne and Krynauw, 2005). It was assessed as being Endangered (EN), due mainly to its limited distribution range (the extent of occurrence being less than 3 000 km²) and its fragmented habitat (Burgoyne and Krynauw, 2005). Populations of the species are continually declining, as suitable habitats are increasingly being threatened by

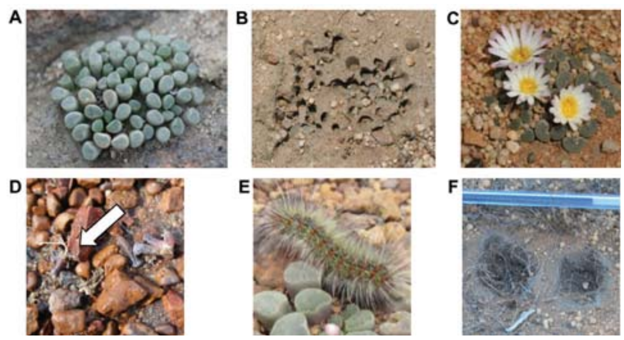

Figure 3—*Frithia humilis* is a dwarf succulent characterized by cylindrical, retracting leaves (A), each with a windowed tip which facillitates photosynthesis when the plant retracts underground (B) during dry periods. The plant is conspicuous only when it bears pinkish-white flowers (C) from November to March. Translocated individuals are mostly threatened by heavy rains washing plants out of their sods (white arrow pointing at exposed roots) (D), herbivory of leafs (E), and rodents digging up the plants in winter (F). (Photos: J.H.L. Smit)

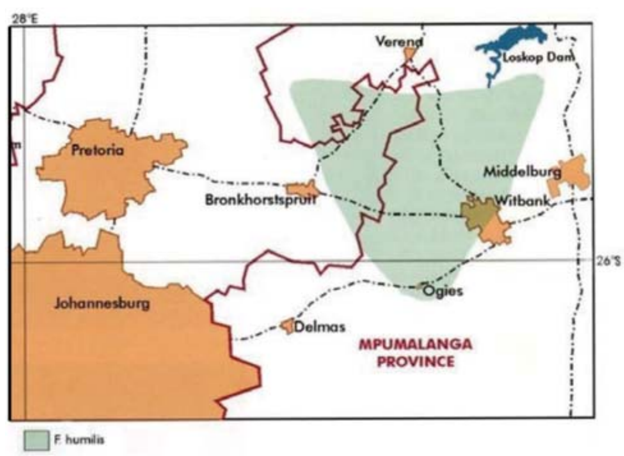

Figure 4—Distribution range of *Frithia humilis* within the limits of the Witbank coalfields (Burgoyne, Krynauw, and Smith, 2000)

expanding mining activities, informal settlements, overgrazing, alien vegetation, and unscrupulous harvesting for the horticultural trade (Burgoyne and Krynauw, 2005).

Study area

The translocation localities (receptor sites) were chosen within the Rand Highveld Grassland vegetation type (Mucina and Rutherford, 2006). Receptor sites were selected between Balmoral and eMalahleni (formerly Witbank) in Mpumalanga Province, on the periphery of the distribution range of the species. A number of potential translocation microsites were identified at each receptor site to which the rescued population was to be transplanted (Figure 5 and Table I).

The following guidelines were applied to select appropriate receptor sites and patches for translocation (Burgoyne and Hoffman, 2011):

1. *F. humilis* is a habitat specialist, requiring porous substrates to avoid inundation during the rainy season; Ecca and Dwyka sandstone of the Karoo Supergroup were the most **suitable geological formations**
2. **Shallow grit-pans** on exposed sandstone ridges had to be present into which the species could be transplanted
3. **Intact habitat** was a prerequisite, with limited ecological disruptions to prevent further disturbance of translocated populations
4. No other *F. humilis* populations should be present to **avoid gene pool contamination**
5. **Sites nearest the donor site** were considered ideal, as too great a distance could impair genetic variation and potential exchange
6. Conserved or **protected areas are priority** to avoid threats and to ensure the long-term persistence of the translocated populations
7. **Minimal slope** was preferred to prevent erosion and the washing out of translocated plants.

After the seven guidelines were considered at a range of potential receptor sites, which were identified during an aerial survey, the largest portion of the original donor population was translocated to a sandstone hill on private property, namely Goedvertroud (G) (Figure 5). This habitat is characterized by outcrops of the Ecca Group and was the only geologically suitable site that adhered to all the guidelines. Quartz pebbles, which facilitate seed germination (Burgoyne, Smith, and Du Plessis, 2000), were present in abundance. Topsoil layers were intact, protecting plants during the dry season. The slope was <3°.

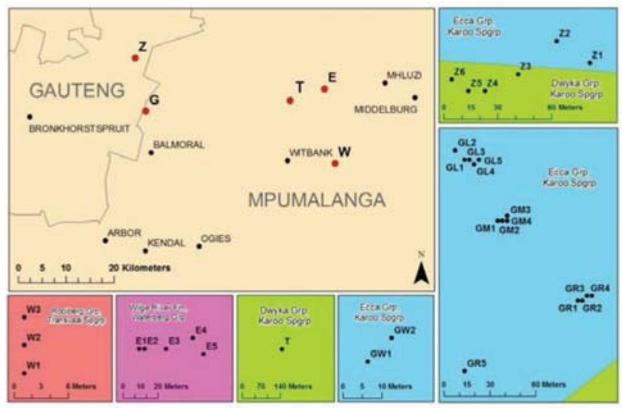

Figure 5—*Frithia humilis* (from locality T) was translocated to three suitable receptor sites (E, Eagles Rock, G, Goedvertroud and W, Witbank Nature Reserve) in 2009. Each receptor site consisted of a number of patches. Z, nearest natural population at Ezemvelo Nature Reserve. Grp, group; Spgrp, supergroup. The background colour is a key to the geology

Table I

Translocated populations and their micro-habitat conditions

Receptor site	Patches	Soil depth	Quartz pebbles	Slope	Species encroachment	Drainage
GL	5	Sufficient	Present, but washes away easily with rainwater runoff, leaving unconsolidated soil and exposed rocks	Steep enough for rainwater to cause damage to plants at *GL*1-4	Considerable peripheral presence of *Sellaginella dregei*, acting as catchment for washed away seeds	Good, no waterlogging
GM	4	Sufficient	See *GL*	Steep enough for rainwater to cause damage to *GM*1, 2, 4	See *GL*	See *GL*
GR	5	Sufficient	Present at all sites except *GR*4 and *GR*5, where pebbles wash away	Steep enough forrainwater to cause damage to *GR*4. Population expansion is promoted by slope at *GR*5, as downslope area is suitable for seed germination	*S. dregei* present only at two patches (*GR*1 and 2), leaving the remaining sites dry and prone to evaporative water loss. The miniature Crassula setulosa is present at *GR*5	See *GL*
GW	2	Sufficient	Present and stable	Very slight with little rainwater runoff	Peripheral encroachment of *S.* dregei at both sites	See *GL*
E	4	Sufficient	Imported and prone to washing way	Steep enough for rainwater to remove top layer of pebbles at *E*1-3	*S. dregei* encroachment at *E*4. *Microchola caffra* mainly present at *E*1	*E*4 prone to waterlogging
W	3	Shallower, more compact soil	Absent, instead a more angular pebble is present	Very slight	*Anacampseros subnuda, Crassula setulosa and M. caffra present*	Waterlogging apparent at all patches

Receptor site G is not protected by law and forms part of an abandoned coal mine with acid mine drainage along the footslopes of the hill. The mine water does not directly affect the upslope translocated populations (Burgoyne and Hoffman, 2011). Furthermore, past mining activities have resulted in major structural cracks which impede expansion of *F. humilis* populations due to severe water runoff. An established population of invasive *Acacia mearnsii* (black wattle trees) is present close to the populations, but no invasion of the receptor patches has been noticed.

Plants translocated to receptor site G were planted in patch clusters according to the availability of appropriate sandstone plates, namely GL, GM, GR, and GW. Each cluster was treated as a separate population, due to differing micro-environmental conditions (Table I) (Jusaitis, 2005). Dividing the G population in this manner also enabled more accurate statistical analyses.

Experimental translocations were also performed to test the response of the species, an edaphic specialist, to non-native geologies (Burgoyne and Hoffman, 2011). Neither of the two chosen receptor sites contained the typical geological substrate preferred by *F. humilis*. A part of the donor population was translocated to Eagles Rock Private Estate (E), a privately owned farm north-east of eMalahleni, and to a municipal reserve, Witbank Nature Reserve (W). The futures of the populations at these sites were more secure as receptor site E is managed by a trust and W is gazetted.

The E habitat comprises Waterberg Group sandstone, which is more compact (and less porous) than Ecca sandstones. Dominant outcrops at W were felsite rock plates from the Rooiberg Group (Transvaal Supergroup). These igneous rocks are also denser than those of typical *F. humilis* habitats. Both of these sites therefore posed an inundation risk during the rainy season, creating sub-optimal conditions for plant health (Burgoyne and Hoffman, 2011).

Patches of receptor site E have gentle slopes (5°) which are prone to sheet erosion. Hence, the patches are prone to topsoil and quartz pebbles being washed away, which could leave many adult plants uncovered with roots exposed (Figure 3D). One patch hosted *Selaginella dregei*, while another was the only other patch housing another species, namely a miniature grass, *Microchloa caffra*.

At receptor site W, the patches did not slope, which heightened the risk of inundation during the rainy season. Furthermore, this receptor site did not contain appropriate quartz pebbles, but larger, angular pebbles, which did not seem to provide appropriate protective conditions for germination. However, the presence of larger rocks provided protection for adult plants. Miniature succulent species, *Anacampseros subnuda* and *Crassula setulosa*, were present.

Sods of 40 x 40 x 5 (thick) cm containing plants and seed bank were lifted from the rock plates of the donor population during the translocation procedure, and transported and placed securely on rock plates at the receptor sites, creating 23 patches (Figure 5; Table I).

Post-translocation monitoring

Population censuses

An intensive post-translocation monitoring programme, by means of population censuses, was implemented over the course of three years (2010 – 2012) to gather data on trends in population sizes. Accurate and informative population data could be gathered whereby each plant was accounted for (Joseph *et al.*, 2006).

The presence of reproductive individuals (*i.e.* flowering plants) and seedlings is a prerequisite to estimating potential population persistence (Mueck, 2000). Over 3000 adult individuals and seedlings, as well as the seed banks, were translocated in soil sods (Burgoyne and Hoffman, 2011). The large sample size, and the difficulty of tracking individual plants due to their small size and seasonal retraction, required a system to measure the progress of population survival, plant growth, and reproductive success.

Relative size classes

Size classes for succulents can be determined by the number of branches in case of shrubs (*e.g. Euphorbia*; Knowles and Witkowski, 2000), rosette diameter when studying large forbs (*e.g. Aloe*; Pfab and Scholes, 2004), or number of leaves where small forbs are concerned (*e.g. Haworthia*; Biko'o *et al.*, 2011). Relative size classes were established for *F. humilis* (Table II) based on the number of leaves per plant.

Results from *ex-situ* studies on the species revealed that the number of leaves is a credible indication of relative *F. humilis* age. These surveys showed that no individual with less than three leaves produced flowers (Orlekowsky *et al.*, 2013). Such individuals could therefore be regarded as juveniles (non-reproductive individuals). The remaining groups comprised flower-bearing, reproductive individuals with size class 3–5 classified as the sub-adult group since its flower frequency represents a transition between juveniles and peak reproductive phases (Orlekowsky *et al.*, 2013). All other size classes were regarded as adult (Table II).

Size classes enabled the convenient comparison of trends in the translocated populations. Hence, the stabilization or demise of populations over time could be derived and estimations of population establishment made. Monitoring data, when related to population structure (size class distribution), and thus reproductive potential, provide a valuable gauge to estimate the success of the translocation.

Total counts

The main approach with total counts is to account for every individual in a translocation patch. Such a detailed survey serves as a baseline for future comparative purposes. Comprehensive baseline data was gathered for the translocated populations and all individuals at each translo-

Table II

Relative size class (RSC) classification for *Frithia*, based on the number of leaves per rosette

RSC class (Nr of leaves per plant)	Maturity	RSC description
<3	Juvenile	Non-reproductive
3–5	Sub-adult	Reproductive
6–10	Adult	Reproductive
11–15	Adult	Reproductive
16–20	Adult	Reproductive
21–30	Adult	Reproductive
>30	Adult	Reproductive

cation patch were counted. Count data was converted to mean total abundance per size class per translocation patch for each receptor site.

Monitoring season

Due to the seasonal appearance of *F. humilis*, *i.e.* it being cryptic during the dry winter months (Figure 3B), the populations were monitored only during the rainy season and peak flowering time (November to February).

Data analysis

Repeated measures analysis of variance (ANOVA) was applied to the data-set to determine significant differences in relative size class abundance and flowering between sites and over time. A mixed model analysis was also performed, enabling a more accurate and robust comparison between sites over time. A mixed model considers the dependency of the data, as each population at a particular site is derived from the previous season's population (StatSoft, 2011)

Results

Monitoring began in November 2009, six months after the translocation. No comprehensive data was collected on population size at the time of translocation in 2009, and the figures recorded during the first survey were therefore considered as a baseline. The results therefore depict the initial (short-term) response (2010–2012) of the populations to translocation disturbance.

The translocated cohort as a whole has shown neither a significant decline nor increase over the course of three years, as p-values from mixed model statistical analyses ranged from 0.398 to 0.968 (a p-value of <0.05 indicates a significant difference between yearly population sizes). Despite an initial decline in the mean total cohort during 2011, the plant numbers increased during 2012. Three receptor sites (GL, GR, and GW) contributed to the growth of the translocation cohort during this period (Figure 6).

To understand population size fluctuations, rainfall trends also had to be considered. Even though these trends were not statistically analysed, patterns observed in mean seasonal precipitation can be loosely linked with patterns in population size. Overall precipitation in the study area decreased over the monitoring period (Figure 7) (SAWS, 2013). The decrease was most pronounced in the eMalahleni area, which included receptor sites E and W.

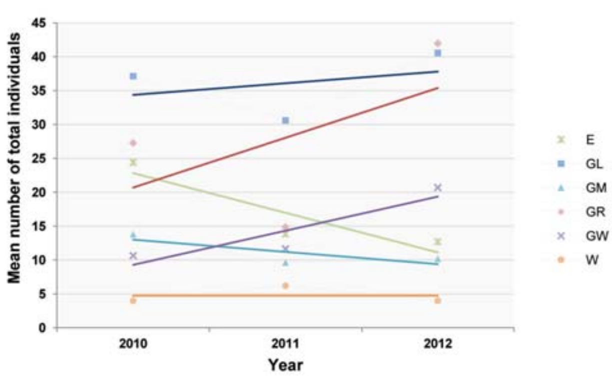

Figure 6—Mean number of individuals per translocation patch for each receptor site, spanning the initial monitoring period

Smaller plants in size classes <3 (seedling) and 3-5 (sub-adult) contributed significantly ($p < 0.05$) to the overall cohort population size, as the mean numbers of these groups had *p*-values between 0.000 and 0.001, when compared to older groups (Figure 8). The mean sizes of the seedling and sub-adult groups did not differ significantly. More importantly, these groups were the only size classes that fluctuated noticeably over time. Larger size classes were more stable in numbers (Figure 8).

Seedling recruitment by the translocation cohort in different receptor habitats required a closer look at the seedling (size class <3) component at each receptor site. Statistical tests indicated that translocation receptor sites did influence the differences in mean seedling number (p-value 0.046). GL and GR had significantly more seedlings than the other sites. Three sites (GL, GR, and GW) also showed an increase in seedling numbers over the three years (Figure 9).

The mean number of flowers, an indication of reproductive or seed-producing potential, significantly increased per patch over the total monitoring period, across all study populations (p-value 0.000). The decrease in flowering from 2011 to 2012 was not found to be significant (p-value 0.305). A closer look at which populations flowered most abundantly revealed that populations at E and GL flowered significantly more than the other populations overall, but that GW had the steepest increase in flowering over the monitoring period (Figure 10). GR and GW showed a significant overall increase in flowering (p-value 0.022 and 0.032 respectively).

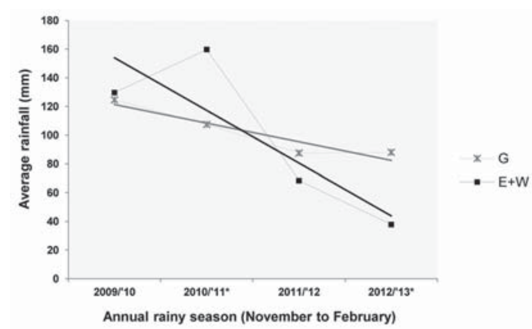

Figure 7—Mean rainfall (mm) of the wettest quarters for receptor sites at Bronkhorstspruit/Balmoral and eMmalahleni (SAWS, 2013)

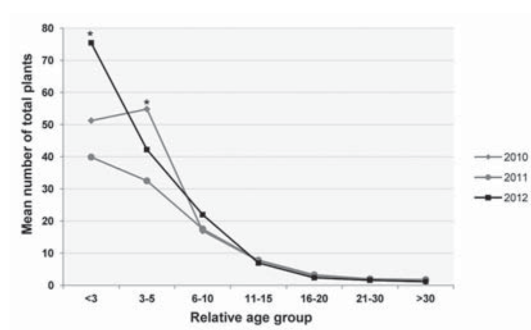

Figure 8—Mean number of individuals per patch for each relative age group. Each monitoring year is indicated separately. * Indicates size classes that differ significantly from other classes within a year ($p < 0.05$)

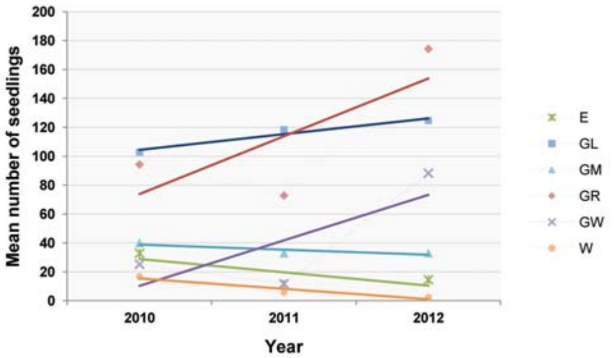

Figure 9—Mean number of seedlings (relative age group <3) per translocation patch for each receptor site over three years

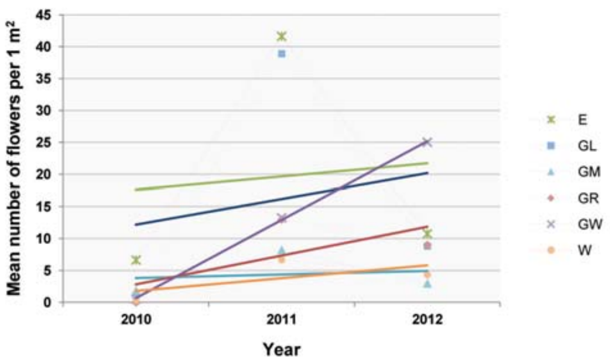

Figure 10—Mean number of flowers per translocation patch for each receptor site over three years

Discussion

The decline in population numbers from 2010 to 2011 (Figure 6) is an indication of the mega-disturbance caused by the translocation (Fahselt, 2007). Mortality is usually high when individuals are shifted to new environments, *e.g.* Mueck (2000). In the case of *Frithia humilis* it can be ascribed mainly to physical damage during the translocation, erosion that exposed the root systems (Figure 3D), and herbivory by rodents and insects (Figure 3E, F).

Rainfall is an important determinant in plant growth and establishment (Good *et al.*, 1999; Jusaitis, Polomka, and Sorensen, 2004). Sites E and W experienced less rain during the wettest quarter since the 2011/2012 rainy season than did sites at G (Figure 7). The G sites showed substantial population growth from 2011 to 2012, while a reduction in E and W populations was observed over this period. This suggests that rainfall could be a vital factor in population growth and establishment during the initial years. However, flowering declined in all populations, except GW, since the 2011/2012 rainy season. This requires further investigation.

Seedlings and juveniles comprised the largest portion of the translocated populations (Figure 8). More importantly, these groups were the only size classes that increased noticeably over time. Although not statistically significant, these changes were notable, since younger groups contribute significantly to population size, as was shown for the succulent *Euphorbia barnardii* (Knowles and Witkowski, 2000). High numbers of seedlings and stability in the number of reproductive individuals indicated effective seedling recruitment and population persistence in such populations (Knowles and Witkowski, 2000). Similarly, Biko'o, Du Plessis, and Myburgh (2011) found in populations of *Haworthia koelmaniorum* var. *mcmurtryi* that low numbers of seedlings indicated low recruitment rates, heightening the probability of extinction in such populations.

The overall fluctuation of the *F. humilis* translocation cohort was more pronounced in the younger size classes (<3, 3-5, and 6-10), indicating fluctuations in seedling recruitment, while older groups remained more stable (Figure 8). The seedling group is responsible for the largest increase in population size from 2011–2012 (Figure 8), which is ascribed partially to the significant upsurge in flowering from 2010 to 2011 and possible seed production during 2011. Germination and seedling recruitment in the 2011/2012 growing season was therefore successful, in spite of the reduction in flowering over this period. Although the increase in seedling numbers (GL, GR, and GW) was not statistically significant (Figure 9), it showed that post-translocation seed from flowering translocated individuals was viable.

Fluctuations in seedling numbers also showed similarities to general rainfall trends at different sites (Figure 7 and Figure 9): overall seedling numbers at sites E and W decreased with a reduction in flowering in the 2011/2012 season (Figure 10) and a decrease in mean seasonal rainfall (Figure 7). However, seedling numbers at sites GL, GR, and GW increased, despite a reduction in flowering at GL and GR. The lower precipitation at these sites was much less pronounced than at the E and W receptor sites.

Only site GW showed an increase in flowering during the 2011/2012 season. This is the site where plants were observed to be healthiest and where microsite conditions were optimal. There was only peripheral interference from other plant species, resulting in reduced interspecific competition, and limited erosion due to a relatively level slope. The quartz pebble and top soil layers were intact, protecting plants during the dry season.

The presence of the indigenous fern ally, *Selaginella dregei*, on the edges of the patches might have accounted for the 2011–2012 increase in seedlings at GR, GW, and E, as well as the stability of seedling numbers at GM. Despite the slight slope at these sites, the seeds were caught in the prostrate fern surrounding the sandstone grit pans. The absence of *S. dregei* at W and other E patches contributed to substrate instability in rainy seasons and poor seed retention/germination at these sites. The presence of pioneer species, including the grass species *Microchloa caffra*, also indicated slightly deeper and more stable soil on sandstone plates, where *F. humilis* seedlings were able to establish more successfully. Some parts of E (E1-3), as well as the W habitat, had noticeably less co-occurring species, shallower soils, and conspicuous water runoff areas.

Conclusions

Fluctuations in numbers have thus far not been significantly detrimental to the translocated population, since flowering was abundant and seedling recruitment ongoing. Seedlings contributed significantly to population size and thus ensured the persistence of translocated *F. humilis* plants at the receptor sites from season to season. Fluctuations in population numbers will continue for some years until the population has settled.

Furthermore, the overall increase in seedling numbers points to appropriate germination conditions at many receptor sites, especially those at G, the receptor sites comprising typical *F. humilis* geological substrate. Ideal conditions include the abiotic micro-environment (level slope, sufficient drainage, and soil stabilizing species). Our findings suggest that receptor sites with similar geological conditions to the donor site must receive priority during the translocation of an endangered habitat specialist.

In-situ conservation obviously remains the most effective and safest way of preserving endangered species. However, in the face of human development impinging on natural habitats, research such as this study that clarifies the response of such species to translocation (which may become inevitable in many cases) may prove invaluable for the design of future translocation procedures and monitoring strategies. The results of this study serve as a baseline for future studies at the receptor sites. Ongoing monitoring will endeavour to determine whether translocation was a successful mitigation measure. Even if the future outcome is negative, this study would have contributed to our knowledge of translocation ecology in South Africa.

General recommendations

With the probability of translocation becoming an increasingly important environmental mitigation tool in the mining sector, along with the lack of peer-reviewed literature on translocation in South Africa (Milton *et al.*, 1999), scientifically sound research on translocation procedures and their effects is required. Furthermore, no reference is made to translocation for conservation purposes in South African legislation regarding endangered wildlife species (National Environmental Management: Biodiversity Act, 10 of 2004). Hence, translocation is very rarely considered as a mitigation measure when species are threatened by local extinctions.

Insights gleaned from this study will inform mining institutions faced with similar conservation challenges. Firstly, comprehensive knowledge of the target species, its habitat requirements, and ecological interactions is needed when a translocation protocol for a specific species is designed (Gordon, 1996; Parsons and Zedler, 1997).The participation of conservation biologists is therefore imperative.

Secondly, a long-term monitoring programme has to be initiated. Information gathered from post-translocation monitoring is the cornerstone of reliable knowledge on species translocation (Menges, 2008). Clear research questions, scientifically robust monitoring methodology, and appropriate sample size whereby statistically practical data sampling can be employed are pivotal to acquiring data for meaningful analyses. Volunteer organizations such as CREW (Custodians of Rare and Endangered Wildflowers)[1] should be involved in the monitoring and to encourage public participation.

The above-mentioned recommendations are well within the capacity of mining companies, as proved by Inyanda Coal and Exxaro. Mining companies can vastly improve our knowledge of rare or endangered species translocation in South Africa by involving relevant expertise, research institutes, and volunteer organizations (Milton *et al.*, 1999). Properly recorded, documented, analysed, and published monitoring data can regularly advise future policies on species translocations.

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Comparison between artisanal and small-scale mining in Ghana and South Africa: lessons learnt and ways forward

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Synopsis

Artisanal and small-scale mining (ASM) plays a fundamental role in the national and local economies of resource-rich countries in Africa. As such, more effort must be geared towards fostering this type of economic activity to sustain livelihoods in rural communities. Across Africa, efforts to operationalize ASM based on a sustainable development framework have been quite tedious and often ineffective. This is because most of these frameworks lacked context and an understanding of the continuum from the artisanal through small-scale and up to the junior miner, grouped under the general term 'ASM'. Driven by the need to contextualize some of the definitional issues in this niche sector, and gain a clearer understanding of their peculiar challenges, this paper aims to contribute to the debate on ASM by considering two of Africa's resource-rich countries – Ghana and South Africa. Since South Africa has made greater inroads in protecting the interests of small-scale miners, we thus draw comparisons from both countries' approach to ASM, outline the lessons learnt, and provide recommendations regarding the ways forward.

Keywords

artisanal and small-scale mining, ASM, poverty reduction, legal framework, value addition, support structures.

Introduction

Artisanal and small-scale mining (ASM) is one of the major contributors to national income and is a recognized pillar for poverty reduction in the mineral economies of the developing south (Hentschel *et al.*, 2003; IIED, 2002; ISG, 2011). As an economic activity it has the potential to contribute to sustainable development while successfully aiding the development of rural communities. However, despite this recognized potential, ASM activities remain largely informal, with many attempts at formalization or regulation being sub-optimal (ILO, 2002; AMV, 2009; World Bank, 2013). Furthermore, although the African Mining Vision has acknowledged the importance of ASM, this niche sub-sector of the mining industry continues to face challenges and is still lacking regulation specific to its needs. But, realistically, would regulation of ASM activities mitigate its debilitating effect on the environment?

South Africa, which is a global mining powerhouse and provides the best-case scenario for harnessing mineral rents for growth and development in Africa (Sinkala, 2009), has put in place structures to safeguard the interests of artisanal and small-scale miners under the Mineral and Petroleum Resources Development Act (MPRDA), Act 28 of 2002. However, pertinent issues such as lack of a common definition of ASM; being unable to distinguish and categorize the different types and levels of artisanal and small-scale miners; the high standards or benchmarks for environmental and social regulations; and other geo-political dynamics, also make providing tailored solutions to ASM difficult. That said, South Africa has made greater inroads in addressing some of the challenges of small-scale mining (SSM) at the formal level than most developing countries. Even in this context, a significant proportion of the sub-sector is still not captured or does not operate within the legal framework.

Ghana has been chosen in comparison to South Africa because it is a trailblazer in global mineral production, but lacks context-specific guidelines for ASM. The promulgation of its Minerals and Mining Act (MMA) – Act 703 of 2006, largely incorporated the former mining laws, *i.e.* the Provisional National Defence Council Law (PNDCL) 153 and the small-scale gold mining law (PNDCL 218). This new law, to some extent, also intensified illegal artisanal mining in the country.[1] The reason for this is because in both the MMA and the Environmental Protection Act, there are undefined social and environmental guidelines for regulating ASM concessions. As

1The local terms for illegal mining are different in Ghana and South Africa. In the Ghanaian parlance, illegal mining is termed 'galamsey', which is translated as 'gather them and sell' or (get them and sell). Zama zama is the local South African term for illegal mining

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a result, unregulated mining activities in communities have been on the rise, despite ASM being instrumental in allaying poverty at the rural level (see arguments in UNECA and AU, 2009 on ASM).

Regionally, the impacts of ASM are mixed due to the overshadowing effect of its negative externalities on land and the environment at large. In Tanzania for example, ASM workers earn ten times more than farmers, and incomes from ASM are invested in shops, taxis, bars, building guesthouses, and farming. In a sense, this sensitive sub-sector presents an opportunity as an alternative source of livelihood for rural dwellers and for local economic development. As such, there are lessons to be learnt from the implications of a highly regulated ASM environment, as is the case of South Africa, and that of the less regulated regime in Ghana, which may help address the critical challenge of mitigating the negative effects of ASM and maximizing its potential benefits.

Undoubtedly, ASM's fundamental role in local economies requires identifying 'ways forward' that can best inform an integrated approach to the drafting of a common international and regional framework for the sub-sector. The objective of this paper, therefore, is to draw parallels from Ghana's and South Africa's approaches to ASM, in terms of the economic, social, environmental, and legal aspects within the broader framework of the African Mining Vision (AMV). This is geared towards specific inputs into the MPRDA and the MMA Act 703 while identifying the 'continuum' challenge between the artisanal and the small-scale miner. We distinguish between artisanal and small-scale mining. 'Artisanal' as used in this paper refers to unorganized mining activity that does not make use of sophisticated machinery, whereas 'small-scale' is used in the context of organized miners that may not necessarily use sophisticated machinery but have a higher revenue turnover.

The regional frameworks: Yaoundé Vision and the MMSD in the AMV

The African regional frameworks on mining (large or small) are hinged on the current African Mining Vision, which aims to transform Africa's mining sector into a knowledge-based economy premised on the 'optimal exploitation of mineral resources to underpin broad-based sustainable growth' for the continent (UNECA and AU, 2009). The AMV is a home-grown vision and structure developed by African governments that incorporates most international and regional calls on sustainable development, particularly the Mining Minerals and Sustainable Development (MMSD) and the Yaoundé Vision on ASM. The Yaoundé Vision, which is specific to ASM, is a declaration document on the importance of the sub-sector, the need to build capacity, and to encourage interlinkages with the broader social economy. This niche sub-sector is the backbone of many rural economies in Africa and provides an alternative source of livelihoods while increasing local purchasing power, but has been quite neglected. The conclusion from the AMV is that the sector has the potential to catalyse small-scale and medium enterprises (SMEs) in rural communities for poverty alleviation. This is, however, often constrained by sustainability issues on the continent, and undefined international and local agenda that are not specific to the needs of SMEs (UNECA and AU, 2009).

Poverty cycles in rural communities are in most cases aggravated by mining regimes and regulations not based on the differing needs of the artisanal, small-scale, and the junior miner. As a result of this constraint, the AMV further contends that artisanal and small-scale miners cannot use their mining rights to access funds, or generate adequate incomes to enter into joint ventures with more capable partners. This is because most mining regimes lump the interests of ASM together, and hence are able to target only those in the small and junior-scale mining categories. Most often, the needs of the artisanal miner is not captured under such formal regimes. Previous interventions recognized the problem not in these terms, but rather in terms of the broader constraints, such as lack of basic mining technologies, top-down approach to dealing with the sub-sector, and a lack of continuity in funding activities for the sub-sector. There has been, on the whole, a poor understanding of the sub-sector and its peculiar needs. This is not just akin to the location and the size of the industry or the geographically-specific economic challenges, but more about the nature and the different needs of the upper and lower bounds within each group of the three categories. Here, we suggest that even within the artisanal group, there are differing needs based on ability to access resources and how the mining regime can capture operators' interests. This also applies to small-scale and junior miners.

On the whole, the AMV identified problems within the wider sub-sector as stemming from:

- Inadequate regulation
- Lack of understanding of the peculiarities of the sub-sector
- Problems with local infrastructure
- Lack of research and developmental support by government to provide a basis for this type of economic activity
- Failure in terms of funding of environmental management education
- Lack of access to orebodies
- A lack of understanding of business management fundamentals and principles (UNECA and AU, 2009).

This analysis feeds into the 'categorization' dimension of viewing the sub-sector, and helps in tailoring solutions specific to each group. In this light, there must be exploration of the broad interlinkages between ASM and other sectors and ways of fostering the growth of the sub-sector. Furthermore, training must be aligned to the different groups within each category, as well as incorporating sound business management principles. In the short term, building capacity of ASM should be aimed at addressing the problems identified in the AMV to help build resilient ASM communities and the transitioning of the Yaoundé Vision. In addition, the AMV's 'Action Plan' seems like a logical framework that recognizes some of the needs of the sub-sector, and provides measures and indices on how to incorporate the sub-sector into policy frameworks. However, without an understanding of the different categories (as well as groups) in each dimension, and their different needs, it would be difficult to enhance the formalization, efficiency, and effectiveness of the sub-sector.

The above discussion leads to three key points of relevance that shape our further reflections of the ASM sub-sector in South Africa and Ghana. Firstly, the need for well-targeted interventions, which can only be possible when the definitional issues in both regimes can be tailored for the different groups within each category of artisanal, small-scale, and junior miners. The second intent, which is tied to the first, is orchestrating programmes that can enhance value-addition, especially of metallic and precious minerals, to facilitate a broader linkage to the mineral value chain and the social economies of these two countries. Furthermore, interlinking the institutions that are part of the broader mineral value chain can enhance the quality of the metallic, precious, and industrial mineral products through an ASM beneficiation strategy at an appropriate level of mineral development. This must be aimed at building the capacity of the rural economy, and relieving dependence on the urban economy. These reflections are incorporated into the following discussions by first providing a general overview of both countries' ASM sub-sectors and some of the challenges that may have created dichotomies and intensified informality within the sub-sector.

Case studies: overview of ASM in Ghana and South Africa

Ghana

Ghana is one of the oldest mining countries in Africa, and has extensively rich mineral resources in gold, diamonds, bauxite, and manganese; and unmined but proven deposits of feldspar, limestone, and silica. Small-scale mining in Ghana predates the arrival of the Europeans, and the country has a 2000 year history of gold mining (Hilson, 2001). This type of economic activity has been a source of livelihood to many artisanal miners and others involved directly or indirectly in the sub-sector. ASM has often been overlooked as an effective contributor to gross foreign earnings because production is mostly at the artisanal level (*ibid*). However, the sub-sector has been supportive in alleviating poverty and fostering rural development in many deprived communities. As an important sub-sector, it is highly unregulated, with laxities in the mineral and environmental regimes in protecting the interests and safety of both miners and indigenes alike.

ASM in Ghana involves gold and diamond mining, and to a lesser degree sand and stone quarrying activities. Gavin Hilson's extensive research on small-scale mining concludes that the sub-sector is overly reliant on gold because of its propensity to generate wealth quickly, with the economic importance of the sub-sector often overlooked by national gold mining analyses (Hilson, 2002). ASM activities are found in the Obuasi, Tarkwa, and Wassa areas in the Western, Ashanti, Brong, Ahafo, and northern regions of Ghana, as well as along major water bodies.

Economic ontributions

According to Tschakert and Singha (2007), over the past decade ASM production, which is dependent on gold and diamonds, has risen dramatically in Ghana because of rising mineral prices. Economic contributions from the sub-sector accounted for an estimation of US$461.2 million in 2003, with current contributions to the national economy unknown. The current labour force participation extends to well over one million miners involved in gold, diamonds, sand winning, and quarrying industries that are predominantly informal or are illegal (Aryee, 2012).

With regards to the formalized sub-sector, only slightly over 300 small-scale miners are registered or are licensed with the Minerals Commission and receive some form of assistance from the government (Mbendi, 2013). However, this form of assistance to aid formalization has been sub-optimal. Hilson (2003) contextualizes this, in his review of ASM under the MMSD that the efforts by government to aid the sub-sector have gradually waned. On the whole, the sub-sector's contribution in terms of production has risen, showing a gradual increase from 1989 until 2003 (per available figures by Tschakert and Singha, 2007). However, the immense number of one million illegal miners compared to just over three hundred licensed or registered small-scale miners should warrant greater justification for effective legalisation of the sub-sector. 'Formalization' as a key policy concern would increase the potential for curbing illegal smuggling channels, and subsequently increase local mineral output. This should be a major government priority, because essentially the sub-sector contributes not only to the national coffers, but also to alleviating poverty. Most illegal Ghanaian miners also use the incomes they receive as start-up capital for business ventures such as shops, pubs, etc. An International Labour Organisation (ILO) report in 2003 confirmed that the majority of the 13 million people worldwide directly dependent on ASM had two or more dependents to support.

The path of formalizing the ASM sub-sector started 1989 when the government of Ghana embarked on a structural adjustment of the economy with technical support from international financial institutions. Mining was identified as a core area to be restructured. Thus, the government of Ghana also recognized the need to progress with formalization of the illegal small-scale gold sub-sector due to the leakage of revenue. In that effort, the Precious Mineral's Marketing Corporation (PMMC) Law (PNDCL 219) was enacted, establishing a government corporation that was solely responsible for the buying of all precious minerals and stones from artisanal and small-scale miners. PMMC, currently a quasi-governmental company instead of a 'corporation', operates through licensed agents that buy gold, silver, and diamonds from legal miners. Thus by law, gold and other minerals produced on a small-scale level cannot be sold or exported without having gone through the PMMC. Only large-scale mining companies export refined gold and or polished precious minerals.

Environmental and social Impacts

According to Ghana's Minerals Commission, gold is found along a series of tectonic boundaries that were active some 2 billion years ago. This caused gold belts to be formed containing Proterozoic greenstone-type gold lode deposits in Birimian rocks. This mineralization extends into Senegal and Mauritania, and northwards into Burkina Faso (Hilson, 2002). The Tarkwaian gold-bearing deposits constitute a second gold belt formed under different conditions, and consist of auriferous quartz-pebble conglomerate deposits.

As a result of the nature of this type of formation (*i.e.* placer or alluvial gold) and the geography of its location, it presents no physical entry barriers to any person that wants to engage in the sub-sector. Similarly, in most parts of the world where 'placer gold' exists, it is relatively easy for ASM to be centred around this type of mining, because very low capital investment is required, and the use of simple but destructive techniques requires a low level of technical specialization. These factors result in disastrous effects on the environment, due to the rudimentary practices applied, such as sluice boxes, hammers, buckets, shovels, and pans for prospecting, and removal of vegetative cover on mineral-rich soils.

There has been a lack of adherence to safety and health standards, as well as structural deficiency such as support for excavations. Furthermore, there has been degradation of landscapes, and destruction of water bodies through the use of mercury in the amalgamation process. This threatens human health, pollutes water bodies, and causes other ecological impacts. According to the Wassa Association of Communities Affected by Mining, over 200 water bodies have been polluted due to incorrect mercury usage, resulting in serious health hazards such as damage to the central nervous systems of humans and animals, and increased risk of skin cancer in areas where ASM is prevalent (Ghana Business News, 2011). NSR (1994) research on ASM miners found, from urine, hair and blood samples taken from the miners, that they have been increasingly exposed to large quantities of mercury. Substantially, the careless use of mercury and land degradation from ASM are the greatest threats to the environment in Ghana. As a result, the biggest barrier to an effective and formalized ASM sub-sector has been the environmental and mineral regimes. These have been sub-optimal in addressing the differential needs of the different categories of ASM, the methods used, and the consequences of these methods.

Tschakert and Singha, (2007) have argued that although ASM activities predominate because of poverty, the Ghanaian populace see the sub-sector as a nuisance to the environment. However, ASM is a direct consequence of the history and intensity of poverty in rural communities. Hence, the mineral and environmental regime may need to revise the older approach of viewing the consequence of ASM activities as a nuisance, to one that must facilitate coherence with the legislature. That can be made possible only when tailored solutions to environmental problems take into account the peculiar and differentiated needs of the different categories within ASM, as well as the different types and groups.

Organization of ASM and challenges within the legal framework (MMA, Act, 703)

As per the current law (Mineral and Mining Act – MMA, Act 703), a small-scale mining licence is granted when an interested party first obtains a customary and legal right to use the land from the Chief of the area (Appiah, 1998). Observing all customary procedures, a person applies to the Minister for a mining license, which is distinct from a mineral right, through the Minerals Commission. The Minerals Commission assesses the credibility of the applicant and forwards the prospective miner's application to the Environmental Protection Agency to assess the environmental impacts. This Agency is the environmental regulatory body responsible for environmental protection. It then makes its decision on whether the Minister should grant the applicant the mining license. Besides this bureaucratic procedure, Tschakert and Singha (2007) contend that the District Assemblies, which are municipal bodies, require an upfront (lump sum) payment, and thereafter a yearly payment to mitigate the environmental impacts of mining activities. On reflection, this serves as a disincentive to Ghanaian individuals (largely those within the category of 'artisanal') wanting to formally register their operations with the Commission. Most would therefore prefer to operate outside of the legal regime to avoid paying the lump sum and annual contributions for environmental remediation.

With regard to the Mining Law (MMA), the interests of ASM are captured under articles 81 to 99 of the Act. In the Act, small-scale mining is clearly recognized as a prudent economic activity reserved for citizens of Ghana. However, the different types of ASM activities are not differentiated in the Act. The law applies across the board and lumps the interests of all small-scale mining operatives together. The flaw in this, the authors believe, stems from the fact that the older and more specific law (PNDL 218 in 1989), which was the first legal framework to legalize the activities of small-scale gold mining, was specific to that industry. Hence the incorporation of its abridged version into the current legal framework should have been sensitive to the different types of mining activity. Furthermore, it should have considered the nature of the socio-economic status of individuals involved in mining at the artisanal and small-scale levels as a criterion for providing for their varied needs.

This is key to any regime that wants to provide a rural development and poverty alleviation system, especially where the communities are artisanal and small-scale miners and rural. This is because the impact of this sub-sector at the artisanal level on mitigating poverty and transforming rural economies is greater than that of many large-scale mining operations. In this regard, Hilson (2002) notes that the pivotal role of ASM in poverty alleviation justifies an increase in community capital and government help to diversify such local economies.

Even though the AMV has recognized the importance of building capacity, Ghana has yet to specifically translate some of the outcomes in Cluster Goal 4 of the AMV's Action Plan into a proper ASM policy framework in this light. Thus for Ghana's MMA, Act 703, the challenges hinge on:

1. Incorporation of best practices of international and regional frameworks
2. Identifying the varied interests and definition of the various categories under ASM
3. The inability to contextualize and quantify the impacts on the environment based on a set of established guidelines.

Finally, and pertinent to the challenges discussed, it is essential to understand that there is a continuum from the artisanal to the small-scale and then to the junior miner. Therefore, the provision of support services, environmental guidelines, and benchmarks may have to consider the varied dimensions of the ASM sector for better quantification and formalization.

South Africa's ASM sub-sector

The South African minerals sector is one of the most diverse in the world. South Africa is home to the largest deposits of chrome, manganese, platinum group metals, vanadium, and vermiculite. South Africa was formerly the leading producer of gold and diamonds (USGS, 2012). Unlike Ghana, the country has been able to harness its mineral resources for tangible growth and development, and is currently the most developed country on the African continent. Traditionally, both large- and small-scale mining have been the building blocks of the economy, with large-scale mining having had a positive impact GDP and development.

The small-scale mining (SSM) sub-sector in South Africa, like elsewhere, is very difficult to classify and categorise (Mutemeri *et al.*, 2010). It is also significantly smaller than the Ghanaian sub-sector. Firstly, there is no clear and encompassing definition of SSM, and related to this, a general lack of data on the size, activities, and geographical distribution of the sub-sector. The Mineral and Petroleum Resources Development Act (MPRDA), which regulates mining activities in South Africa, does not define SSM but makes provision for a Mining Permit which includes those activities that would generally be accepted as SSM, based on the physical size of an operation (limiting it to 1.5 ha) and the duration of the mining activity (3 years).

A broader definition of ASM, however, includes mining operations with no or low levels of mechanization, undertaken by individuals, families, or groups. The activities are possibly on a subsistence level, and are often seasonal or supplementary to other economic activities, and in many cases are informal (outside of the legal system) (DME, 2007). Within the South African sector, mining activities range from artisanal mining to small-scale and junior mining and to very large, industrial-scale mining. It is argued here that the MPRDA does not address this full range of activities, with the focus on the SSM being on the small, rather than artisanal, miners. It is understood that the size of the SSM sub-sector has increased since the transition to democracy, with the sub-sector opening up to more people. There is, however, a significant lack of reliable data (Mutemeri *et al.*, 2010). Mutemeri and Petersen (2002) estimated that there were around 20 000 miners active in the sub-sector, although a more recent report estimates the number to be 10 000 (Buxton, 2013), with many of them women. Of these, only an estimated 6000 were operating within the legal framework and mostly on the small-scale mining end of the spectrum (DME, 2007) (note that these figures are from a 2001 report and hence refer to the previous legal framework).

Artisanal and small-scale miners are active in a range of commodities, depending largely on the availability of deposits, ease of mining, processing, and extraction, and access to markets (Mutemeri and Petersen, 2002). Gold, diamonds, coal, and construction materials (*e.g.* sand, clay, sandstone, slate, granite) are more commonly mined, with construction materials predominating (Mutemeri *et al.*, 2010). Due to the nature of ASM, the methods are limited to open pit and primitive underground excavations. The level of beneficiation depends on the commodity, and with the exception of construction material, is limited. In the case of construction materials, finished products (*e.g.* bricks) are often produced by ASM operatives (Mutemeri *et al.*, 2010).

The re-opening of old mine workings is not uncommon in ASM and is presenting a significant environmental, safety, and security challenge to the large mining companies that are either still operating or are responsible for these mines. In this case there is a blurred line between informal ASM and illegal mining. Illegal mining in South Africa is a criminal industry involving national and international syndicates and valued at around R5.6 billion (address by the Minister of Mineral Resources to the National Council of Provinces in the debate on illegal mining, 16 September 2009), and has been increasing since the early 1990s, largely due to downscaling in the large-scale mining sector. Illegal miners (zama-zamas) access disused mines, largely gold mines, to extract the small quantities of remaining ore. The areas around Barberton, Westonaria, and the Free State gold fields have been hardest hit by their activities (SA Government News Agency, 19 July 2012).

Legal framework and support structures

As already noted, the MPRDA makes provision for a mining permit to accommodate small-scale miners. The maximum size (limited to 1.5 ha) and the duration of the permit (3 years) are both small in comparison to the mining rights granted to large operators for a period of 30 years, where the size is not limited. Prior to the MPRDA the majority of South Africans did not have access to mineral rights and this was seen as a major block to the development of SSM, which was identified as 'a vehicle for the creation of jobs', a 'channel for increased access to the mining industry', and an opportunity to optimally exploit resources that large-scale miners are unable to operate profitably (DME, 1998). The 1998 White Paper, *A Minerals and Mining Policy for South Africa*, further stressed that all forms of mining should be subject to the same requirements in respect of licensing, safety, health, and the environment and hence the requirements of the MPRDA, which from the perspective of ASM are onerous.

The application for a mining permit requires the submission of an Environmental Management Plan (an abbreviated version of the Environmental Management Programme required for a mining right) notification and consultation with the landowner, occupier, and other affected parties. With the exception of the less arduous environmental requirements and the social and labour plan, which is required only for a mining right, mining permit holders have to meet the same requirements as those for large-scale mining, namely reporting, monitoring, and performance assessment requirements, the requirement to make financial provision for environmental remediation, and the need to plan for and obtain closure. In addition to the MPRDA, artisanal and small-scale miners may also need to comply with the requirements of the National Environmental Management Act (NEMA) should any of their associated activities (*e.g.* roads, pipelines) trigger a Basic Assessment or Scoping and full Environmental Impact Assessment; the National Water Act for any water uses; and a range of other environmental, labour, health and safety, and business requirements. The financial resources, skills, and capacity required to meet this range of legal requirements are high, acting as a barrier to artisanal and small-scale miners who wish to enter the sub-sector legally and a severe constraint on the ability of the sub-sector to contribute to poverty alleviation (Hoadley and Limpitlaw, 2004). This is especially true of those closer to the artisanal end of the spectrum. The question is thus – how can artisanal and small-scale miners be accommodated in the formal system, recognizing the need to maintain environmental, social, and labour standards?

A partial answer to this question is – with support. The Department of Mineral Resources (DMR) through their Directorate for Small-Scale Mining, along with other institutions such as Mintek, the Council for Geoscience, and the Mining Qualifications Authority (MQA) offer support specifically to the SSM sub-sector so as to enable greater participation. The DMR's major focus is on assisting small-scale miners to meet the legal requirements, with the Small Scale Mining Board providing capacity and experience in planning and developing viable mining projects through their pre-feasibility stages (DMR, 2013). Furthermore, Mintek's Small-Scale Mining and Beneficiation Division supports the sub-sector through research and development of appropriate technologies and by providing training and business development skills on the manufacturing and marketing of products from clay, sand, gold, and granite (Mintek, 2013). The MQA has also set aside funds for the provision of technical training in minerals extraction, geological aspects, health and safety, environmental management, and mining legislation (MQA, 2013).

Parallels between South Africa's regime and Ghana's

The overview of the case studies shows how neither the MPRDA or MMA are able to identify the varied interests of the artisanal, and sometimes the small-scale, miner. As illustrated in Figure 1, the mining legislation in Ghana and South Africa addresses only a portion of the current activities in the SSM sub-sector, with those at the lower end of the spectrum, the artisanal miners, functioning outside the legal framework. The arduous nature of the different legislations acts as a barrier to entry in both cases, with the impacts of the mining laws not being felt at the lower end of the continuum. With resources and technical and financial support, the range of artisanal miners being included in the formal sub-sector can increase, albeit to a limited degree. These are increasingly available to those at the top end of the ASM continuum.

South Africa's MPRDA is stringent on environmental protection, as is shown in Table I. Thus, it is easier under both the MPRDA and the MMA for the upper bound, from small-scale to junior miner, to be captured, regulated, and furthermore to obtain a mining license or permit than for those in the bracket of the lower bound of the artisanal. Ghana's somewhat relaxed regime also makes no mention of artisanal mining, nor does it attempt to categorize the different types of SSM and their peculiarities in the MMA. The MMA regime therefore makes it very easy for miners to operate informally, with no mining license/ permit.

Hence, on the whole, the impact of both regimes regarding support services and resources is felt only within the identified niche (somewhere between the ranges of 2 to 3 in Figure 1). In South Africa's context, the MPRDA is also not able to differentiate between artisanal and small-scale mining, with no reference to or definition of what artisanal means in the Act. As a result, the impact of both regimes has been questionable as regards mitigating the needs of the mining rural poor, who are in most cases heavily dependent on the artisanal form of mining for direct or indirect livelihoods. Understanding these contexts (in Figure 1) leads to the similarities and parallels that can be drawn from both case studies. Table I lists some of the core issues that have been identified by the AMV as pertinent to addressing some of the challenges of the ASM sub-sector in Africa and the need for a drive towards a sustainable rural socio-economic development.

Contextualizing the issues of ASM (what have been the lessons?)

From both the Ghanaian and South African contexts, it is evident that the lack of a definition and, specifically in the South African case, the shortage of reliable data, is a hindrance to the development of the ASM sub-sector. The broad range of activities that are grouped under the general title of 'artisanal and small-scale mining' needs further and finer classification in order to understand and provide for the specific requirements of the different sub-groups. Collecting data that illustrates this diversity within the sub-sector, the scale and distribution of ASM, and its contribution to the economy would allow for more informed and hopefully better decision-making by the authorities and development agencies. The 'size limit' of the South African Mining Permit is an example where a 'one-size-fits-all' approach has been taken without considering the continuum of participants active in the sub-sector and the differences between the various orebodies. The size of the permit or licence granted

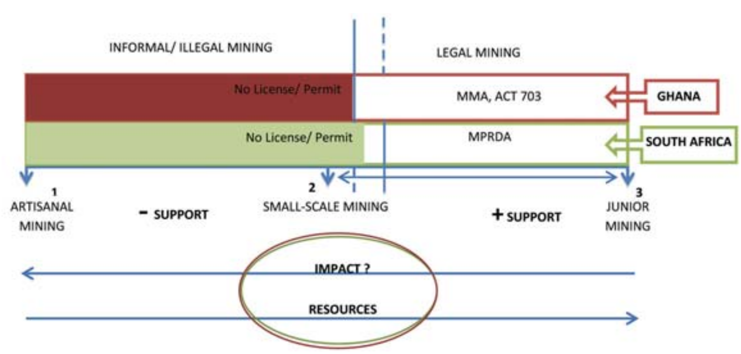

Figure 1—Authors' interpretation of the impact of South Africa's and Ghana's mineral regimes on informality

Table I

Parallels and similarities between South Africa and Ghana's ASM regimes

	South Africa's MPRDA	Ghana's MMA, Act 703
Definitional issues	a) The law does not define small-scale mining but makes provision for a mining permit, for small–scale operations. b) No provision is made for artisanal mining in the Act. c) Regulation covers all minerals, whether occurring naturally or in residue deposits or residue stockpiles. d) Guidelines to assist small-scale miners have been developed within various government departments, including Mineral Resources and Water Affairs.	a) The law is applicable to only small-scale mining with no reference to the different categories of small-scale miners b) No provision is made for artisanal mining in the Act or attempt to define them c) Regulation is tailored to mining only gold, diamonds, and some forms of industrial minerals and winning and quarrying, but even at the artisanal level there is no clarity or distinction d) No environmental limits and guidelines specific to the varied artisanal and small-scale miner needs are provided.
Rights	**Mining Permit**	**Mining License**
Size and duration	1.5 ha for 2 years, renewable for a further 3 periods each not exceeding 1 year.	21 ha for 5 years, renewable subject to the Minister's discretion.
Environmental requirements	An Environmental Management Plan is required prior to granting the Mining Permit (vs. Environmental Management Programme required for Mining Rights for large-scale mining). Additional requirements in other pieces of legislation.	Government body (Environmental Protection Agency does the assessment). No EMP is required of the miner applicant at the small-scale level.
Fund for rehabilitation	Requirement to make financial provision for rehabilitation and management of negative environmental impacts. This should be reassessed annually.	Payment of lump sum to the District Office (Environment) and a subsequent annual payment. No production and financial reporting as a pre-requisite for the payment of lump sum when project is exhausted.
Social and Labour Plans (SLP)	No Social and Labour Plan requirements for Mining Permit.	No Social and Labour Plan requirements for Mining License.
Royalties	The legislation requires holders of a Mining Permit to pay the state royalties. However, below a certain threshold level (R100 000) this is waived (as per Mineral and Petroleum Resources Royalty Act 28 of 2008).	Payment of between 3% to 6% required of small-scale miners as royalty.
Market access	No specific provisions around marketing.	Subsidized below market price and saleable only to the requisite government body – in this case the Precious Mineral and Marketing Company (PMMC).
Level of reach of regulatory body.	Mineral resources are a national competency with regional offices based in each of the nine regions (provinces).	District Offices of the Minerals Commission are located in all areas where small-scale mining activity is present.
Support structures	Various agencies providing services, including the Department of Mineral Resources: Small-Scale Mining Directorate, Mintek, Mining Qualifications Authority, Council for Geoscience, Small Enterprise Finance Agency (previously Khula).	Minerals Commission, Ministry of Lands and Natural Resources, Geological and Survey Department.
Cohesion between LSM and ASM	The relationship between ASM and large-scale mining ranges from support and assistance, cooperation to conflict.	There is non-cohesion between LSM and ASM, although some LSM companies have implemented programmes to facilitate cohesion.
Other legal frameworks	Environmental requirements under the National Environmental Management Act, water use and licensing requirements in terms of the National Water Act, Mine Health and Safety Act; and a range of other pieces of legislation related to labour and skills and business operation.	Environmental Protection Act, 490; New instruments to aid in the MMA- mine support services, compensation and re-settlement, licensing, explosives and health and safety regulations have been recently passed in 2011. However, as to their application to the sub-sector, this is not very clear.

for ASM is a factor since the orebody formation can extend beyond the licence or permit boundaries. There is thus a need for legal regimes to consider the type of mineral deposit and the geological formation, and define a prerequisite size for the different groups within the categories of artisanal and small-scale miners. This would aid in improving the regulation and management of the different variants in ASM. For instance, although this distinction is also not made clear in the Ghanaian situation, the number of years for which a mining licence/permit is granted, and the larger size, give the small-scale miner an added advantage in recouping profit compared to the South African case.

Another pertinent issue is that of environmental protection. The laxity in Ghana's framework and a lack of proper guidelines and practice makes it very easy for even registered small-scale miners to abscond with profits without due diligence on the environment (notably mine plan and closure). As a result, the EMP in South Africa's case, which is sometimes a stumbling block as noted above, may be a key solution that can be tailored to fit the Ghanaian context. This would enable the country to curb the land degradation and pollution that currently prevail in areas of ASM activity. However, only when government is able to systemically identify and categorize the different types of ASM on the continuum scale (Figure 1) will the 'EMP solution' work in the instance of Ghana. Even in the case of South Africa, where support structures have been provided for anyone requiring help with an EMP, the hurdle is quite high for an uneducated artisanal miner who may be at the bottom of the tier (Figure 1). As such, consideration must be given to firstly defining the interests of all the groups on the continuum scale, and their varied needs, before such regulations and guidelines are determined.

Furthermore, in both Ghana and South Africa, value addition is limited, yet this is an important opportunity for increasing the revenue generated from ASM. This was suggested in the AMV review section as a key import to dealing with the sub-sector. Critical to this is skills development, access to appropriate technology, and reliable and fair markets, as was recognized in the AMV. In this regard, sustainability certification is also a recent opportunity leveraging market demand for sustainability to improve social and environmental conditions and outcomes. Additional benefits include access to better markets, greater returns, and an opportunity for learning by artisanal and small-scale miners (Blackmore *et al.*, 2013). The 'Fairtrade' and 'Fairmined' Gold and 'Associated Precious Metals' Initiative is one such scheme focusing on ASM in Latin America. Such sustainability certification comes with a range of requirements but with operation within the legal system not being varied or categorized. Thus, in addition, it could become onerous for artisanal miners not captured in the formal regime to comply with the assessment standards for certification. However, creating a local beneficiation strategy such as that currently being implemented by Mintek (although limited to small-scale miners) and lowering the bar for 'fairtrade' and 'fairmined' sustainability certification can be an opportunity for value creation and linking with the broader social economy.

As was discussed earlier, there are a number of institutions in South Africa that aid SSM, although the capacity and resources may not be matched to the size of the sub-sector. This support is limited in the Ghanaian context. However, Ghana's district offices of the Minerals Commission, which are located in all areas where small-scale mining activities are present, is one that South Africa could consider. Having officials located in the major small-scale mining areas will not only assist with data collection and monitoring, but also facilitate compliance by the miners. Although this institutional support structure is available in Ghana, support services for value-addition as well catering to the needs of ASM are lacking because of funding issues (Hilson, 2001). Therefore, providing a 'one-stop-shop' at the district level where information on the legal requirements and financial support is freely available will be helpful in redressing these lessons learnt in the Ghanaian case.

Conclusions and ways forward

Some have argued that the environmental and social costs of artisanal mining outweigh the benefits, and so these activities should not be encouraged. However, the immense contribution of artisanal mining to poverty eradication at the community level cannot be ignored; and hence every attempt must be made to address the negative aspects and optimize the benefits in order to find a better balance between the two. Nevertheless, the question would always remain whether this form of mining should be encouraged (see Scott, 1998 in Mutemeri and Petersen, 2002). The answer the authors purport is that simplistically, the major aim of ASM is poverty alleviation, hence it must be encouraged, although not at the expense of the environment. Stringent and cautious efforts must be made by the governments of both Ghana and South Africa to address some of the peculiar challenges that the ASM sub-sector is fraught with, in order to promote the interests of the artisanal, small-scale and junior miner as well as regulate their activities to aid in the protection of the environment.

From the lessons learnt and the schematic 'Action Plan' by the African Mining Vision, it is expedient that the first point of call in terms of policy objective would be tailoring a solution that recognizes the different types of ASM along the continuum scale of the three types of miners, as indicated in Figure 1. As indicated by both case studies, the MPRDA and the MMA must aim to define artisanal mining, and refine their definition of small-scale mining, to incorporate the needs of all along the continuum. This would further mean a systematic analysis based on the socio-economic status of the miners, the type of minerals exploited, the number of miners to be defined as artisanal, small-scale, or junior, their production values, and strategies to foster effective mineral beneficiation. At face value, the EMP presents the ultimate way forward in dealing with environmental protection, but it seemingly creates a barrier for the artisanal miner who cannot afford to meet the benchmarks. As such, there is need for a simplified EMP supported by institutional structures that can reach those already involved in illegal artisanal mining and to protect their interests as well as the environment.

In the instance of Ghana, the following are recommended to improve the MMA, Act 703 and facilitate clarity on the issue of ASM:

- ➤ Operationalize the AMV's 'action plan' into a one-stop-shop at the Mineral Commission's district offices
- ➤ Identify some of the best practices through a simplified environmental management code of practice on land degradation and reclamation, water and air quality, and mine closure that are specific to the different dimension within the ASM sub-sector
- ➤ Set health and safety standards and promote awareness
- ➤ Regularize the informal sub-sector through approaches that recognize the varied interests of all artisanal and small-scale miners
- ➤ Provide the institutional support structures that aim to give backing in terms of mineral value-addition, and to link it with the broader socio-economic framework in rural communities.

Impliedly, the justification is for a holistic and multi-pronged approach at the international level that would feed into a regional and local policy framework. However, this can be effected only if international integrated benchmarks and guidelines are developed to grow the ASM sub-sector as a burgeoning 'economic activity'. This would be in order to address the core need of poverty alleviation at the national level, as well as build alternative and sustainable livelihoods and economic infrastructure for rural dwellers.

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Strategy towards a mining industry-wide Buy-and-Maintain Quiet initiative to reduce noise induced hearing loss

by H. Gumede*, K. Blomerus*, D. Coutts†, and J. DeBeer‡

Synopsis

The challenges of noise emission in the mining industry are well known. These challenges are exacerbated by the increasing trend towards mechanized mining, and there is general consensus that an effective industry-wide Buy Quiet initiative (BQI) will significantly assist in reducing noise-induced hearing loss by minimizing noise at its source.

In its endeavours to improve the health of workers, the MOSH Noise Team has facilitated development of a proposed strategy and structure for a BQI. Extensive consultation with stakeholders resulted in support for the initiative. The MOSH Noise Team was advised to solicit the contributions of consulting mechanical and electrical engineers (CM&EEs), whose support is viewed as critical for realization of the initiative, since elimination of noise at source is an engineering challenge, and most procurement standards and specifications are set and managed by engineers.

A workshop with CM&EEs and their representatives, as well as group environmental engineers (GEEs), confirmed the urgent need for the initiative and provided valuable insights. The workshop used obstacle-based planning techniques to identify the factors on which the success of this BQI will depend.

Most potential obstacles to the implementation revolved around proper scoping, leadership commitment, and companies' adherence to the initiative. Lack of involvement by the relevant stakeholders and economic issues were also identified as potential obstacles.

Delegates at the workshop felt that the successful implementation of the industry-wide BQI, will depend on the mining industry addressing the specific obstacles. The most critical and urgent issue was identified as the formation of a properly constituted industry-wide BQI task team that includes representatives from critical stakeholder groups and which is mandated and empowered to drive the initiative.

Keywords
occupational safety and health, noise-induced hearing loss, noise reduction, Buy Quiet initiative.

Introduction

The mining industry's zero harm vision and 2013 health and safety milestones demonstrate the commitment that mining companies have made towards elimination of noise hazards in the workplace. There is a general consensus that the challenge requires more than a willing and able occupational health practitioner supported by personalized PPE, and that the industry will have to focus most of its energies on the elimination of noise at source. This is no simple and easy task, and will require leadership involvement across the industry in addressing noise hazards.

The CoM MOSH Learning Hub Noise Team has been promoting an industry-wide Buy Quiet initiative (BQI). In the last decade, individual mining companies have established Buy Quiet policies, albeit with limited success. Unless industry partners with and motivates suppliers to invest specifically in the development of quieter equipment, efforts to eliminate noise hazards will remain reactive. It has now become imperative for the mining industry to embrace the challenge and develop an industry-wide BQI that will create a 'step change' in noise management and reduction.

Various critical stakeholders, including the Learning Hub, group environmental engineers (GEEs), the MOSH Task Team, mine professional associations (MPAs), independent consultants, the MOSH Noise Team sponsor, and consulting mechanical and electrical engineers (CM&EEs) have been consulted regarding this initiative, and all confirmed the need for it and pledged support. It is widely believed that the CM&EEs is the critical industry group in this initiative, because noise elimination at source is largely an engineering function and most procurement standards fall under the responsibilities of engineers.

An industry-wide Buy Quiet commitment is required, and for it to succeed a firm decision from mining companies to procure only equipment and machinery that complies with specific noise emission standards is essential. The motivation for an industry-wide Buy Quiet commitment is based on the following factors:

- In the last decade, individual mining companies that have established Buy Quiet policies have met with limited success
- While individual Buy Quiet policies from mining companies do help, it is only

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through the collective demand of the mining industry that suppliers will be motivated to focus on noise reduction as a critical part of their product development and performance

➤ In order for industry to be sustainable in future, and owing to the effects of globalization, the mining industry is going to become even more mechanized. Therefore it is imperative to manage noise at the design stage of the machinery/equipment. With equipment life of 5 to 10 years or longer, industry must become proactive and play a collective facilitative role towards 'real innovation' that can significantly lower noise at source. Industry-wide cooperation with suppliers will create a win-win result for both parties, as suppliers that already meet the legal requirements will have the potential to offset their development costs against a potential increase in market share

➤ Industry has spent a substantial amount of money over the last decade in compensation for the hearing loss induced by high noise levels emitted by machinery. Profitability and sustainability challenges make this scenario going forward very expensive. The financial impact could be even greater if companies are faced with class actions for compensation by former mining employees

➤ It is substantially cheaper and more effective for mining companies to embark on an industry-wide BQI as opposed to individual companies undertaking reactive developments in engineering and PPE.

Practical path towards a mining industry-wide Buy Quiet initiative

To effectively setup an industry-wide BQI, the mining industry must meet the following strategic objectives:

a. Identify and rank noise sources throughout the industry. Mining companies have done remarkably well in this regard and this information is readily available. However, it needs to be collated and normalized
b. Establish 'stretched' noise emission targets per machine or type of equipment based on the noise source and noise level
c. Determine the approximate aggregate demand for specific machinery/equipment that mining companies use currently and will use over the next 10 years, as well as the demand for specific spares equipment
d. Engage with a wide spectrum of suppliers at executive level to communicate and obtain commitment milestones for the first two points above.

There might be a need to classify equipment that is specific to South Africa so that noise hazard for global equipment can be addressed by global initiatives such as Earth Moving Equipment Safety Round Table (EMERST) and the coordination of noise-related research and development.

Key steps towards the achievement of these strategic objectives are:

i. Establish a mining industry Buy Quiet task team with sub-teams as required, with the sole mandate of executing the above objectives. The team establishment to be facilitated by the MOSH Learning Hub
ii. Set up round-table discussions at the executive level with the supplier groups to facilitate the BQI at the highest level
iii. Establish specific standards based on equipment/machinery *life–cycle cost* as opposed to *purchase cost*. Develop standards for noise emission levels at the start-of-use (new equipment), mid-life use, and end-of-life use. Requirements must also include maintenance requirements for maintaining low noise emission during the operating life of equipment
iv. Establish realistic and equipment-specific noise reduction targets and milestones with the task teams and suppliers
v. Monitor and manage progress towards the milestones.

It is important that an industry-wide BQI is developed with the active participation of mining industry executives. This on its own will constitute a step change, because noise hazard is currently the responsibility of occupational health departments, and there is no effective involvement of executives nor the integration of engineering and procurement departments.

Challenges in executing a mining industry-wide Buy Quiet initiative

As mentioned, initiatives to date have had limited success and it is important to learn from the potential pitfalls that have been identified:

➤ Inability of the industry to collaborate on this initiative
➤ A fixation on purchase cost as opposed to life-cycle cost
➤ Inability of mining companies to sell this strategy to their individual operations
➤ Supplier resistance based on international product specifications and requirements
➤ Suppliers resistance due mainly to upfront investment that might be required in some research and development initiatives and the targets set by task teams
➤ Potential reduction of competition and monopoly issues
➤ Potential intellectual property issues.

The above challenges require specific mitigation and action, but they are surmountable.

Industry consultations

The establishment of a BQI for the mining industry is an ambitious goal and requires wide consultation.

After extensive consultation with the MOSH Task Force, MPAS, and key executives the initiative was presented to the CM&EEs, since they are seen as the potential custodians of the initiative. The CM&EEs agreed to the initiative in principle and requested that a work session be organized to define the details.

The MOSH Noise Team facilitated the majority of the consultative workshops and used obstacle-based planning techniques and systems approach principles for scoping the challenges. Briefly, the process applies the following logic:

a) Soliciting obstacles (from the delegates) that will cause the failure of BQI. This step was inclusive and all obstacles were considered and extensively discussed

b) Deriving intermediate objectives to mitigate and eliminate the obstacles identified
c) Verbalizing the obstacles and intermediate objectives
d) Classification and correlation of the obstacles
e) Deriving an intermediate objectives map.

The obstacles, together with the accompanying intermediate objectives, are shown in Table I. The obstacles were classified into the following five categories:

a) *Leadership commitment* – issues relating to commitment by the mining industry leadership to adhere to and implement the BQI
b) *Scoping issues* – issues relating to the scoping, planning, scheduling, and execution of the BQI with the main aim of maintaining a focused approach to the initiative. They also included issues around the creation of verifiable but generic standards; the creation of standardized equipment noise databases; accompanying change management processes; explicit terms of reference; and measurable outputs. Precursors such as the formation and composition of the task teams were also grouped under the scoping issues. The scoping of this initiative should seriously consider and include an industry-wide Buy and Maintain Quiet initiative, as opposed to the BQI only
c) *Stakeholder management* – how and when to involve all relevant stakeholders such as OEMs, labour unions, other engineering stakeholders, and State departments
d) *Economic viability issues* – related to the balance between economic realities, technological limitations, and management of the noise hazard, and included the feasibility of some endeavours
e) *Others* – mostly operational concerns that can be overcome by implementing effective HCPs, COPs, and operational discipline procedures. Most of these concerns are generally not part of the BQI scope.

In summary, the obstacles showed that:

a) About half of the identified obstacles to implementing the BQI are related to scoping issues
b) The most urgent and pertinent issue regarding

Table I

Obstacles and intermediate objectives

No.	Identified obstacles	Intermediate objectives
1	Non-adoption of the industry-wide Buy Quiet Initiative (BQI). Not adhering to the agreed BQI	- Mining industry CEOs and leadership to sign off, commit and adhere to the BQI
2	Lack of management commitment	- Mining industry CEOs and leadership to sign off, commit, and adhere to the BQI - Mining industry CEOs to provide effective leadership - Chamber of Mines (CoM) to lobby non-affiliated organizations to sign off and adhere to the initiative
3	Inadequate involvement of engineers	- CM&EEs to take the responsibility of involving other engineering stakeholders *(e.g.* AMRE, SAIMechE, SAIMM) - Task team nominations should include representatives from other engineering stakeholders (e.g. AMRE, SAIMechE)
4	Absence of a clear strategy that deals with existing equipment	- BQI to incorporate new and existing machine components - A clear strategy from the industry to replace existing non-compliant machinery - Scoping and terms of reference from task teams should be explicit on this strategy
5	Absence of a proper framework during design (goals/objectives/vision, structures)	- Proper scoping and definition of generic standards, including the verification of these standards for the industry
6	Expense involved in designing quieter equipment (normally at the expense of productivity)	- Identify, prioritize, and rank noise sources throughout the mining industry - Creation of machinery noise database - Mining companies to set long-term noise reduction/tolerance targets
7	Stakeholders not having a common interpretation and understanding of the new requirements	- Proper scoping and definition of generic standards, including the verification of these standards - Terms of reference of the task team should prioritize and deliver the proper scope and standards for the entire initiative
8	Absence of a proper change management procedure for this initiative	- Terms of reference of the task team should prioritize this - Use of MOSH change management initiative
9	Unrealistic expectations	- Clear measurable framework - Establish and set noise emission targets per machine/equipment (ALARP) - Obtain extensive involvement of relevant experts
10	Not involving OEMs	- OEMs should be part of task teams - Establish a list of OEMs, who will nominate representatives to this initiative - Mining industry to stipulate the parameters of OEMs' involvement
11	Companies continuing to purchase from existing suppliers (OEMS) that do not conform to the BQI	- Firm commitment from mining companies to procure from BQI-compliant suppliers - Mining industry CEOs and leadership to sign off, commit, and adhere to the BQI
12	Not implementing penalties for non-compliance	- Explicitly include this during scoping and on the terms of reference for the task teams - Firm commitment from mining companies to procure from BQI-compliant suppliers
13	Failure to address the total cost of ownership and economic viability	- Value each case per equipment/ machinery - Identify, prioritize, and rank noise sources throughout the industry - Creation of noisy machinery database (part of identification) - Mining companies should set long-term noise reduction/tolerance targets
14	Being overwhelmed by the BQI challenge	- Positive mindset and realistic plan - Proper prioritization (part of scoping by the task team)
15	R&D teams not focusing on common noise -reduction techniques and possibilities (including funding)	- Common approach by and funding to the R&D teams

Table I (continued)

Obstacles and intermediate objectives

No.	Identified obstacles	Intermediate objectives
16	Non-accountability of line management	- Change management process for implementing the BQI to include mitigation of this obstacle
17	Lack of an industry-wide, verifiable equipment noise database	- Build and improve on existing database
18	Absence of a common approach for the whole industry	- Emphasis that occupational health and safety is for sharing, not competition - Proper scoping and definition of generic standards, including verification of these standard
19	Not developing realistic targets that all stakeholders agree on, commit to, and sign off	- Proper scoping and definition of generic standards, including verification of these standards - Terms of reference of the task team should prioritize and deliver the proper scope and generic standards for the entire initiative
20	Lack of buy-in to the initiative	- Change management process for implementing the BQI to involve all stakeholders - Use of MOSH change management initiative
21	Current lack of technologies to address the noise hazard in some equipment	- Effective use of hearing conservation programmes (HCPs) - Firm commitment from mining companies to procure from BQI-compliant suppliers
22	Non-involvement of procurement departments	- Change management process to involve procurement departments
23	Poor maintenance and scoping	- Scoping should include Maintain Quiet as opposed to Buy Quiet only
24	Inadequate monitoring	- Scoping should include Maintain Quiet as opposed to Buy Quiet only - Documentation of the work for referencing
25	Inability to identify suitable OEMs	- OEMs/suppliers should be part of task teams - Establish a list of OEMs, who will nominate representatives to this initiative - Mining industry to stipulate the parameters of OEMs/supplier involvement
26	Lack of standards to verify noise levels claimed by OEMs	- Proper scoping and definition of generic standards, including verification of these standards - Terms of reference of the task team should prioritize and deliver the proper scope and generic standards for the entire initiative
27	Lack of a weighted and signed-off industry noise database	- Identify, prioritize, and rank noise sources throughout the mining industry - Creation of machinery noise database - part of identification Mining companies should set long-term noise reduction/tolerance targets
28	Trying to address all the problems within this BQI, including scope creep	- Proper scoping and definition of generic standards, including verification of these standards - Terms of reference of the task team should prioritize and deliver the proper scope and generic standards for the entire initiative
29	Lack of incentive for coming up with correct solution	- Terms of reference of the task team should prioritize and deliver on this - Firm commitment from the mining companies to procure from BQI-compliant suppliers
30	Absence of involvement and acknowledgement of the noise challenge by the State	- Detailed strategy to involve the State
31	Poor communication – sharing and combining noise reduction initiatives	- To be achieved through MOSH Leading Practice Initiative
32	Poor business cases/solutions that do not make economic sense	- Value case per equipment/ machinery - Identify, prioritize, and rank noise sources throughout the mining industry - Creation of machinery noise database (part of identification) - Mining companies should set long-term noise reduction/tolerance targets - Terms of reference of the task team should prioritize and deliver on this - Firm commitment from mining companies to procure from BQI-compliant suppliers
33	Poor composition of task teams – appointment/ secondment of wrong people to task teams	- Mining leadership and all stakeholders to appoint / second right task team members
34	Consolidation of previous investigations on noise reduction	- Consolidate previous work (especially since 2002) - Part of MOSH responsibility
35	Lack of manufacturer and supplier liability	- Proper and explicit scoping and terms of reference of the task team should prioritize and deliver on this
36	Industry and suppliers not understanding and implementing Section 21 of the MHSA 29/1996	- Proper and explicit scoping and terms of reference of the task team should prioritize and deliver on this
37	Scops of the BQI too limited	- Proper scoping should be along the lines of Buy and Maintain Quiet as opposed to Buy Quiet only
38	Incorporating the agreement to SABS standards	- Proper and explicit scoping and terms of reference of the task team should prioritize and deliver on this
39	Not learning from past failures in noise control	- Need for a forum to close the loop – feedback from different initiatives - MOSH process can be that forum
40	Accepting and implementing easier solutions in noise control, such as HPDs	- Effective HCPs and COPs should address this - Proper leadership on the BQI
41	Actions in case of emergencies and equipment availability	- Keep record of un-silenced equipment - Critical spares and equipment should have the same standards as other equipment
42	Not educating and demystifying the scientific silencing of equipment	- MOSH process can assist with this - Understand what is required on silencing of equipment as part of scoping
43	Not marketing the BQI to suppliers	- OEMs/suppliers should be part of task teams - Establish a list of OEMs, who will nominate representatives to this initiative - Mining industry to stipulate parameters of OEMs/supplier involvement
44	Non-involvement of research institutions	- Involve through MOSH

Table I (continued)

Obstacles and intermediate objectives

No.	Identified obstacles	Intermediate objectives
45	Non-availability of generic measurement standards	- Proper scoping and definition of generic standards, including verification of these standards - Proper and explicit scoping and terms of reference of the task team should prioritize and deliver on this
46	Alignment with the other State departments *e.g.* labour	- Detailed strategy to involve relevant State dpartments
47	Involvement of organized labour	- Unions should be part of the task teams - Detailed strategy to involve unions
48	Unethical tendencies by mining companies	- Mining industry CEOs and leadership to sign off, commit, and adhere to the BQI - Firm commitment from mining companies to procure from BQI-compliant suppliers
49	Lack of a holistic approach to noise management *e.g.* not removing workers from high-risk areas	- Effective HCPs and COPs should be able to address this
50	Not involving service providers and the SME portion of the market	- Task teams should include representatives from SMEs
51	Absence of clear and unambiguous definitions	- Proper scoping and definition of generic standards, including verification of these standards - Proper and explicit scoping and terms of reference of the task team should prioritize and deliver on this
52	Not addressing and implementing any of the above	- Mining industry CEOs and leadership to sign off, commit, and adhere to the BQI - Mining industry CEOs to provide effective leadership

scoping is the nomination and creation of properly constituted task teams. The governance structure and terms of reference of the teams must be clarified up-front, although the teams should establish their own execution strategies and plans. Once the task teams have been formed, they should expedite the following:

- Explicit project scoping to avoid scope creep
- Serious consideration of, and include in the scoping, an industry-wide *Buy and Maintain Quiet* initiative as opposed to BQI only
- Identification and prioritizing of noise sources throughout the mining industry
- Creation of a noisy machinery/equipment database
- Creation of an equipment supplier/OEM database
- Setting of long-term noise reduction/tolerance targets

c) The scoping should be explicit on the change management that is required for this initiative and should use the MOSH methodology

d) There was general consensus on the need for mining leaders to provide effective leadership by signing off, committing, and adhering to the BQI

e) The mining industry must involve all relevant stakeholders (*e.g.* OEMs, labour unions, State, and research institutions). These stakeholders should have representatives on the task teams. However, the mining industry has to be very tactful in the stipulation of the parameters for stakeholder involvement. The task teams are expected to provide leadership in this regard

f) Task teams should take into consideration economic viability issues during target setting. Some of the activities that are critical in achieving this include:

  i. Value case per equipment
  ii. Identify, prioritize, and rank noise sources throughout the mining industry
  iii. Creation of a noisy machinery database
  iv. Setting of long-term noise reduction /tolerance targets.

Conclusion and recommendations

Extensive consultations have indicated that the mining industry believes that the industry-wide Buy Quiet initiative is a proactive endeavour that will greatly assist in combating noise-induced hearing loss and the management of noise at the 'real' source. Although the Buy Quiet policies of individual mining companies do help in this regard, it is only through the collective focus and commitment of the mining industry, backed up by aggregate equipment spend, that suppliers will be motivated to focus on noise reduction as a key issue in product development and performance.

To institute the industry-wide Buy Quiet initiative, the mining industry has to effectively address the identified obstacles. The most critical and urgent issue is the formation of a properly constituted industry-wide task team, which must include representatives from key industry stakeholders. However, great tact should be exercised in stipulating the parameters of general stakeholder involvement. Properly constituted, this initiative has the potential to be the path-finder and a benchmark for other challenges that require extensive cooperation within the mining industry.

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➤ The Theory of Constraint (TOC) body of knowledge.

Glossary of terms

ALARP	As low as reasonably practicable
AMRE	Association of Mine Resident Engineers – *Association responsible for originating and promoting the general advancement of all matters appertaining to the work of engineers in the mining industry*
BQI	Buy Quiet initiative
CEO	Chief Executive Officer
CoM	Chamber of Mines of South Africa
COP	Code of Practice
CM& EEs	Consulting Mechanical and Electrical Engineers - *Technical Committee within the CoM*
GEEs	Group Environmental Engineers – *Technical Committee within the CoM*
HCP	Hearing conservation programme
HPD	Hearing protection device
HPD TAS	Hearing protection device, training awareness and selection
Leadership	Applies to leadership in different levels and roles
MOSH	Mining Occupational Safety and Health leading practice adoption system
MOSH Noise Team	A MOSH Team - *responsible for facilitating the adoption of noise prevention leading practices*
MPAs	Mining professional associations
OH	Occupational health
OEMs	Original equipment manufacturers (*in this report, is used interchangeable with suppliers and service providers*)
NIHL	Noise-induced hearing loss
R&D	Research and development
SAIMM	Southern African Institute of Mining and Metallurgy
SAIMechE	South African Institute of Mechanical Engineering
SMEs	Small and medium enterprises
State	South African Government. ◆

Optimizing value on a copper mine by adopting a geometallurgical solution

by A.S. Macfarlane* and T.P. Williams†

Synopsis

This paper describes how knowledge of the orebody morphology and ore morphology can be used to optimize the planning, mining, and metallurgical output from an open pit copper mining operation, such as to significantly increase the stability of the whole value chain process, and increase the reliability and value of the process outputs.

In the case under consideration, the orebody contains both copper and cobalt. This in itself provides a challenge, in that the two metals do not occur in consistent ratios across the orebody as a whole.

Furthermore, mineralogical differences within the orebody have a significant impact on plant performance in terms of throughput rates, acid consumption, and recoveries.

In order to stabilize and optimize the plant performance, it is necessary to firstly have a complete understanding of the geometallurgical factors that affect performance, and then to have a sound knowledge of how these are distributed within the orebody.

These models then inform the mine planning strategy that optimizes cash flow and NPV, and also allow the development of a stockpiling strategy that not only stabilizes the plant, but also allows variations in the plant feed according to ore type and grade in volatile price scenarios.

Integral to the realization of these opportunities is the establishment of an appropriate measuring, control, and reconciliation system, customized to the optimization objectives.

The paper describes how all of these factors and strategies can be integrated to produce optimal value from the orebody through to final dispatched product.

It also shows the significant value that can be released through such an approach.

Keywords
Central African Copperbelt, Ruashi, morphology, geometallurgy, cut-off grades, stockpile management.

Background

Ruashi is an opencast copper and cobalt mine situated near Lubumbashi in the Katanga province of the Democratic Republic of Congo. The mine produces copper cathode and cobalt carbonate/hydroxide, which are sold under offtake contracts. Copper is produced by a hydrometallurgical process that incorporates leaching-decantation, solvent extraction and electrowinning(SX-EW), and cobalt precipitation operations.

The property has been prospected and operated intermittently since its discovery in 1919, being operated as a quarry-type operation, before extensive drilling was carried out during the feasibility process under Metorex, in 2005/06. A first-phase oxide flotation concentration plant was commissioned in 2006, and subsequently put on care and maintenance once replaced by the phase 2 hydrometallurgical plant in 2008.

Mining is by conventional open pit means, with truck and shovel operation (Figure 1). The softness of the oxide ore allows a considerable amount of free-dig operation, while harder strata require drilling and blasting.

The relatively low rock mass rating also results in shallow pit slopes, which produces a constraint on the operation, given that the mine borders on urban development from Lubumbashi.

The mine operates with 5 m bench heights and 40 t articulated dump trucks. This allows a reasonable amount of flexibility and grade control.

Grade control is done using initial grid drilling, followed by infill drilling to improve confidence and detail. Thereafter, production drill-holes are sampled to provide dig plans and polygons, which are laid out by the mine surveyors. This allows the grade control model to be approximately 4 months ahead of mining, which now appears to be insufficient, given the orebody complexity.

A limited amount of in-pit mapping has been done, and models and estimates have been updated on an annual basis. Again, given the complexity of the orebody, this is too infrequent.

As more information has become available, the structural and mineralogical complexity of the orebody has become increasingly apparent.

Among the various geological units and ore types, copper and cobalt grades are variable, and generally, inversely correlated. Cobalt tends to be concentrated in the Black Mineralized Ore Zone (BOMZ) ore, which carries relatively low copper grades.

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Figure 1—Mining at Ruashi open pit

As a result, equivalent grades have been applied to optimization and planning work.

The CMN ore carries high-grade malachite stringers, but the average ore grade based on 'normal' drill-hole spacings has meant that modelling has 'smeared' grades and underestimated the CMN ore grade on an equivalent basis.

Copper and cobalt prices have been volatile (Figure 2), with copper at record highs in early 2011, followed by a slide and a slight recovery in 2012, before a further slide to current levels.

Cobalt prices have been on a constant downward trend, with further pressure coming from oversupply into a relatively small market. The lower price has resulted in a significant increase in the cut-off grade for cobalt, as well as in the equivalent cut-off grade. This has impacted on the payability of BOMZ ore.

Geology and geological setting (Metorex, 2009)

The Ruashi deposits are stratiform, sediment-hosted copper deposits (SSCs) located in the Central African Copperbelt. The Copperbelt forms one of the world's largest metallogenic provinces, containing over one-third of the world's cobalt mineral reserves and one-tenth of the world's copper mineral reserves.

The copper-cobalt deposits of the Central African Copperbelt are hosted within a strongly deformed, arcuate belt of rocks that extends from northeastern Angola through southern DRC and into Zambia, referred to as the Lufilian Arc. The Katangan Sequence is divided into three supergroups separated by two marker conglomerates, which are described briefly below (from youngest to oldest).

- The Upper Kundelungu Supergroup (Ks) consists of detrital marine sediments, predominantly dolomitic, and is divided into three groups (Ks3, Ks2, and Ksl) based on sedimentary cycles. Minor sandstone units are scattered through the succession, as follows.
- The Lower Kundelungu Supergroup (Ki) consists of detrital marine sediments, again predominantly dolomitic but with limestones and dolostone in the south (the Kakontwe Limestone) The sequence is divided into two groups (Ki 2 and Ki 1), based on sedimentary cycles, and is up to 3000 m thick
- The Roan Supergroup (R) consists of lagoonal and fluvial marine sediments (dolostone, dolomitic siltstones, and black shales) with interstratified collapse breccias formed by the dissolution of evaporitic horizons, arkosic sandstones, and conglomerate units, and has a total thickness of 1500 m.

In the DRC, the Roan Supergroup is divided into the Roches Argileuses Talceuse (RAT), Mines, Dipeta, and Mwachya groups. The Mines Group is frequently referred to as the *Series des Mines*.

The different nomenclature for the basal Roan Supergroup reflects not only the different geological history of the belt but also a lack of correlation across national boundaries. Consequently, two sub-types of SSC deposits are distinguished in the rocks of the Central African Copperbelt. These are divided on geographical lines into a northwest district in the DRC ('Congolese Copperbelt') and a southeast district in Zambia ('Zambian Copperbelt').

The metasedimentary successions in the DRC are strongly thrusted and folded into a series of broken anticlines and synclines that are commonly overturned towards the north. Despite the obvious disruption of the sequence, the pre-Katangan basement is not exposed anywhere along the belt in the DRC.

The stratiform ores in the DRC occur within two principal formations confined to a 40 m thick succession at the base of the Mines Series. The upper formation is a sandy shale containing some carbonates, and the lower is a bedded dolomitic sandstone. The ore formations average approximately 10 m in thickness, separated by 20 m to 30 m of siliceous dolomite. Ore grades commonly vary between 4% and 6% copper and around 0.4% cobalt, with the ratio of copper to cobalt in the order of 8:1.

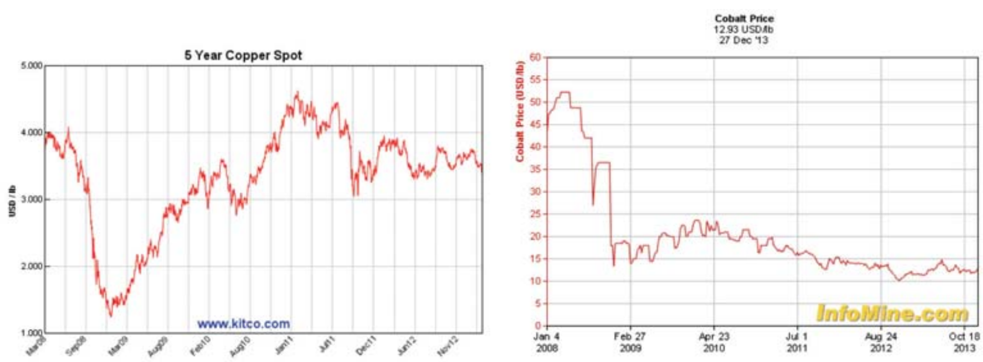

Figure 2—Copper and cobalt 5-year price histories

The weathered oxide zone generally extends to a depth of between 70 m and 150 m, but this may vary considerably between deposits. The weathering process commonly gives rise to high-grade supergene deposits near surface, but may also result in leaching of the mineralization in places and/or concentration in otherwise barren horizons.

At depth, a mixed oxide-sulphide zone grades into sulphide ore, sometimes at depths greater than 250 m.

Local geology and mineralization

The Ruashi deposits are typical of the Congolese Copperbelt deposits and are geologically similar to the Tenke Fungurume and Kamoto deposits. The stratiform Cu-Co deposits represent the largest and most important of the ore types, covering the area from Kasumbalesa in the southeast to Kolwezi in the northwest.

The detailed stratigraphy of the Lower Roan Group, *Series des Mines*, is shown in Table I.

The Ruashi copper-cobalt orebodies are situated within a 24 km long by 2 km wide, northwest to southeast-trending fold structure. The Lukuni-Ruashi-Etoile trend consists of a recumbent, synclinal fold, with flanks made up of Kundelungu rocks and the core by the Mines Group, all occurring to the southwest of a prominent northwest to southeast-trending thrust fault. Three orebodies have been identified at Ruashi, namely Ruashi I, Ruashi II, and Ruashi III. Historically, mining by UMHK focused on near-surface oxide copper in the form of malachite and chrysocolla mineralization (Figure 3). The high-grade oxides formed a 30 m to 60 m supergene mineralization blanket in the saprolitic rock close to surface, overlying the primary sulphide orebodies. This irregular blanket of mineralization extended beyond the limits of the underlying primary sulphide ores, as is schematically portrayed in the respective cross sections below.

Oxide minerals at Ruashi include malachite, chrysocolla, cuprite, cornetite, and heterogenite. Native copper also occurs. Trace quantities of oxidized uranium minerals have been observed but are very uncommon.

Bornite and chalcopyrite dominate the sulphide zone. Cobalt sulphides in the form of linnaeite and carrollite are irregularly distributed in intimate mixtures with the copper sulphides, with sporadic abnormal concentrations. Pyrite is found disseminated in small quantities in all the formations and occurs as small amorphous masses in the grey RAT. Chalcocite, together with malachite, occurs below the water table in the transition zone as replacement rims on primary bornite and chalcopyrite sulphides. Cobalt sulphides generally decrease with depth beyond the transition zone.

The current life of mine

Previous life-of-mine (LoM) plans had been run using a Whittle optimization process, which essentially created a mine-to-plant profile. This, although optimized on the basis of net present value, did not create a constant metal profile.

Figure 3—Malachite (left) and chrysocalla (right) ores

Table I

Principal geological units

System	Series	Local Name	Description	Thickness
Katanga	Upper Kundelungu		Sediments	30–50 m
		DIAMICTITE	Glacial sediments, tillite	
	Lower Kundelungu		Sediments, sandstones, and shales	200–500 m
		DIAMICTITE	Glacial sediments (Grand Conglomerate)	
	Roan	MWASHYA	Black shales, siltstone, sandstone, dolomites	50–100 m
		DIPETA	Shales and sandy schists	1000 m
		RGS	Sandstones	100–200 m
		CMN	Talcose clays, sandy wad, dolomite	110 m
		MIN CMN	Telcose clay, wad	0–20 m
		BOMZ	Wad (manganeferous earth)	3–20 m
		SDS	Dolomitic shales, black graphitic shales	50–80 m
		SDB	Basal dolomitic shales	10–15 m
		RSC	Stromatolitic dolomites	12–25 m
		RSF	Foliated, silicious dolomites	5 m
		D STRAT	Stratified, argilfaceous dolomites	3 m
		MV	Massive green siltstone	2–10 m
		RAT 2	Talcose argillites	100 m
		RAT 1	Talcose argillites	40 m
		POUDINGUE	Unknown transitional conglomerates	
Basement			Volcano-sedimentary deposits, granite-gneiss	

Instead, it created a profile that mined from the pits in a logical sequence, and delivered the mining profile directly to the plant.

In a way, this created a 'just-in-time' approach to plant feed, meaning that the plant had to deal with what it was given.

Stockpiling strategy has previously relied upon 'strategic' stockpile levels on the run-of-mine stockpiles, which allows a 'buffer' of four months of ore stocks. These stocks have been separated into low-grade, medium-grade, high-grade, and super-grade, with a separate stockpile for the cobalt-enriched BOMZ ore. However, these stockpiles have rarely been able to sustain the strategic levels, apart from the low-grade and BOMZ stockpiles. Furthermore, 'fingers' were established on the ROM stockpiles to attempt to control the acid consumption in the plant, and the talcose ore feed, by loading these ores into the plant in a controlled manner. However, the volumes and inconsistent feed from the mine have meant that this is a 'hand-to-mouth' solution, which does not result in consistent performance.

The consequences of this strategy can be summarized as follows:

- The ex-pit mining sequence is not necessarily optimal
- Various optimization opportunities are not evaluated
- The plan is based on a 'balanced system' approach which assumes that all parts of the system operate optimally, and coincidentally
- Variability in various input and performance factors may result in serious under-performance, unless smoothed
- The plant feed is not smoothed in terms of geometallurgical or mineralogical characteristsics
- As a result of inconsistent feed, plant performance is not stable in terms of acid and reagent consumption, throughput, and recovery
- The resultant life-of-mine profile for metal production is variable, resulting in inconsistent copper and cobalt production, as shown in the profile in Figure 4.

The business target for the operation is 36 000 t of copper production per annum, but the profile clearly shows a shortfall in most years as a result of the ex-pit grade and mineralogy, and an inconsistent cobalt production profile. It was realized that these profiles would not produce the business cash flow required, and left the operation vulnerable. This required a new assessment of the LoM strategy.

Geometallurgical issues

The constraint on acid availability and cost, coupled with the need to stabilize plant performance, indicated that there was a need to focus on geometallurgical issues within the orebody that affect plant performance (Table II).

Initial discussions indicated that the issues that were of immediate importance were as follows:

- The amount of feed of talcose material, mainly from the CMN ore, which impacts on circuit densities, in that lower densities in the leach circuits reduce throughput and recoveries. It is optimal to reduce this ore type to a maximum of 15-20% of the feed
- The BOMZ ore, which consists of manganiferous earth material, increases manganese in the circuit, resulting in contamination of the organics by permanganate in the electrowinning circuit, with resultant loss of recovery. This requires the addition of iron to the circuit to restore the design Fe:Mn ratio. This ore type should also be limited to 15% of plant feed

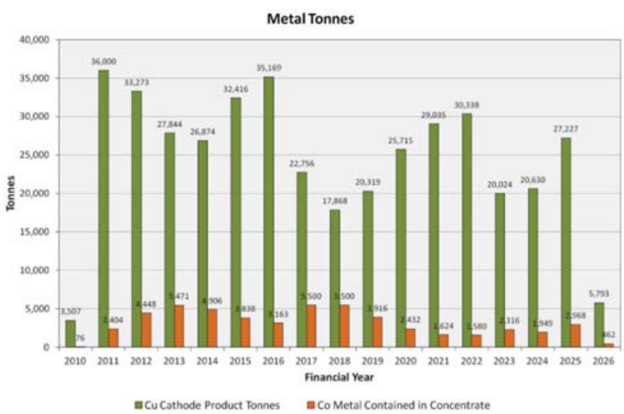

Figure 4—Current LoM metal profile

Table II

Geometallurgical characteristics at Ruashi Mining

O/Reserve code	Unit codes	Ore type description	Treatment related characteristics
1	CMN	Talcose clays, sandy wad, dolomite	Talc reduces densities in leach circuit which affects throughput and recovery. Should be controlled to below 15–20%. Dolomite increases acid consumption
2	BOMZ	Wad (manganiferous earth)	Increases manganese in the circuit, which affects Fe:Mn ratio. May result in contamination of organics by permanganeate in electrowinning. Controlled in plant by Fe addition
3	SDS	Dolomitic, shales, black graphitic shales	Increases acid consumption
4	SDB	Basal dolomitic shales	Increases acid consumption
5	RSC	Stromatolitic dolomites	Increases acid consumption
6	RSF	Foliated, silicious dolomites	Increased acid consumption, silica may increase steel cost marginally in mills
7	D STRAT	Stratified, argillaceous dolomites	Increases acid consumption
8	MV	Massive green siltstone	No effect
9	RAT 1& 2	Massive green siltstone	No effect

- Dolomitic ores are generally harder, and consume higher amounts of acid in the leach circuit (given the constraint and cost of acid, this is significant)
- Other geometallurgical issues associated with the mineralogy (for example, the presence of chrysocolla and other copper minerals) have not been assessed as yet.

In order to manage the ratios of these ore types in the feed to the plant, it is clear that stockpiling is necessary, from which the correct ratios can be drawn. This indicates that over-mining from the pits will be necessary on the one hand to create the necessary volumes on these stockpiles, while on the other hand ensuring that sufficient ore in the various grade categories is stockpiled. In this way it is then possible to better manage plant feed grade.

The revised life of mine

The considerations of ensuring a consistent metal production profile, as a result of managed plant feed, in terms of grade and geometallurgical characteristics, indicated that a mine to stockpile to plant philosophy should be built into the LoM plans.

The implications of such a change are:

- The requirement for an increased mining rate from the pits
- The need to establish minimum levels of tonnage on the various stockpiles
- The requirement to revisit cut-off grades and grade intervals for the stockpiles
- The need to modify the mining plan to allow high-grade ore to be mined at a higher rate, to ensure sufficient high grade feed in the early years (to maximize NPV), and to allow the high-grade stockpiles to build up
- The need to increase waste stripping rates as a result of the higher mining rate
- A reduction in the life of the pits as a result of higher volumes from the pits
- The establishment of large stocks of medium- and low-grade ore, which then are fed to the plant once the pits deplete. At this time, these stocks carry the marginal cost of re-handling and treatment only, thus allowing the lower grades to be processed.

Cut-off grades

A recalculation of cut-off grades was necessary, primarily to establish the lower limit of the categorization of ore. This raised the issue of whether an equivalent cut-off grade, or a copper-only, and cobalt-only cut-off, should be applied.

Lane (1988) recommends that equivalent grades should be used in the following circumstances.

Firstly, when mineral association is reasonably consistent. This is not the case at Ruashi, due to the multiple ore types.

Secondly, when market predictability of both or all metals is reasonable consistent. This is also not the case at Ruashi, since the cobalt price does not correlate with the copper price.

Additionally, in the case of Ruashi, the following conclusions were drawn:

- Copper is the prime product that defines profitability in the short/medium term, and the focus on cash flow indicates that consistent copper production is essential
- The equivalent grade has value in the long term, and should therefore be used in the LoM scenarios
- Cobalt-enriched material that is below the budget cut-off grade but above the cobalt breakeven should be stockpiled.

Cut-off grades were therefore calculated for the definition of ore at the low grade. Classically, for open pit operations, a marginal cut-off grade would be calculated, based on variable cost only. Previously, this material was termed 'mineralized waste' and was stockpiled for later treatment. This applied to this ore, which would have to be mined anyway, in order to expose higher grade ore.

However, once the new LoM was run, it became apparent that this material would consume valuable stockpiling space, and therefore it was decided that this material should be placed in a 'quarantined' area of the waste dump.

Grade intervals for the stockpiles were then defined, using intervals that defined low grade, medium grade, and high grade. The low grade was then further subdivided into low grade and intermediate grade, to allow more control over the plant feed grade.

Within these intervals, ore types are to be stockpiled separately, and BOMZ is to be stockpiled in its own area. The advantage of this is that this cobalt-enriched material can be fed to the plant once cobalt prices recover.

The category 'super grade' was abandoned, since from a cash flow point of view it does not seem logical to stockpile this material, as opposed to feeding it directly to the plant.

The LoM profile that has been developed as a result of a number of scenario analyses is shown in Figure 5. This indicates an accelerated mining rate from the pits in the first two years, in order to build stockpiles, while still feeding the plant with relatively high grade. Waste stripping is also accelerated, through additional pushbacks that are required to expose higher grade ore earlier in the LoM.

As discussed previously, the profile shows that the LoM has been reduced by three years, although metal production from stockpiles continues until 2024.

The resultant metal profile is shown in Figure 6. This indicates a relatively constant 36 000 t of copper cathode per annum, and a relatively constant cobalt profile.

The stockpiling volumes have been calculated on an annualized basis in order to ascertain the stockpiling space that is required and the re-handling arrangements (Figure 7). The graph shows the establishment of the high-grade stockpile in the earlier years, and the considerable build-up of the cobalt-enriched BOMZ material.

The revised LoM plan, incorporating these considerations, and the stockpiling strategy, has been evaluated from a cash flow point of view.

It would be expected that the change to a grade profile with an emphasis on high grade at the front end would increase the NPV of the LoM compared with the previous LoM. Also, the higher copper production would be expected to increase the annual cash flow, and the NPV. Indeed, runs conducted using discounted cash flow analysis at a 10% discount rate have indicated that the new LoM adds $127 million in free cash flow.

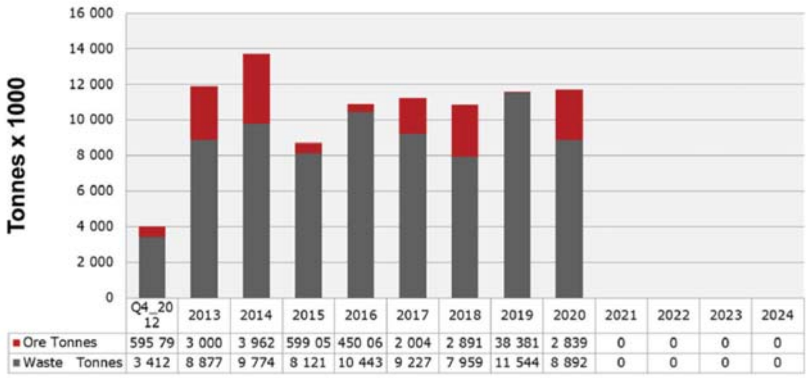

Figure 5—New LoM profile showing ore and waste tonnages mined

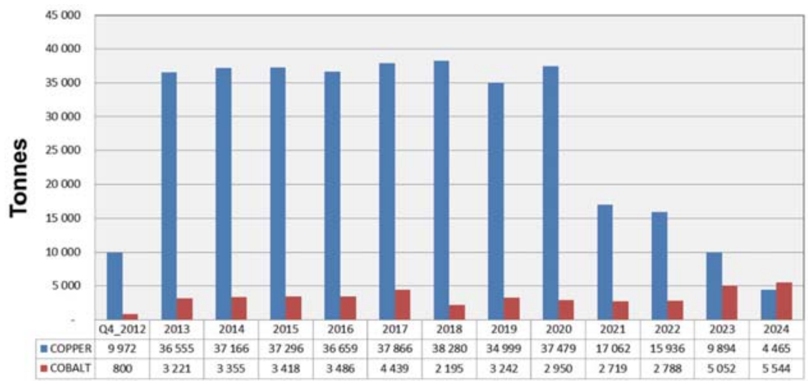

Figure 6—Metal tonnages produced from new LoM plan

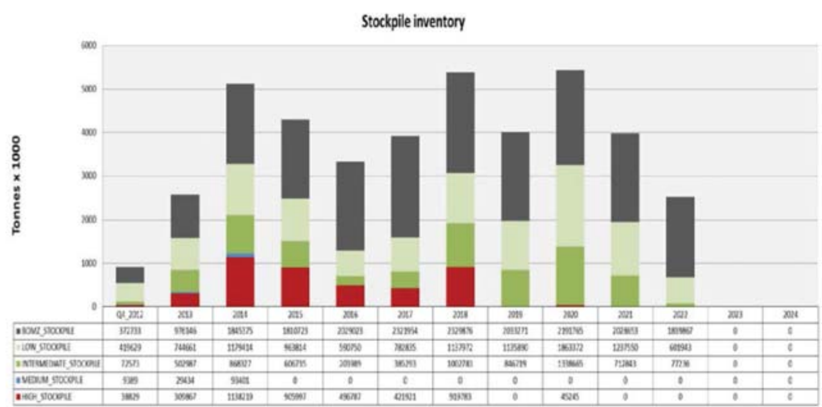

Figure 7—Stockpile inventories per annum in new LoM plan

This includes the extra stripping costs, and the re-handling costs associated with stockpiling.

This confirms that, from an economic perspective, costs involved in the achievement of more consistent and controlled plant feed, including the costs associated with increased mining rates, are exceeded in the circumstances by the revenue achieved by the strategy.

However, significant increases in mining costs in the early years are not fully recovered by revenue, since ore is mined and stockpiled without treatment or sale. This indicates that, from a pure cash flow perspective, there may be further opportunity for optimization.

Management considerations

The change from the traditional approach to the stockpiling strategy, and the management of the system, represents a significant change in the way in which the operation is to be managed. This required that an extensive risk assessment be conducted, and that identified risks are managed effectively.

The principal risks that were identified were as follows.

1. Knowledge of the orebody will be critical in terms of the geological and mineralogical boundaries. This will require increased infill drilling and geological modelling to determine geological units and

boundaries, and to define the geometallurgical inputs that can form the basis of a geometallurgical model. Failure to do so could result in ore being misclassified, and sent to the wrong destinations. As a result, a more detailed drilling and mapping programme has been instituted

2. Grade control procedures and technologies need to be appropriate for the level of control that is required, to ensure the management control required over the identification of ore units, and their dispatch to the correct destinations. This requires proactive sampling and mapping, and quick turnaround for model updates. It also requires that the grade control 'front' is extended to at least six months ahead of mining. Current grade control procedures rely on manual dispatch of trucks to stockpiles, whereas the new LoM requires automatic dispatch of loads, and management control systems which track and monitor ore movements
3. Stockpile management must be adequate to ensure that stockpile volumes and grades are monitored and controlled on a real-time basis. This includes the monitoring of movements on and off stockpiles, and the maintenance of inventory stocks in terms of tons and grade. It also requires that geometallurgical units are demarcated adequately, and that feed to the plant is controlled in response to plant requirements
4. Mine planning must ensure that the requirements identified through the LoM are translated into medium- and short-term plans. Additionally, more emphasis is required on planning compliance, in terms of plan to actual comparisons. Mine planning must also ensure that planning ensures that extraction is scheduled, as far as possible, so that that grade and mineralogy are extracted from the pits in such a way as to enhance the requirements of the LoM (although stockpiling is designed to smooth any variations that occur)
5. Waste and ore stockpiling space is critical to the success of the plan. Increased waste stripping tonnages must be accommodated on limited physical space within the boundaries of the property. Thus, detailed planning, design, and scheduling of waste dumps is essential. Similarly, ore stockpiles will be considerably larger than currently, with the result that footprints need to be designed and prepared, and that detailed scheduling of tonnages onto stockpiles needs to be done at all levels of planning
6. The changes in scheduling and ore handling require that changes be made to the contract, and that the contractor is fully involved in the planning and scheduling of ore movements
7. In order to maintain control of ore movements, depletions, and discrepancies, a full reconciliation system is required, that monitors ore and waste movement from end to end, and allows reconciliation across identified arcs along the value chain (Macfarlane, 2011)
8. Management information systems must be integrated such as to ensure 'one version of the truth' and real-time monitoring and control. This involves the establishment of a central control room, and dashboard control of critical variables and value drivers
9. All of the above require a realignment of the roles, responsibilities, and structures in the organization. Management control needs to become process-based and value-chain aligned, with areas such as grade control and reconciliation requiring an integrated and multidisciplinary 'community of practice' approach
10. Change management initiatives are necessary to constantly reinforce the strategy and objectives of the exercise, and to ensure that all departments are aligned to the process of implementation of the new plan. If this is not the case, functional and personal intervention will result in regression to previous practices. This change includes the development of appropriate procedures and protocols, and the establishment of key performance indicators that can be incorporated into performance management systems.

Further opportunities

The development of an integrated and optimized LoM based on full value chain optimization results in a constant search for further optimization opportunities.

In the case of Ruashi Mining, these include:

- ➤ Smoothing of stockpiling volumes over the LoM
- ➤ Optimizing on the basis of cash flow over the first five years
- ➤ Identification of optimization opportunities associated with debottlenecking of plant capacities
- ➤ Further geometallurgical considerations could result in further optimization and selectivity.

Subsequent interventions

Since this work was completed, a number of situations have occurred that have modified the approach described above. These include:

- ➤ Electrical power interruptions, due to the inability of the national power utility to supply the required power consistently
- ➤ A drop in the copper price, which has affected the cut-off grade, and thus the pit limits.

Although these two factors have affected the plan to some extent, the principle of stockpiling and grade control as described still remains. Indeed, it becomes more critical as margins become reduced as a result of price volatility. The power shortages have been addressed by the addition of power generators, but this comes at a cost, further affecting the optimal pit outlines and the LoM plans.

Tthe revised plan now delivers a marginally higher grade to the plant, for a slightly shorter life, but still with strategic stockpiling.

Conclusions

Over the history of the Ruashi deposit and mining operations, it has become increasingly apparent that the orebody is considerably more complex than was originally anticipated in terms of structure, morphology, mineralogy, and geotechnical characteristics.

This is not atypical of Copperbelt orebodies, and leads to the clear conclusion that optimization of the extraction of the orebody will always depend on a critical level of knowledge of the orebody and ore morphology.

This requires detailed understanding of the mineralogy and the geometallurgical characteristics that impact on the plant performance.

This is also essential in order to plan the extraction in such a way as to ensure a realistically consistent feed to the plant in terms of geometallurgical characteristics and grade. This can be enhanced through the application of a stockpiling strategy that allows, through effective stockpile management, a consistent feed to the plant.

This approach creates an over-mining situation, where mining capacity exceeds plant capacity, resulting in building of stockpile volumes while at the same time maintaining plant feed volume and grade.

Such a stockpiling and grade management programme requires tight management of ore movements, stockpile additions and depletions, cut-off grades, grade control, and contractor discipline.

These matters have all been addressed at Ruashi Mining, whereby a US$127 million improvement in the NPV of the operation is apparent in the revised plan.

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Liquid-liquid extraction and separation of copper(II) and nickel(II) using LIX®984N

by N.B. Devi* and B. Nayak*

Synopsis

The extraction of copper(II) from sulphate solution was investigated using LIX®984N in kerosene. The parameters that could affect the extraction, such as equilibrium pH, extractant concentration, salt concentration, various diluents, and temperature, were separately investigated. On the basis of slope analysis, the complex formed in the organic phase is proposed to be CuR_2, where R is the anionic part of LIX®984N. The extraction equilibrium constant and Gibbs free energy (ΔG) of the extraction process were determined. The positive value of ΔH obtained from temperature variation studies showed that the extraction process is endothermic. The extraction of copper was lowest when chloroform was used as the diluent. Separation and recovery of copper from a synthetic copper-nickel solution containing 6.35 g/L Cu(II) and 0.58 g/L Ni(II) was carried out using 20%(v/v) LIX® 984N. The separation factor ($\beta = D_{Cu}/D_{Ni}$) was found to be pH-dependent. A two-stage batch countercurrent extraction was carried out at an O:A ratio of 3:4 at equilibrium pH 1.05 for extraction of copper from copper-nickel solution, followed by copper stripping from the loaded organic phase with 15% H_2SO_4 at an O:A ratio of 3:1.

Keywords
copper, nickel, LIX® 984N, solvent extraction, stripping.

Introduction

In recent years, the demand for copper and nickel has risen world-wide due to their use in printed circuit boards, batteries, application in marine alloys (due to excellent resistance to corrosion by seawater), and a wide range applications in day-to-day life (Doebrich, 2009). Increasing demand for these metals is leading to rapid depletion of high-grade resources. Alternative sources, such as e-wastes, lithium ion batteries, copper converter slags, polymetallic nodules *etc.*, are needed to meet future demand. The copper-nickel system was chosen for this investigation because some slags (copper converter slag, anode slag of Hindustan Copper, and by-products of UCIL Jaduguda) contain high amounts of both copper and nickel. Hydrometallurgical routes play a vital role in the processing of these secondary sources. Solvent extraction is a well-established technique for the removal and separation of various metal ions. About 30% of the world's copper is produced by acid leaching, solvent extraction (SX), and electrowinning (Cox, 2004). Hydroxyoximes are well-known extractants which are widely used for copper extraction from dilute acidic sulphate solutions (Ritcey and Ashbrook, 1979; Szymanowski, 1993; Szymanowski, 1990).

Only two classes of extractants, *i.e.* ketoximes and aldoximes, have gained commercial acceptance as reagents for solvent extraction from acidic leach solutions. Oxime mixtures have been shown to be advantageous over the individual group ketoximes and aldoximes (Kordosky *et al.*, 1985). Rodriguez *et al.* (1997) studied the extraction of several metal ions using LIX® 984, which is a 1:1 volume blend of LIX® 860 and LIX® 84 in n-heptane. They reported the equilibrium constant values for the extraction reactions, and proposed the species extracted into the organic phase. Fouad (2007) studied the extraction equilibria of copper(II) with Cyanex 301, LIX® 984N, and mixtures of these two reagents. The enthalpy change (ΔH) of the individual extractants and their mixtures was determined and the endothermic process elucicated. Kul and Cetinkaya (2009) developed a complete hydrometallurgical process on a laboratory scale for recovering copper from copper electroplating second rinse bath liquor containing 2.5 g/L copper using LIX® 984N-C in kerosene. Recovery of copper from waste printed circuit boards (PCBs) by nitric acid leaching and extraction using LIX® 984N was reported by Long Le *et al.* (2011). They first studied the co-extraction of other metals (Pb, Zn, Fe, and Ni) from a diluted leach liquor with 10% LIX® 984N, and found that the co-extraction of these metals was negligible up to pH 1.9, except for iron (6.4%). Based on these results, they used 50% LIX®

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984N to recover all the copper from the actual leach liquor of composition 42.11 g/L Cu, 2.12 g/L Fe, 4.02 g/L Pb, 1.58 g/L Zn, and 0.48 g/L Ni at an A:O ratio of 1:1.5 in three stages and at pH 1.5. Sulphuric acid (H_2SO_4 -360 g/L) was used for stripping. Qing-ming *et al.* (2008) studied the separation of copper and iron from dump bioleaching solution from Dexing Copper Mine using LIX® 984N. Kinoshita *et al.* (2003) reported the separation of copper and nickel from nitrate media containing 11 180 mg/L Cu and 1160 mg/L Ni using 200 g/L LIX® 984. Extraction and separation of copper and nickel by LIX® 984N from ammoniacal medium was investigated by Sridhar *et al.* (2009). They found that both the metals co-extracted over the pH range 7 to 9. A selective stripping method was used to separate copper and nickel.

The use of LIX® 984N has received attention for extracting copper from copper-rich leach liquors. There are few reports available regarding equilibrium studies of the copper-LIX® 984N system (Aminian and Bazin, 2000) and the separation of copper and nickel from sulphate medium (Ochromowicz and Chmielewski, 2013). The present study investigates the extraction equilibrium in the copper-LIX® 984N system, the species extracted into the organic phase, and evaluates the thermodynamic parameters in addition to diluent and salt effects. McCabe-Thiele plots and batch countercurrent extractions were also been carried out to study the separation and recovery of copper from a synthetic copper and nickel solution.

Experimental

Solutions and reagents

Stock solutions of copper(II) and nickel(II) (1M each) were prepared by dissolving the sulphate salts in double-distilled water. LIX® 984N (a mixture of 5-nonylsalicylaldoxime and 2-hydroxy-5-nonylacetophenone oxime) was supplied by Cognis Inc. and was used without further purification. Distilled kerosene was used as diluent for the organic phase. All other reagents used were of analytical reagent grade.

Experimental methods

Solvent extraction

The metal-bearing solution was equilibrated with an equal volume of LIX® 984N for 5 minutes in a separating funnel. The pH of the aqueous solution before extraction was adjusted by adding dilute H_2SO_4 or NaOH solution. After phase separation the aqueous phase was collected and the equilibrium pH was measured. The metal content in the aqueous phase was determined by the thiosulphate method using starch as the indicator (Bassett *et al.*, 1984). When both copper and nickel were present, the aqueous phase was analysed by atomic absorption spectrophotometry (AAS) using an ELICO-type instrument. The concentration of the metal ion in the organic phase was calculated by the difference in concentration before and after extraction. When required, the organic phase metal concentrations were determined after filtration through 1PS phase separating paper and stripping with 20% H_2SO_4, followed by analysis with AAS. All the extraction and stripping experiments were carried out at 30±1°C, except for the temperature variation study.

Extraction and stripping isotherms

While keeping the total volume of the aqueous and the organic phases constant, the solutions at different O:A ratios were shaken for 5 minutes at 30±1°C. After the extraction process, the metal concentrations in the raffinate (R) were determined by AAS and the metal concentration in the loaded organic (LO) phase was calculated by mass balance. After the stripping process, the metal concentration in the spent organic (SO) was determined by AAS and the metal in the aqueous calculated by mass balance. McCabe-Thiele constructions were drawn for the extraction and stripping isotherms.

Countercurrent SX process

A two-step countercurrent extraction process was simulated by batch experiments using a synthetic solution containing copper (6.35 g/L) and nickel (0.58 g/L) up to five cycles at an O:A ratio of 3:4. In each step, 80 mL of aqueous phase and 60 mL of organic phase (20% (v/v) LIX® 984N) were mixed in a separating funnel for 5 minutes. A schematic representation of countercurrent steps is given in Figure 1. The raffinates and the loaded organic phases (after stripping with H_2SO_4) were analysed by AAS. Similar steps were carried out for the batch countercurrent stripping process, which involves three stages at an O:A ratio of 3:1.

Results and discussion

Extraction of copper using LIX 984N

Effect of equilibrium pH

Experiments were carried out at room temperature to study the effect of equilibrium pH on the extraction of 0.1M Cu(II) using 15% (v/v) LIX® 984N in kerosene. The results are presented in Figure 2 as percentage of copper extraction *versus* equilibrium pH. As expected, the percentage extraction increased with increasing equilibrium pH; however, it remained practically constant at equilibrium after sometime. At an equilibrium pH of 0.53, the percentage copper extraction into the organic phase was 78%, whereas 87% copper was extracted at equilibrium pH 0.61 and 88% at equilibrium pH 0.71. This behaviour was also reported by Asghari *et al.* (2009) and Rodriguez *et al.* (1997), who found that copper extraction increased with increasing equilibrium pH to a certain value, after which it was independent of pH variation. In this work, the maximum extraction of copper was 88% (equilibrium pH range 0.63 to 0.71) with 15% LIX®984N. These extraction and equilibrium pH values are low compared to the values reported by Asghari *et al.* (2009). One reason may be the higher initial copper concentration –

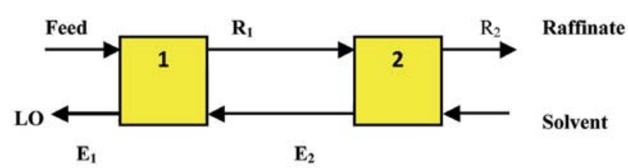

Figure 1—Schematic diagram of countercurrent extraction

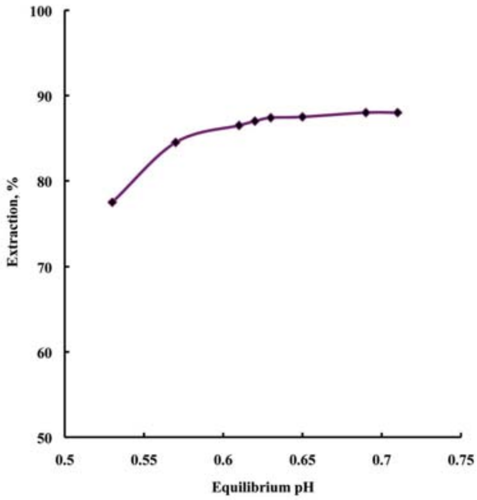

Figure 2—Effect of equilibrium pH on copper extraction (0.1 M) using 15%(v/v) LIX® 984N in kerosene

6.35 g/L used in this study, compared with 2.5 g/L used by Asghari *et al.* Due to the availability of more copper ions, extraction is favoured and the release of more H^+ ions results in a decreasing equilibrium pH value.

Effect of extractant concentration

The effect of extractant concentration on copper extraction was studied by contacting sulphate solutions containing 0.1M copper(II) at an initial pH value of 3.95 with LIX® 984N at concentrations from 5–25% (v/v) . As shown in Figure 3, copper extraction increases from 2.8 g/L (44%) to 6.27 g/L (98.7%) with increase in extractant concentration from 5% to 25% (v/v) LIX® 984N.

Extraction mechanism

As LIX® 984N is a chelating extractant, it will form neutral complexes with copper(II) coordinating with the nitrogen atom of the oxime group and releasing two H+ ions into aqueous solution. The extraction equation can be written as:

$$Cu^{2+}{}_{(aq)} + n(HR)_{org} \rightleftharpoons CuR_2(n-2)HR_{(org)} + 2H^+{}_{(aq)}, \quad [1]$$

where n is the solvation number of the extractant, LIX® 984N.

The extraction equilibrium constant can be represented as:

$$K_{ex} = \frac{[CuR_2.n-2(HR)]_{org}[H^+]^2_{eq}}{[Cu^{2+}]_{aq}[HR]^n_{eq}} \quad [2]$$

The distribution ratio (D) is the ratio of metal concentration in organic phase to the metal concentration in aqueous phase at reaction equilibrium. Substituting D in Equation [2] yields

$$K_{ex} = \frac{D[H^+]^2_{eq}}{[HR]^n_{eq}} \quad [3]$$

Therefore,

$$\log D = \log K_{ex} + 2pH + n\log[HR]_{eq} \quad [4]$$

The concentration of copper chosen for the present study is 0.1M, and the results of the pH variation study led to the consideration of the equilibrium concentration of the organic phase (free extractant concentration remained after equilibration). This can be calculated as:

$$[HR]_{equilibrium} = [HR]_{initial} - n[Cu^{2+}]_{org} \quad [5]$$

The use of various concentrations of LIX 984 to determine the solvation number was reported by Rodriguez *et al.* (1997), Aminian and Bazin (2000), and Fouad (2009). The plot of log D - $n$log $[HR]_{eq}$ *versus* equilibrium pH for different values of the number of extractant molecules (n) is shown in Figure 4. The line that has a slope of approximately 2.0 has been selected. The slope is equal to the number of H^+ ions in Equation [1].

Based on the above results, the extraction equilibrium reaction is written as:

$$Cu^{2+}{}_{(aq)} + 2(HR)_{org} \Leftrightarrow CuR_{2(org)} + 2H^+{}_{(aq)}$$

Buketova (2009) analysed the IR spectrum and confirmed that the structure of this CuR_2 complex with LIX® 984N is non-polar. The intercept of the graph in Figure 4 is the logarithmic value of the extraction equilibrium constant. The equilibrium constant (K_{ex}) for the above equilibrium is therefore 2.90 and the Gibbs free energy of the extraction is -2.69 kJ mol^{-1} (T = 303 K).

Effect of different media

Some metals are recovered via a hydrometallurgical route consisting of three unit operations – leaching, SX, and electrowinning. The SX process depends mainly on the nature of the leach liquor. In addition to leach liquors in a single medium, recovery of metals from mixed-medium leach liquors are also of importance nowadays (Sarangi *et al.*, 2007; El-Hefny *et al.*, 2010). Sarangi *et al.* studied the separation and recovery of iron(III), copper(II), and zinc(II) from mixed sulphate and chloride media, whereas El-Hefny *et al.* used sulphate/thiocyanate media for zinc and cobalt separation. Keeping this in mind, the extraction of 0.1M Cu(II) was carried out with 15% (v/v) LIX® 984N in the

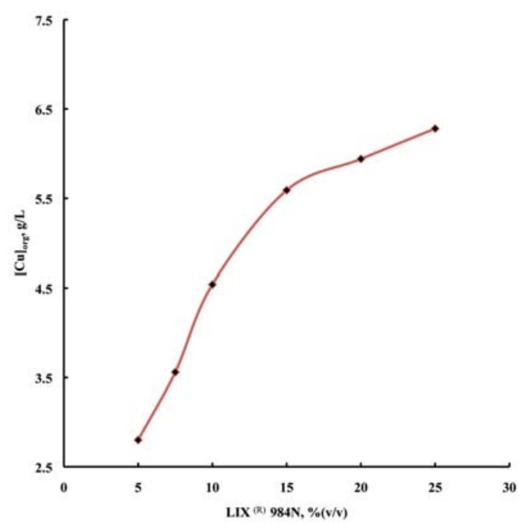

Figure 3—Effect of extractant concentration on copper extraction (0.1M)

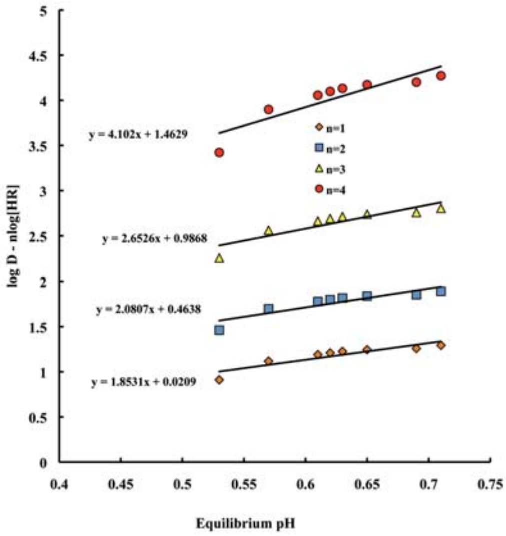

Figure 4—Plot of log *D* - *n*/2 log [*HR*] vs equilibrium pH. Cu(II) (0.1M),15% (v/v) LIX® 984N

presence of different salts such as sodium sulphate, sodium chloride, and sodium nitrate over the concentration range 0.1 to 1M. The results showed that the distribution coefficient of copper increased with increasing sodium sulphate concentration from 0.1M (D=9.08) to 1 M (D=17.68), but decreased with increase in sodium chloride concentration. In presences of 0.1M sodium nitrate, the distribution coefficient is more than the distribution coefficient value when sodium nitrate was absent, but it decreased constantly with further increase of $NaNO_3$ concentration (Table I). However, the decrease is more significant with sodium chloride than with sodium nitrate. The decrease in extraction may be due to a salting-out effect.

Effect of diluent

The choice of diluent is an important aspect of successful SX operation. A diluent reduces the viscosity of the extractants, but sometimes the nature of diluent affects the extraction process. To investigate this, the extraction of copper(II) with 15% (v/v) LIX® 984N was carried out using different diluents such as kerosene, benzene, xylene, toluene, carbon tetrachloride, and chloroform. The result showed that copper extraction depends on the dielectric constant value of the diluent – the higher the value of the dielectric constant, the lower the percentage extraction of copper (Table II). The reason for this is that with an increase in the dielectric constant of the diluent, the interaction between the diluent and the extractant is increased, thus decreasing the availability of the extractant for extraction of copper. The same trend was observed by Reazai and Nedjate (2003) and El-Nadi (2010) while studying the effect of diluents on the extraction of nickel and rare earths.

Effect of temperature

The extraction efficiency of certain extractants depends significantly on temperature, and therefore the extraction of 0.1M Cu(II) was studied at different temperatures (299–323K) with 15%(v/v) LIX® 984N in kerosene. It was observed that with increasing temperature the distribution ratio of copper extraction increased from 7.35 (299K) to 9.08 (323K). This indicates that the extraction is endothermic. The thermodynamic parameters such as enthalpy change (ΔH) and entropy change (ΔS) were calculated by plotting log K_{eq} against 1000/T (Figure 5). From the plot, ΔH and ΔS were calculated and found to be 10.224 kJ mol^{-1} and 4.05 J K^{-1} mol^{-1} respectively. Aminian and Bazin (2000) also reported that the extraction of copper with LIX® 984 was endothermic, with a ΔH of 5.88 kJ mol^{-1} under the experimental conditions used (0.94 g/L Cu, pH = 2 and O:A = 0.1). Although in both cases the process was found to be endothermic, the difference in ΔH values may be due to the different experimental conditions.

Table I

Effect of different media on extraction of 0.1M Cu(II) with 15% (v/v) LIX® 984N in kerosene

	Distribution coefficient		
[Salt], M	Na_2SO_4	NaCl	$NaNO_3$
0	7.47	7.47	7.47
0.1	9.08	6.74	9.58
0.2	10.98	6.41	9.08
0.3	13.27	6.15	8.62
0.6	14.88	5.90	8.10
0.8	16.21	5.29	7.70
1.0	17.68	4.89	7.36

Table II

Effect of diluent on extraction of 0.1M Cu(II) with 15% (v/v) LIX® 984N

Diluents	Dielectric constant	*D*
Chloroform	4.81	3.26
Xylene	2.57	4.25
Toluene	2.38	4.75
Benzene	2.27	5.29
Carbon tetrachloride	2.24	5.48
Kerosene	1.8	7.47

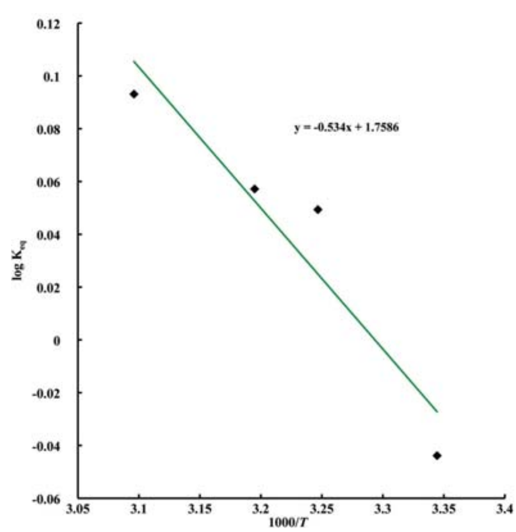

Figure 5—Plot of log K_{eq} vs 1000/*T*. Cu(II) (0.1M),15% (v/v) LIX® 984N

Solvent extraction behaviour of copper in presence of nickel

To study the extraction behaviour of copper in presence of nickel, an aqueous solution containing 0.1M Cu(II) (6.35 g/L) and 0.01M Ni(II) (0.58 g/L) was chosen. Copper extraction was 98% with 25% (v/v) LIX® 984N, and 93% with 20% (v/v) LIX® 984N. In an industrial application the viscosity of the solvent should not be very high, therefore 20% (v/v) LIX® 984N in kerosene was selected to study copper-nickel extraction. Figure 6 represents the percentage extraction of Cu(II) and Ni(II) as a function of equilibrium pH of the aqueous solution. Extraction of copper increased from 61% to 91% with an increase in equilibrium pH from 0.36 to 0.91, while the extraction of nickel was within 6% to 8% over the equilibrium pH range 0.56 to 1.08. Kinoshita *et al.* (2003) reported the extraction of nickel to be 3–4 % around that range of equilibrium pH in the presence of copper. This result demonstrated that copper can easily be separated from nickel. The separation factor ($\beta = D_{Cu} / D_{Ni}$) was calculated and is tabulated in Table III with respect to equilibrium pH. The separation factor was the highest (123.8) at equilibrium pH 0.95 and the lowest (63.3) at equilibrium pH 0.56.

Extraction isotherms for copper and nickel and McCabe-Thiele plots

An aqueous solution containing 6.35 g/L copper(II) and 0.58 g/L nickel(II) with an initial pH of 3.95 was used for the extraction of copper with 20% (v/v) LIX®984N in kerosene. To determine the number of stages required for the extraction of copper, a McCabe-Thiele plot was constructed for O:A ratios from 1:5 to 5:1, with the total volume of the phases kept constant. The data in Figure 7 indicates that < 0.045 g/L copper will remain in the raffinate after two extraction stages at an O:A ratio of 3:4, which suggests that it could be possible to upgrade the copper concentration in the organic phase.

This prediction was confirmed by carrying out a two-stage batch countercurrent simulation study of up to five cycles at an O:A phase ratio of 3:4, in which the partially loaded organic from extraction stage 2 was fed to extraction stage 1. Analysis of copper and nickel values in the aqueous and organic phase confirmed the extraction of 8.4 g/L copper with negligible nickel co-extraction (0.003 g/L) in the loaded organic phase (Table IV). Thus, a loaded organic phase containing 8.4 g/L copper was generated.

Stripping of copper

The copper-loaded organic phase was stripped with different concentrations of sulphuric acid (5–25%) at equal phase ratios for 5 minutes. The aqueous phase was diluted and analysed for copper. The percentage copper stripping increased from 67.4% with 5% H_2SO_4 to 100% with 25% H_2SO_4. A McCabe-Thiele plot was constructed for the 20% loaded organic phase using 15% H_2SO_4 (98.2% stripping), with O:A phase ratios in the range 1:5 to 5:1. The data in Figure 8 suggests three stages of stripping at an O:A ratio of 3:1. A three-stage batch countercurrent experiment was carried out at the above O:A ratio using 15% H_2SO_4 strip

Table III

Effect of equilibrium pH on separation factor (β) of copper and nickel. Aqueous phase: 6.35 g/L Cu(II) and 0.58 g/L Ni(II), organic phase: 20%(v/v) LIX® 984N in kerosene

Equilibrium pH	D_{Cu}	D_{Ni}	$\beta = D_{Cu} / D_{Ni}$
1.08	11.43	0.10	119.92
0.95	10.87	0.09	123.8
0.91	9.85	0.09	113.61
0.92	7.99	0.08	102.05
0.76	6.06	0.07	84.0
0.7	5.24	0.07	74.85
0.56	4.18	0.07	63.3
0.36	1.57	0.01	114.81

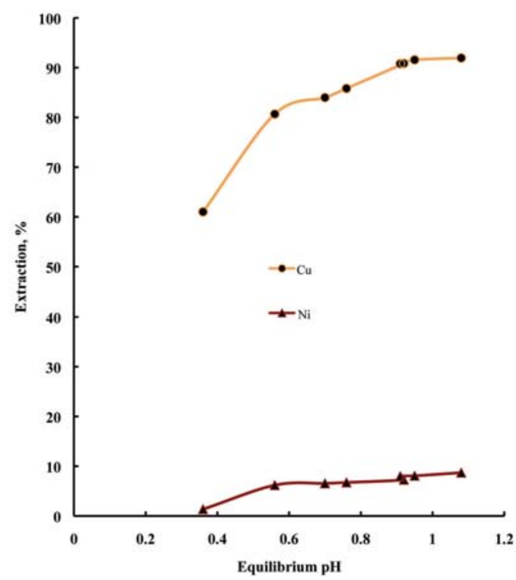

Figure 6—Effect of equilibrium pH on extraction of copper and nickel. Cu(II) (6.35 g/L) Ni(II) (0.58 g/L), 20% (v/v) LIX®984N

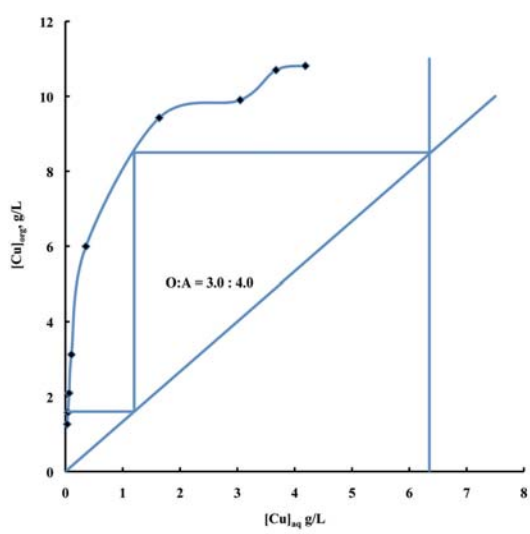

Figure 7—Mc-Cabe-Thiele plot for extraction of copper using 20% (v/v) LIX® 984N

Table IV

Results of a two-stage batch countercurrent simulation for copper extraction with 20% (v/v) LIX® 984N at an O:A ratio of 3:4

Raffinate	Equilibrium pH	$[Cu]_{raff.}$ g/L	$[Ni]_{raff.}$ g/L	Organic phase	$[Cu]_{org.}$ g/L	$[Ni]_{org.}$ g/L
R_{2-5}	0.87	0.03	0.583	E_{1-6}	7.56	0.003
R_{2-4}	0.9	0.029	0.585	E_{1-5}	8.24	0.0025
R_{2-3}	0.92	0.026	0.586	E_{1-4}	8.42	0.003
R_{2-2}	0.94	0.025	0.58	E_{1-3}	8.44	0.0026
R_{2-1}	0.87	0.015	0.58	E_{1-2}	8.4	0.003
				$E1_{-1}$	8.4	0.003

solution. The analysis of the aqueous phase showed an upgrading of copper to 25.1 g/L with 0.0089 g/L Ni in the loaded strip solution, leaving only 0.002 g/L copper in the organic phase (Table V).

Conclusions

The extraction of 0.1M Cu(II) from sulphate solution using 15% (v/v) LIX® 984N showed a pH dependence up to 0.61, after which it is independent of equilibrium pH. The extraction of copper increased with increasing extractant concentration. The species extracted into the organic phase is proposed to be CuR_2. The equilibrium constant and Gibbs free energy were found to be 2.9 and 2.69 kJ mol^{-1} respectively. The percentage extraction of copper increased with increasing sodium sulphate concentration. With increasing dielectric constant of different diluents, the copper extraction was found to decrease. Effective separation of copper and nickel from an aqueous feed solution containing 6.35 g/L copper(II) and 0.58 g/L nickel(II) could be achieved with 20% (v/v) LIX® 984N in kerosene in the initial pH range (2.15–3.96), corresponding to an equilibrium pH of 0.91–1.08). A two-stage batch countercurrent extraction experiment at an O:A ratio of 3:4 resulted in upgrading the copper from 6.35 g/L in the feed solution to 8.4 g/L in the loaded organic phase. Using 15% H_2SO_4 as the stripping agent, 25.1 g/L copper(II) was stripped into the loaded strip liquor, which could be suitable for electrowinning. A flow sheet is proposed for separation of copper and nickel (Figure 9) that could be used for treatment of sulphate leach liquors obtained from pressure leaching of copper converter slags, nickel smelter slags, and copper sulphide concentrates.

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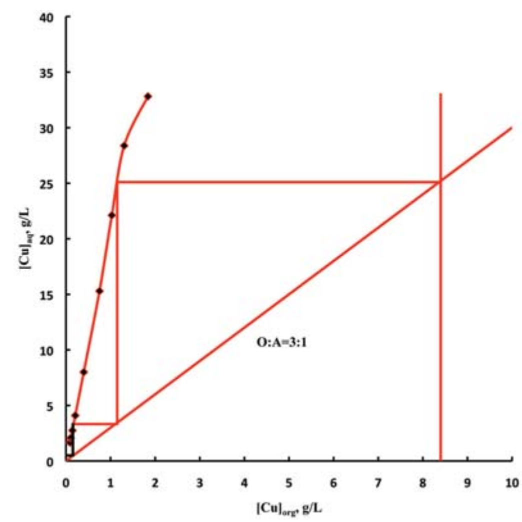

Figure 8—Mc-Cabe-Thiele plot for stripping of loaded copper from 20% (v/v) LIX® 984N using 15%(v/v) H_2SO_4

Table V

Results of a three-stage batch countercurrent simulation for copper stripping with 15%(v/v) H_2SO_4 at an O:A ratio of 3:1

Raffinate	$[Cu]_{raff.}$ g/L	$[Ni]_{raff.}$ g/L	Spent organic	$[Cu]_{org.}$ g/L
R_{3-6}	24.95	0.007	SO_{1-6}	0.003
R_{3-5}	25.1	0.0087	SO_{1-5}	0.002
R_{3-4}	25.0	0.0089	SO_{1-4}	0.0025
R_{3-3}	25.1	0.009	SO_{1-3}	0.002
R_{3-2}	25.11	0.0089	SO_{1-2}	0.002
R_{3-1}	25.1	0.0089	SO_{1-1}	0.002

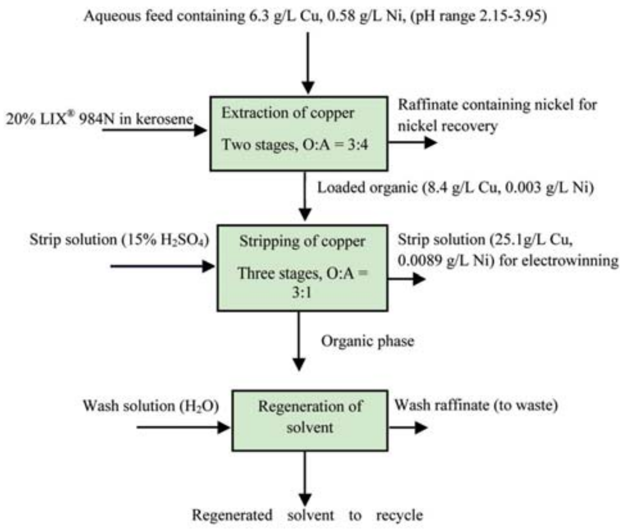

Figure 9—Proposed flow sheet for treatment of Cu-Ni leach liquor

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Characterization and flocculation studies of fine coal tailings

by S. Kumar*, S. Bhattacharya*, and N.R. Mandre*

Synopsis

The re-use of waste water from coal preparation plant tailings is always desirable, but is generally problematic in terms of solid-liquid separation. Dewatering and disposal of coal slurry at a high percentage of moisture poses a major technological and environmental challenge to mining and mineral processing industries world-wide. Characterization and flocculation of these coal tailings reveals that the separation of fine coal tailings depends on factors such as size distribution, slurry viscosity, zeta potential, pulp density, circuit design, plant operating parameters, and the behaviour of solid particles in an aqueous medium. The present study was carried out on -600 mm coal tailings collected from a coking coal preparation plant of Jharia Coalfield, India, using anionic flocculent. Characterization studies revealed that the zeta potential was highest (-44 mV) at a pH of 9.0, the size range of the particles was 1.1–700 μm, and the average ash content was 62.57%. Flocculation studies were performed at different solid concentrations, pH values, and polymer dosages. The results indicated an efficient settling rate of 178.15 mm/min at 8% solid (w/w) at a flocculent dosage of 32.50 g/t solid. The turbidity of the clear liquid obtained was 7.42 NTU.

Keywords
flocculation, coal fines, settling, dewatering.

Introduction

Coal mining has essentially become a set of mechanized operations. Mining and subsequent processing generate considerable amounts of fine tailings. About 20% of the product from a typical coal preparation plant (CPP) is less than 500 μm in size (Parekh, 2009). Generally this fine fraction is discarded due to the high cost of processing it. The fine solid particles in CPP tailings also present many environmental and economic challenges to society and industry. Discard of fines also disturbs the overall water balance of the circuit by increasing make-up water requirements to the plant. Therefore dewatering of such coal tailings is fast emerging as one of the priorities for CPPs around the world.

With the development of advanced coal cleaning technologies such as flotation, the Jameson Cell, Pneufloats, *etc.*, cleaning of fine size coal to low ash and low sulphur contents is feasible nowadays. However, the commercialization of these technologies is hindered, partly due to the poor efficiency of dewatering circuits for fine coal slurry, which may be attributed to the presence of coal particles of different sizes, shapes, surface area, and specific gravities, and their unique behaviour in the aqueous environment. Furthermore, industrial waste slurries containing colloidal particulate matter, in particular coal and mineral processing plant tailings with a high proportion of clay materials, pose significant challenge in dewatering (Philip *et al.*, 2011).

Therefore, to significantly improve the dewatering performance, it is important to understand the characteristics of coal, the chemistry of the carrier liquid, the impurities present, and their influences on the solids content. Industrial fine coal dewatering circuits contain thickeners, cyclones, screens, filters, centrifuges *etc.*, either in combination or individually. However, most of these dewatering options, which reduce the moisture level to 20–30%, entail high capital and operating costs and hence conventionally are used for dewatering of clean coal and not for coal tailings.

Most CPP tailings are settled in tailing ponds, usually at high water content, 65–75% (w/w), causing continuous loss of water. Therefore, it is essential to model a suitable low-cost dewatering method, usually by sedimentation in a thickener, to make it possible to recycle a large volume of clean water in CPPs (Sabah *et al.*, 2004). Thickeners are the most commonly used equipment for dewatering of slurry; the design considerations are based on the settling rates of the slowest settling particles and conditions for minimum disturbance of the medium (water) through which the solid particles are allowed to settle

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(Gupta *et al.*, 2006). From the literature it may be seen that waste slurries produced from CPPs contain high percentages of ultrafine particles and inorganic impurities, which are composed of clay minerals such as kaolinite and illite, muscovite, quartz, and coal particles (Das *et al.*, 2006). The natural sedimentation rate of these particles in colloidal and finely divided suspended form is very low. Flocculation technology is applied in most CPPs to enhance the settling rate of solids and to recover water from the tailings.

Flocculation is a complex process and its effectiveness depends not only on the use of appropriate chemical reagents (coagulants, flocculants *etc.*) and their method of addition, but also on the mineral composition (Sabah *et al.*, 2004). Accurate determination of the physical, chemical, and electrokinetic properties of solid matters in pulp, especially when using flocculants, plays a key role in the success of destabilizing fine-particle suspensions.

Addition of flocculents (long-chain polymers) in a dilute stable suspension bridges particles together, leading to the formation of highly porous and irregularly shaped flocs that have complex shapes, and possess rapid initial settling velocity, trapping some liquid in their structures (Parsapour *et al.*, 2014). The nature of flocs depends on factors such as the physical properties of the solids (surface chemistry, size, size distribution, shape, density), the nature of the liquid (viscosity, dielectric constant), the nature of the suspension (electric charge, pH, ionic strength, temperature), and the nature of the flocculent (chemical properties of the main part and chains, molecular weight, molecular weight distribution, electric charge, charge density). Also, the properties of flocs, such as flocs size, density, structure, and strength significantly influence the settling rate and hence the performance of solid–liquid separation.

Furthermore, an understanding of the interaction mechanism between polymeric flocculent and solid particles in a slurry and the associated flocculation mechanism is of great practical and fundamental importance in mineral processing and interface science (Yaguan Ji *et al.*, 2013). For effective flocculation, synthetic or natural polymeric reagents are generally used as flocculating agents in most CPPs. However, the optimization of process parameters such as suspension pH, polymer type, and dosage are also important to achieve the desired settling rate and the water clarity values (Das *et al.*, 2006). This paper presents the results of a study of the physical and electrochemical characteristics of coal tailings and the flocculation process, using a synthetic polymer at various pulp densities and slurry pH values.

Experimental

Materials

The coal sample used in the experiments was collected from Jharia Coalfield, India. The capacity of the plant (plant feed) was 200 t/h (ROM coal), of which 25–30 t/h reports as plant tailings. A high molecular weight polyacrylamide-based anionic polymer, Magnafloc1011 (M1011) supplied by BASF India, was used in the flocculation tests, having a bulk density of 0.7 g/cm^2, size 98% <1000 μm, and viscosity varying from 300 cP at 0.1% concentration to 1997 cP at 1% concentration.

Prior to the flocculation tests, a homogeneous stock solution (0.25% w/w) of polymer was prepared using distilled water. The stock solution was further diluted to 0.02% (w/w) concentration for the flocculation tests. Slurry pH was adjusted by addition of either HCl or lime solution prior to adding the flocculants.

Methods

Characterization studies

Size analysis of a representative sample was done at sieve sizes of 600, 425, 300, 211, 152, 104, 75, and 53 μm. Sub-sieve analysis of the -53 μm size sample was carried out using a Warman Cyclosizer. A Nano-S90 zeta sizer was used to analyse smallest size particles.

For zeta potential measurement, a suspension containing 0.05–0.1 wt% coal was prepared, the pH value of which was adjusted using either HCl or NaOH. After being left to settle for 6 hours, the upper portion of the diluted fine suspension was extracted for zeta potential measurement using a Zeta-Meter 4.0, which is equipped with a microprocessor unit capable of directly measuring the average zeta potential and its standard deviation. The zeta potential was measured at different level of pH from 2–12.

Flocculation studies

The coal sample was subjected to flocculation tests using a 1000 ml graduated cylinder. For this purpose the desired amount of coal was mixed in water to the desired pulp density and the pH of the slurry was adjusted by using dilute HC1 and NaOH. The water used for the slurry preparation was collected from the tailing thickener overflow in order retain the properties of slurry at actual site conditions. The desired amount of polymer solution was then added into the coal slurry and thoroughly mixed by inverting the cylinder 10–12 times (Mandre and Panigrahi, 1997). After a mixing, the cylinder was allowed to stand undisturbed. The height of the slurry and water interface was recorded as a function of time to calculate the settling rate of the flocculated suspension. Typically, the profiles were characterized by fast initial settling rates followed by an intermediate region of reduced settling rate and then a period of consolidation of the sediment. After 15 minutes' settling time, the clear water was sampled for turbidity measurement using a turbidimeter.

Results and discussion

Characterization of fine coal tailings

Characterization studies of the coal sample indicated a particle size ranging from 1.1 μm to 700 μm as shown in Table I. The ash content of the sample was found to be 62.57% and the solid specific gravity measured was 1.712.

Particle size analysis

The particle size analysis of the sample (Figure 1) indicated that about 7-8% of the sample was larger than 600 μm in size, and about 50% finer than 150 μm. According to the Wentworth classification, about 14% of the sample was in the clay fraction (< 4 μm), 26% was in the in the fraction (4-63 μm) (Sabah *et al.*, 2004); and 60% in the sand fraction (> 63 μm) attributed to the presence of carbonaceous and ash- forming materials as reported in the literature.

Table I

Characterization results of the fine coal tailings

Solid SG	1.712	Carbon content	15.16%
Particle size distribution, µm	1.1–700	Zeta potential of slurry at 8.0 pH, mV	-38
Weight % of -53 µm particles	37.94%	Natural pH of pulp	8.0
Ash content of coal	62.57 %	Concentration of tailing slurry (feed to tailing thickener)	8.0 % solids (w/w)
Equilibrium moisture	1.48 %	Solids content of tailing thickener underflow	27.24% (w/w)
Volatile matter	20.79		

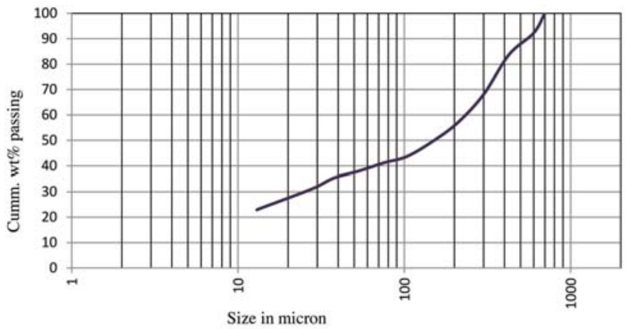

Figure 1—Particle size distribution of coal tailing

Size distribution of ash

The distribution of ash-forming materials in different size ranges was investigated. Figure 2 shows that the ash content decreases with decreasing size fraction, except for the -53 µm size fraction. The higher ash content in the -53 µm size fraction could be attributed to the presence of higher amount of clay and slits in this fraction, while the increase in ash content with increasing size fraction may be due to the presence of non-combustible materials such as quartz and other silicate minerals, as reported by Sabah *et al.* (2004).

Lower rank coals are weakly hydrophobic; hydrophobicity increases with an increase in rank, reaches a maximum for medium-volatile and low-volatile bituminous coals, and decreases for anthracite.

Zeta potential

Zeta potential studies were carried out at different pH values. The results (Figure 3) revealed that the tailings exhibit negative charge at all pH values. The negative value of the charge increases with increasing pH up to 9. Increases in pH above 9 results in decreasing negative zeta potentials, with a value of -16 mV at pH 12. This phenomenon may be attributed to the presence of alumina and silicate particles, which result in lower negative zeta potential values. Furthermore, the varying zeta potential in the acidic medium may be attributed to the change in surface pH, while that in the alkaline region may be ascribed to the binding of more cations.

A moderate zeta potential value of -38 mV was observed at pH of 8, which was the natural pH of the slurry. According to the ASTMD-4187 standard test method, if the zeta potential of colloids in water or waste slurry is above -60 mV, the stability of the system is classified as 'perfect' (Sabah and Erkan, 2006). As the zeta potential of the tailing slurry in the present case was -38 mV at the natural pH of 8 (Figure 3) of the slurry in the plant, it may be classified as highly stable, thus the settling characteristics could be enhanced using flocculation.

Flocculation studies

Effect of solids concentration and slurry pH

Preliminary flocculation studies were carried out to examine the effect of pulp density and slurry pH on the settling rate of particles. Experiments were carried out at solid concentrations of 4, 6, 8, 10, and 12% (w/w) at a fixed polymer dosage of 6.5 g/t solid. Since the suspension pH plays a significant role in polymer adsorption at the particle/water interface and can determine the flocs sizing and the settling rate of solids (Sabah *et al.*, 2004), the slurry pH was also varied, with values of 4, 6, 8, 10, and 12.

As shown in Figure 4, at low pH values, a remarkable decrease in the settling rates were observed at all solid concentrations. Here it may be observed that, at 8% solid concentration with slurry pH of 8, the settling rate is as high as 54.26 mm/min. However, with further increase in pH

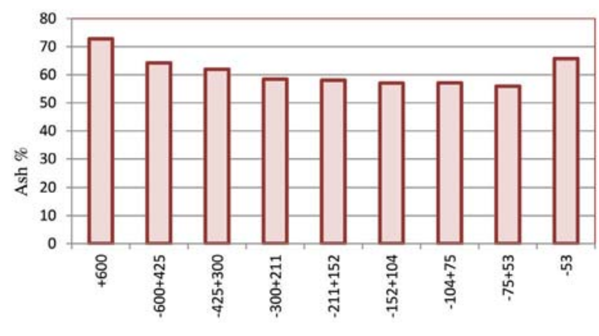

Figure 2—Ash distribution by size fraction

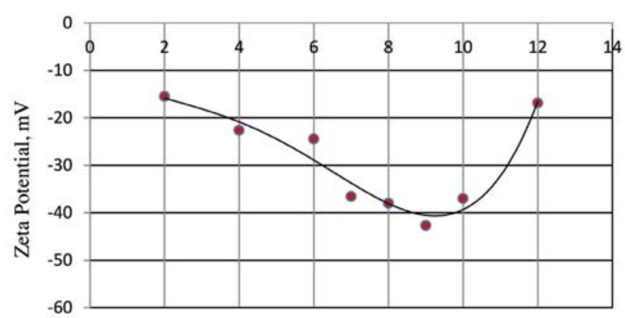

Figure 3—Zeta potential - pH profile

above 8, a decrease in settling rates were observed. This may be attributed to the fact that the suspension pH changes the charge characteristics of polymer chain and their conformation in solution, which directly affects the flocculating power of the polymer and hence results in a change in settling rate of particles (Foshee and Swan, 1982).

Also, at low pH the flocculation power of anionic polymers by the bridging mechanism decreases as the polymer molecules are in a random coil configuration in solution, whereas at relatively high pH configuration of the polymer extends due to electrostatic repulsion between the charged groups on the polymer chain (Taylor and Morris, 2002).

Furthermore, the relatively low settling rate at low pH could be due to the weakened electrostatic attraction of the negative particle surface, since the zeta potential of the original sample was about -16 mV at pH 2, whereas at the natural pH of 8 the zeta potential was about -38 mV. Also, the covalent bond and/or electrostatic bond formation between the (=C–O-) groups of anionic polymers and metal cations on the external surfaces of mineral particles may be inhibited at low pH values (Sabah *et al.*, 2004).

In order to support above findings, some experiments were carried out to study the settling rate of particles without flocculent. These experiments were carried out at 8% solid concentration (w/w) and at pH values of 4, 6, 8, 9, 10, and 12 as previously. The results shown in Figure 5 indicated that, at a slurry pH of 9 where the zeta potential was about -44 mV, the settling rate was as low as 4.13 mm/min. At the natural pH of 8, the settling rate was 5.27 mm/min. Further decreases in pH resulted in a marginal improvement in the settling rate, which reached a maximum value of 6.20 mm/min at a slurry pH of 4. However, the improvement in settling rate with increasing pH was more marked in the basic region. These findings support the supposition that the polymer is definitely disturbing the stability of the suspension, as the settling rate obtained using flocculent (Figure 4) is nearly 10 times higher than that obtained without using flocculent (Figure 5).

Effect of polymer dosage on settling rate

Studies were further extended to investige the effect of polymer dosage on the flocculation of CPP tailings. The studies were carried out at 8% solid concentration with the polymer dosage varying from 3.25 g/t solid to 58.5 g/t solid.

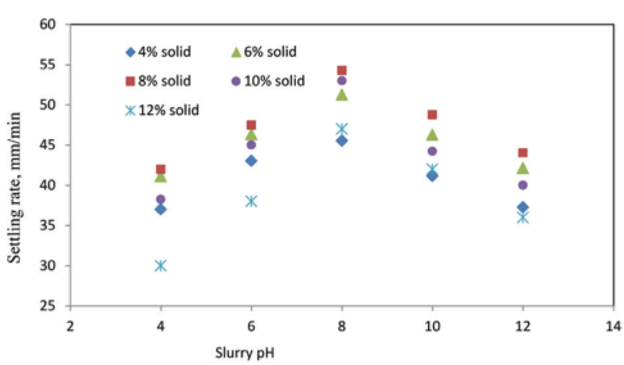

Figure 4—Effect of pulp density on settling rate of solids at various pH values

All tests were carried out at pH of 8, which is the natural pH of the tailing slurry and also provides good settling conditions, as shown in Figure 4. The 8% solids concentration was chosen as it resulted in a better settling rate than other concentrations (Figures 4 and 5). The results (Figure 6) show clearly that the settling rate increases with increasing polymer dosage, reaching a maximum at a dosage of 32.50 g/t solid.

At low polymer dosages, the floc size is very small due to insufficient polymer adsorption on the particles, which results in poor settling rate. With increasing flocculent dosage, the amount of adsorbed polymer increases, resulting in the incorporation of more suspended particles in the flocs and enlargement of the floc size, leading to the enhanced settling rate. From Figure 6, it may also be noted that the optimum settling rate of 178.15 mm/min was achieved at 32.50 g/t solid. The decrease in settling rate with increase in flocculent dosage beyond this point may be attributed to the formation of large size but less compact flocs (Tao and Groppo, 2000).

Studies on pulp density of settled slurry and clear liquid

Apart from obtaining a good settling rate, it is also imperative to analyse the compaction behaviour of settled slurry, as this is a controlling parameter for the determining the concentration of underflow slurry from sedimentation-based equipment such as thickeners. The turbidity of the overflow liquid is also an important parameter, as the liquid is recycled back to the plant as make-up water. Therefore, the studies were further extended to observe the effect of polymer dosage on the concentration of settled slurry and turbidity of the supernatant water. Test work was conducted at a slurry

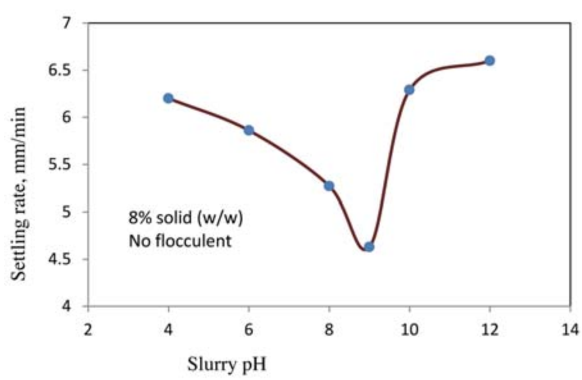

Figure 5—Effect of pH on settling rate without flocculent

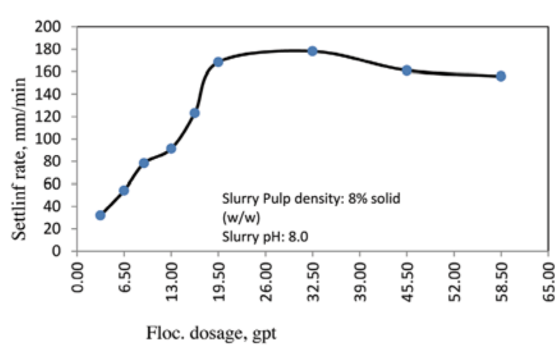

Figure 6—Effect of polymer dosage on settling rate

density of 8% solid concentration (w/w) and pH 8 with different flocculent dosages. The height of the mudline was measured after 15 minutes of settling time and the pulp density was calculated.

Figure 7 shows that with increasing flocculant dosage, the pulp density of the settled slurry increases to a maximum of 1.212 at a dosage of 32.50 g/t solid, and then decreases significantly with further increases in dosage. The pulp density at flocculent dosage of 19.50 g/t solid was only slightly lower than the maximum 1.205 compared with 1.212. This may be attributed to the formation of larger size and less compact flocs (Tao and Groppo, 2000).

Figure 7 also shows that the turbidity of the supernatant liquid (measured after 15 minutes of settling time) decreases rapidly with increasing flocculent dosage up to 19.5 g/t solid, and thereafter shows only a minor decrease with further flocculent additions up to 58.5 g/t solid. At the optimum settling conditions of 32.5 g/t solid and pH 8 (Figures 4 and 6), the turbidity was 7.42 NTU.

Furthermore, the addition of flocculent at an optimum dosage of 32.50 g/t solid improved the settling rate by about 34 times compared with than that obtained without flocculent (Figures 5 and 6). Also, the turbidity of the supernatant liquid was decreased to about 25% of that without flocculent (Figure 7). It may also be noted that the lowest turbidity values were obtained with very a high dosage of polymer (58.5 g/t solid), as shown in Figure 7. However, at this dosage, the settling rate is below the maximum (Figure 6).

Conclusions

Characterization studies of the sample indicated a particle size ranging from 1.1 to 700 μm, with about 50% of material in the -50 μm size fraction; an ash content of 62.57%, fixed carbon 15.16%, and volatile matter 20.79%. The zeta potential was -38 mV at the natural slurry pH of 8 and no isoelectric point occurred between pH values of 2 to 12, hence according to the ASTMD-4187 standard test method, the stability of the suspension may be disturbed by using polymers to enhance settling.

Flocculation studies carried out at pulp pH values from 4 to 12 and densities from 4 to 12% solids (w/w) showed an increase in settling rate up to a pH of 8, followed by a decrease with further increases in pH at all solids concentrations. Studies with varying flocculent dosage at 8% solids concentration (w/w) and pulp pH of 8 (the optimum settling conditions) showed the highest settling rate of 178.15 mm/min at dosage of 32 g/t solid, with a decrease in settling rate at higher dosages.

Turbidity values showed a continuous decrease with increasing flocculent dosage, although the effect was minimal at dosages higher than 32.50 g/t solid. The turbidity was 7.42 NTU under the best settling condition of 8% solid concentration (w/w) and pH 8. Thus flocculation improved the settling rate by about 34 times, and the turbidity of the clear liquid was decreased to about 25% of the original turbidity of the clear liquid obtained without using flocculent.

Under the optimum settling conditions, the pulp density was increased from 1.128 g/cm^2 (the pulp density of tailing slurry discharged from the plant, 27.24% solid, w/w) to 1.212 g/cm^2 (42% solid, w/w). Considering small variations in the actual plant performance, it is estimated that the moisture content of the fine coal tailing can be reduced by around 10–12% from the level currently discharged with the plant final tailing from the thickener underflow. This would significantly reduce the plant operating costs by reducing the fresh make-up water requirement, and also the inventory cost by enabling the use of a lower capacity tailing discharge pump and related pipe, fittings, valves *etc.*

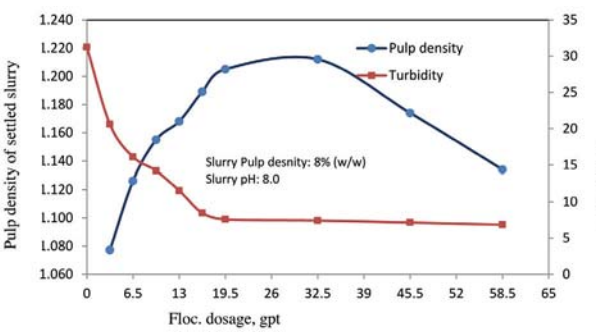

Figure 7—Variation in pulp density and turbidity at different flocculant dosages measured after 15 minutes of settling

Acknowledgement

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Beneficiation of marble from Griekwastad, Northern Cape Province

by N.P. Mahumapelo* and C. Magaseng*

Synopsis

This paper is based on a study to determine the potential beneficiation opportunities for marble from Griekwastad in the Northern Cape Province.

The marble was characterized mineralogically by X-ray diffraction. Major and trace elements were determined using inductively coupled plasma-optical emission spectroscopy. The sample was crushed, and the crushed material beneficiated by tumbling and polishing. The resulting beads were incorporated into a variety of jewellery and other decorative items.

It is concluded that the beneficiation of Griekwastad marble presents a good opportunity for value addition and job creation, provided that an effective marketing strategy for the products can be developed..

Keywords

Griekwastad, beneficiation, marble, chemical analysis.

Introduction

The main economic activities in the Northern Cape Province are farming and mining. Mining activities are concerned mainly with iron and manganese. Diamonds, zinc, and lead are also mined in the province. Other important commodities mined in the region include copper, limestone, gypsum, rose quartz, tiger's eye, mica, verdite, and semi-precious stones. To a large extent, the beneficiation of these metals and minerals takes place outside the province.

Opportunities therefore exist to establish beneficiation plants to add value to these minerals within the Northern Cape, in this case in Griekwastad. The potential spinoffs are job creation, rural development, infrastructure development, and skills development.

The Small Scale Mining and Beneficiation (SSMB) division at Mintek was established to promote mineral-based

activities in rural and marginalized communities through technical assistance and skills development. This is done by developing technologies appropriate for small, medium, and micro enterprises (SMMEs) that participate in the minerals and mining industry. The SSMB division's mandate is to initiate poverty alleviation programmes and support the growth of SMMEs in the mining and mineral sector. The division uses Mintek's high-technology facilities and resources to support SMMEs in mining, extraction, and value addition to minerals through beneficiation. Mineral beneficiation has been identified as an important mechanism to further diversify South Africa's economy, and thereby also create jobs. Potential benefits include employment creation, skills development and transfer, rural development, and poverty alleviation (Paul, 2011).

The Griekwastad community

Griekwastad is a town in the Northern Cape Province of South Africa (Figure 1).

Members of the Griekwastad community mine marble at a subsistence level. The use of children in mining, though undesirable, is mainly driven by poverty in the area. Children are employed in small-scale mining elsewhere in South Africa and Africa, in many cases close to where their parents are working. The mining is carried out illegally, and the miners do not have any formal training in mining and use low-technology methods.

The Department of Trade and Industry, Mintek, the Department of Mineral Resources, the Small Enterprise Development Agency, and the Pixley ka Seme District Municipality are collaborating to develop the Griekwastad community. This will be achieved by:

➤ Creating employment opportunities
➤ Provision of state funds for equipment, training, and marketing of products (Department of Trade and Industry)
➤ Assisting communities to apply for mining permits (Department of Mineral Resources)

* *Mintek,, South Africa.*
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Figure 1—Griekwastad location

- Making buildings available for projects (Pixley ka Seme District Municipality)
- Facilitating registration of informal groups as co-operatives (Small Enterprise Development Agency)
- Evaluation of mineral samples and training the community on safety measures and marble beneficiation (Mintek).

Objective

The objective of this study was to determine the potential beneficiation opportunities for the marble that is mined in the Griekwastad area.

Methodology

The study covered the activities summarized in Figure 2.

Mintek personnel participated in a visit to the Precious Stone and Jewellery Services CC site situated in Griekwastad to interview members and obtain samples for analysis.

A literature study was undertaken to develop a deeper understanding of the marble that is available in the Griekwastad area.

Sample preparation

The samples were crushed with a jaw crusher to 20.5 mm. The crushed marble was split into 6 kg portions and tumbled in a roller mill with steel balls (30 mm, 40 mm, and 50 mm) and 100 ml of water for one day to remove rough edges.

XRD

A pulverized portion of the marble sample was analysed by X-ray diffraction (XRD) in order to identify the minerals present and their relative proportions. This was aimed at an improved understanding of the physical properties that could affect the behaviour during beneficiation. The conditions for XRD analysis were Cu Ka radiation, a 28-scan range of 5–80°, a step size of 0.02° 28, and a counting time of 3 seconds per step. Only crystalline phases in amounts sufficient to diffract (usually 3–4 mass%) under the conditions employed are detectable (Clark, 2013).

Chemical analysis

The crushed marble sample was separately pulverized and submitted to the Analytical Services Division at Mintek for chemical analysis by inductively coupled plasma-optical emission spectroscopy (ICP-OES).

Sieve analysis

Sieve analysis is a method of determining the particle size distribution, which is usually expressed as the weight percentage retained upon each of a series of standard screens of decreasing mesh size. The particle size distribution of the crushed sample is shown in Figure 4.

The sieved marble samples in each of the size fractions were used to manufacture a product *e.g.* the sample retained on the 6 mm sieve was used in a necklace (see Figure 6).

Polishing

An AP1 Struers polishing machine was used to polish the samples. During polishing the operator must hold the sample carefully, because the wheel of the polishing machine rotates at high speeds. Only thick samples were polished for safety reasons.

- First, an 80-grit abrasive, which is coarse, was placed on the polishing wheel. The technician held the sample while the wheel was rotated for 3 minutes. Water was used as a lubricant and dust suppressant. The same procedure was then carried out on the opposite surface of the sample
- Secondly a 220-grit abrasive, which is medium, was used
- Lastly an 800-grit, which is fine, was used to achieve a smooth finish.

Product manufacture

The samples were incorporated into value-added products, using different techniques.

- To form beads from marble, a jewellery drill with a 1.2 mm bit was used to drill holes in each marble fragment
- The necklace and earrings were hand-made with different sizes of marble fragments

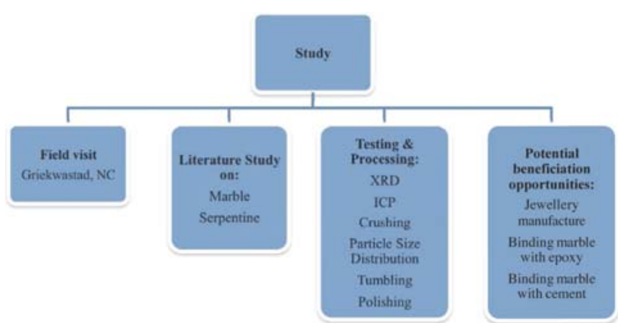

Figure 2—Study activities

- The decorated T-shirt was made by sewing the marble to the T-shirt with a needle and thread
- The ring was made by attaching the polished marble fragment onto the prefabricated metal ring with epoxy
- A cement frame was formed by placing stones into a cement mould.

Results

Field visit

Mintek personnel visited the project site and interviewed members of Precious Stone and Jewellery Services CC. Questions were asked regarding safety aspects, knowledge of stone beneficiation, pricing, marketing, and the impact of mining marble on the environment. The findings were recorded and additional information was obtained telephonically at a later stage. The findings from the field visit were as follows:

- The Griekwastad community has been mining stones for generations. Knowledge has been passed down from generation to generation
- The workers lack knowledge of the safety and health precautionary measures that need to be followed when mining and beneficiating semi-precious stones
- People do not seem to be aware of environmental factors and the impact of their activities on the environment
- Old or traditional methods are still used to mine precious stone and there is little or no knowledge of beneficiation
- People are not aware of hazardous minerals that occur together with semi-precious stones
- Due to the remoteness of Griekwastad, potential clients may be unable to access the products of the industry easily
- The unemployment rate in the area affects local sales; people buy food rather than jewellery, and therefore a market outside the area must be found.

Literature review

Marble is a metamorphic form of limestone, composed mostly of either calcite or dolomite. Marble may also contain varying amounts of minerals such as chlorite, serpentine, garnet, and wollastonite, depending on the composition of the parent rock and the temperature of metamorphism (Power, 1994).

Marble is used principally for cladding buildings and monuments, interior decoration, statues, and table tops (Mesothelioma Center, n.d.).

Serpentine ($Mg_6(OH)_8Si_4O_{10}$), which is a major constituent of the Griekwastad marble, is a microcrystalline mineral that occurs in various shades of green, yellow, and red (Oosterhuis, 1998).

Chemical analysis

ICP-OES analysis showed that the marble sample contained low concentrations of toxic metals. High percentages of some elements in powder form can pose a risk to human health – for example, lead in powder form can be absorbed through the respiratory system. The samples had low levels of cobalt oxide (33 ppm). The inhalation of cobalt particles can cause respiratory sensitization, asthma, shortness of breath, and decreased pulmonary function (Lenntech, n.d.).

The trace amount of some element in the marble indicates that they will be within the accepted limits in respirable dust. For example an acceptable level of 600 ppm of lead in soil is suggested as a 'safe' level (Pubmed, n.d.).

Table I and Table II show the results of the major and trace element analyses.

XRD

The bulk mineralogical results show that the sample is marble, comprising calcite, serpentine, and chlorite. The green colour of the rock is a result of the presence of clinochlore and lizardite (varieties of chlorite and serpentine

Table I

Major element analysis of marble

Major elements	(%)
Al	<0.05
Si	5.68
P	0.14
S	0.12
Cl	0.02
K	<0.01
Ca	12.60
Cr	0.01
Mn	0.03
Fe	0.58

Table II

Trace element analysis of marble

Trace elements	(ppm)
Co	33.0
Ni	15.9
Cu	17.3
Zn	23.9
Ga	7.2
Ge	<0.6
As	3.4
Se	<0.3
Br	3.1
Rb	4.5
Sr	124.8
Y	1.7
Zr	7.9
Nb	0.5
Mo	<0.9
Ag	<0.4
Cd	0.3
In	<0.3
Sn	<0.6
Sb	1.7
Te	<0.8
I	<1.7
Cs	<3.2
Ba	74.2
La	<6.6
Ce	10.4
Hf	3.7
Hg	<1.0
Ti	<0.9
Pb	6.2
Bi	<0.7
Th	1.3
U	<2.5

respectively). Table III indicates the minerals present in the marble sample. Figure 3 illustrates a backscattered electron image showing the distribution of calcite, serpentine, and chlorite.

Particle size distribution

The ideal size of fragments for making into products such as necklaces and rings ranges from 6 mm to 20 mm. The results of the sieve analysis (Figure 4) show that no material was retained between the 0.075 mm and 5 mm sieves. More than 75% of the material was in the size range above 6.7 mm. This is a positive result, since it shows that crushing to 20.5 mm does not generate a significant amount of waste material.

Potential beneficiation opportunities

The raw marble sample collected at Griekwastad had sharp edges, a rough surface, and a pale and dull appearance (Figure 5).

The marble sample was converted into valuable products after processing at Mintek:

- ➤ Different shapes of beads were produced by crushing the samples
- ➤ The texture of the marble sample was smoothed by tumbling
- ➤ The colour of the samples was enhanced by polishing.

Marble beads were used to produce a necklace, earrings, a decorative shirt, and a ring, thus added value to the mineral.

Table III

Bulk mineralogical composition

Mineral	Relative abundance
Calcite	Dominant
Chlorite	Trace
Serpentine	Major

Dominant – >50; major – 20–50 mass%; minor – 5–20 mass%; trace - < 5 mass%; blank – not detected (Note: XRD results are qualitative and should not be used for quantification purposes)

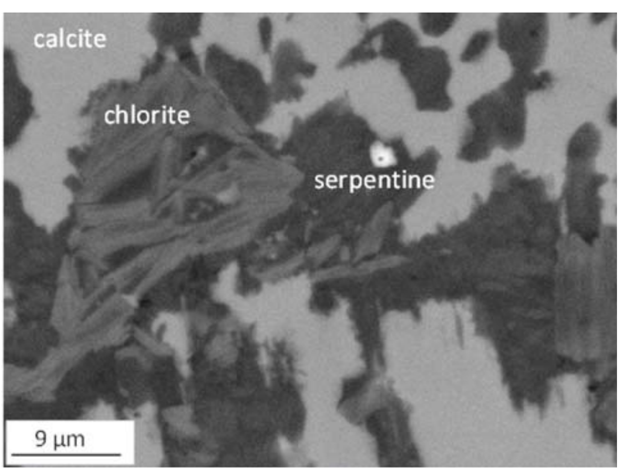

Figure 3—Backscattered electron image showing the distribution of calcite, serpentine, and chlorite

These products are of good quality and aesthetically appealing, as illustrated in Figure 5. The marble and prefabricated metal bonded well with epoxy to form a ring.

Weight plays an important role in the marketability of jewellery products. It has been observed that end-users prefer lightweight jewellery. A weight comparison between marble and glass bead jewellery was conducted. Table IV illustrates the mass of each product. The weights of prototype samples were found to be acceptable.

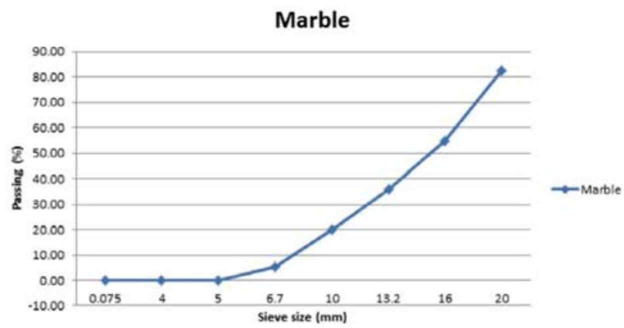

Figure 4—Cumulative particle size distribution of marble samples

Figure 5—Raw marble sample before processing

Figure 6—Marble products made at Mintek

Table IV

Weight comparison between marble and glass jewellery

Product	Marble (g)	Glass beads (g)
Ring	15.8t	11.3
Necklace	65.3	66.3
Earings	5.5	9.5
T-shirt	92.9	98.9

It was proposed that the marble should be complemented with other materials. The marble and other semi- precious stones (jasper, tiger's eye, and brecciated jasper) were randomly placed in a mould and bonded well with the cement. The stones in conjunction with cement could be used for cladding in the building industry, decorative pieces, and artwork. Figure 7 shows that marble can affix to cement well enough to be considered for use as a cladding material.

Figure 7—Brecciated jasper, marble, jasper and tiger's eye cemented at Mintek

Conclusion

Mintek's role in this collaborative project was to perform a technical evaluation of the mineral products in order to determine their properties and the potential beneficiation opportunities. The interview conducted with members of Griekwastad Precious Stone and Jewellery Services CC resulted in a better understanding of the knowledge of the community regarding beneficiation. The information gathered in this study was very valuable, because now we know about the mineralogical composition of the marble. The workability of the marble was good, and all the products were produced with little effort. The aim of the research was achieved, and Mintek will now be able to train the Griekwastad community in marble beneficiation, the minerals present in marble, safe use of equipment, and health and safety.

Recommendations

This study should be developed further. SSMB designers can explore additional designs and uses of marble.

It is recommended that members of the Griekwastad Precious Stone and Jewellery Services CC should be assisted in the following ways:

- Funding to purchase jaw crushers and polishing wheels
- Provision and training in the use of personal protective equipment
- Health and safety education
- Pricing of products
- Safe use of equipment
- Training on the forming and fabrication of different products.

The fact that Griekwastad in particular and the Northern Cape in general is far from major centres of economic activity makes it difficult for these communities to easily access markets. This means that more effective ways of marketing need to be considered; for example, exporting of products to other provinces within South Africa and other countries. It is therefore recommended that the Department of Trade and Industry should conduct a study on the status of marble beneficiation projects.

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Perceptions of the impact of board members' individual perspectives on the social and environmental performance of companies

by J. Stacey* and A. Stacey†

Synopsis

Large mining companies generally follow the distributed ownership corporate model, with a board of directors responsible for decisions that affect both shareholder value and stakeholders of the company. The board is simultaneously responsible for setting the culture and values of the corporation, which drive performance and priorities.

Companies listed on the Johannesburg Securities Exchange (JSE) commit to sustainable development in various ways, either by virtue of implementing the King Code of Governance 2009 (King III) and/or through their own public reporting on social and environmental matters. Many mining companies make public statements regarding their support for environmental stewardship, ethical behaviour, and fair treatment of communities. It is a local, regional, and indeed, global phenomenon that companies fail to deliver on these statements.

Research was carried out through the Institute of Directors of Southern Africa in 2007, and followed up in 2012, regarding directors' understanding of sustainable development issues, the relative priorities, what is needed for 'radical change' to effect sustainable development, and what enables or constrains the latter. Pertinent findings of both surveys are presented in this paper, and it is suggested that 'on-the-ground' performance may be indicative of the nature of leadership and decisions in the topmost ranks of the company.

The results indicated that environmental concerns fall consistently below social issues. Financial capital ranked most important, and while environmental issues are recognized as being of strategic concern for the long-term, they ranked as being the lowest importance of all 'Five Capitals' (Financial, Manufactured, Social, Human, and Natural). Social capital ranked second lowest, with black economic empowerment being the only high-priority social issue. There is also evidence that certain companies within the mining sector fail to recognize their absolute dependence on natural resources.

Much is made in academic and popular literature of the need for a new type of leadership for the radical shift to sustainable development: at company level this implies therefore a new type of director. The research found that only 14 per cent of directors felt that board decisions are consistent with their personal values; while intentions are strong to behave ethically and serve sustainable development, actions to give effect to these intentions lag significantly. Respondents indicated that the top impediments to courageous leadership for sustainable development related to personal issues of maintaining the image of being a director, fear of appearing weak, fear of being a lone voice, and bowing to board-colleague peer pressure.

Keywords
decision-making, sustainable outcomes, courageous leadership, personal values, sustainable development priorities, self-awareness.

Background

The mining industry has a largely negative image and reputation with respect to matters of social responsibility (Kapelus, 2002). A company's internal reasons for poor social and environmental performance can be complex, involving 'on-the-ground' technical and behavioural issues (Fuertes *et al.*, 2013), systemic organizational problems (Aras and Crowther, 2013), and leadership factors (Singer and Dewally, 2012). The focus of this paper is on the potential influence of leadership and decision-making at board level on environmental and social performance.

Most, if not all, large mining companies follow the distributed ownership corporate model, with a board of directors responsible for decisions that affect both shareholder value and stakeholders of the company. The board is simultaneously responsible for setting the culture and values of the corporation (Institute of Directors, 2009), which drive performance and priorities.

Values underpin decision-making (Byrnes, 1998). It has been shown that where capitalism prospers, it does so because people have embraced and internalized certain values (Weber and Parsons, 1998). Classical economic theory separates the economy from the environment and from people (Hall, 2013), and has, as its central value, growth and development (Kovel, 2002). Simultaneously, the legal framework within which directors operate pressures them to deliver short-term financial results, even to the extent of resulting in irresponsible social or environmental outcomes (Avery, 2005; Bogle, 2008).

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Companies listed on the Johannesburg Securities Exchange (JSE) commit to sustainable development in various ways, either by virtue of implementing the King Code of Governance (Institute of Directors, 2009) and/or through their own public reporting on social and environmental matters. Many mining companies make public statements regarding their support for environmental stewardship, ethical behaviour, and fair treatment of communities, often captured within the topic of sustainable development. Yet in practice, there are many examples where companies fail to deliver on these. This is a local, regional, and indeed, global phenomenon.

'A stable and democratic society is impossible ... without widespread acceptance of some common set of values' (Friedman, 1962). Sustainable development requires that the economy, environmental values, and considerations about people influence decision-making. If directors of mining companies have internalized capitalist values, then sustainable development will perpetually be at the mercy of the profit prejudice.

Research was carried out through the Institute of Directors of Southern Africa in 2007, and followed up in 2012, regarding directors' understanding of sustainable development issues, the relative priorities, what is needed for 'radical change' to effect sustainable development, and what enables or constrains the latter. In the five years between the two studies, sustainable development policy and practice has become increasingly prominent in business. In South Africa, the King Code of Governance (Institute of Directors, 2009) came into force in 2011, inextricably linking sustainable development and business strategy, as well as requiring business to operate under a stakeholder-inclusive approach. Multiple amendments and regulations pertaining to the National Environmental Management Act (Republic of South Africa, 1998a) were also enacted in this period. The Voluntary Energy Efficiency Accord was implemented and revised, whereby a 15% reduction in 'final energy demand' for the industrial sector by 2015 was targeted (Republic of South Africa, 2008b) and significant savings were achieved. Social and labour plan requirements, and the Mining Charter, which addresses social aspects of operating were also revised. Despite this increasing focus on environmental and social issues, South Africa has mixed results in the various indicators of environmental and social performance, although not necessarily explicitly linked to measures within the 2007–2012 period. For example, the Gini coefficient improved from 67.4 in 2005 to 63.1 in 2009 (Trading Economics, 2014). Simultaneously, massive-scale water pollution from gold mining increasingly plagues the Witwatersrand (Tutu *et al.*, 2008). Thus, policy focus is not necessarily translating into improved performance.

The intention of this research was to start to investigate to what extent directors within South Africa suffer from 'the tyranny of the tangibles' (Selznick, 1989), potentially sacrificing sustainable outcomes and their personal integrity for the sake of short-term financial delivery.

The role of leadership in organizational performance

'Power is the capacity or potential to influence people' (Northouse, 2013). Directors exert power through their assigned position within the company (Northouse, 2013), and ideally, by virtue of 'personhood': enacting their values in business. Leadership always occurs in the context of interactive relationships (Northouse, 2013). Because of this dyadic process, the leader's concept of self and identity is constantly being influenced, while shaping the behaviour of those within the company through norms and values (Selznick, 1989).

Irrespective of whether leadership is framed within the functionalist, conflict, symbolic interactionist, normative, or utilitarian philosophies, directors are the legal leaders of public organizations (Republic of South Africa, 2008c), the governance of which 'reflects the values of the society in which it operates' (Institute of Directors, 2009). Leadership can be seen as the promotion and protection of values; in the case of directors, this entails energizing followers to take actions that support the higher corporate purpose (Selznick, 1989). While there is a move towards the view that organizations' purposes should transcend economics (Selznick, 1989) and play a broader social role (Institute of Directors, 2009), the prevailing paradigm in South Africa is that of the Anglo / United States version of capitalism (Avery, 2005), in which short-term shareholder value dominates. There are, nonetheless, indications that the longer-term stakeholder-inclusive value model is emerging (Avery, 2005; Institute of Directors, 2009).

Management relates to maintenance, consistency, and order. Leadership relates to change (Northouse, 2013). In order to move the paradigm from the prevailing exclusively financial definition of value to a business model in which social and environmental issues are afforded equivalent priority, directors of mining companies need to internalize social and environmental values, and bring these longer-term, potentially intangible values to bear in decision-making (Bogle, 2008). This results in constant tension with the profit driver, presenting directors with dilemmas (Badaracco and Ellsworth, 1989) and potentially inconsistent demands within a pluralistic value system (Ashforth and Mael, 1989; Hangel, 2013). Simultaneously, as organizational reality is largely constructed by the words and actions of its leadership (Rickards and Clark, 2006), the dominant coalition of the board directors' personal characteristics and decisions have direct bearing on corporate performance (Abebe *et al.*, 2011; Kallunki and Pyykkö, 2013). Personal values are particularly important for understanding support for welfare and other socially relevant concerns (Boer and Fischer, 2013).

Adopting the Five Capitals framework of sustainable development (Forum for the Future, 2011), mining follows the weak sustainability model (Cabeza Gutés, 1996), within which natural capital can be consumed as long as it is translated into manufactured capital of equal value. An extension of this concept is often used by mining companies in justifying environmental degradation through their corporate social responsibility programmes – that by transforming mineral resources, human and social capital are developed. These latter aspects are priorities for South Africa (National Planning Commission, 2011).

Social and environmental performance of the mining industry

Despite commitments by mining companies, extensive deliberations with the Chamber of Mines, and the millions of rands spent on environmental and social considerations, labour and community unrest over social issues relating to mining continues to threaten the viability the industry. Environmental groups are vociferous in denouncing the environmental performance of mining houses and the related policies and regulation (Centre for Environmental Rights, 2011).

Social contributions by mining companies are strongly regulated by the Mining Charter in South Africa (Department of Mineral Resources, 2010), against which companies must report on an annual basis. Corporate social investment (CSI) is often pursued through local economic development (LED) and corporate social responsibility (CSR) programmes, or through mechanisms such as trusts. Social contributions within and between mining companies are often significantly disjointed (Le Roux, 2011).

Mining environmental management is highly fragmented, legislated primarily through the Mineral and Petroleum Resources Development Act (MPRDA), the National Environmental Management Act (NEMA), the National Water Act (NWA), the waste regulations, and other related legislation. Some mines operate without water licences and commence operations prior to full authorization from all regulatory entities (Morgan, 2012), perhaps as a result of capacity issues and difficulty in obtaining licenses, and indicative of lack of enforcement once licenses have been issued. Financial provision for environmental rehabilitation is provided for under the MPRDA.

Thus, the stated intent of mining companies in relation to social and environmental sustainability does not match society's expectations, or at times, their own commitments. This research investigates the role of prevailing values of directors and the drivers and obstacles that may cause or create these situations.

Research approach

The research was undertaken using two surveys, conducted five years apart, in collaboration with the Institute of Directors of Southern Africa (IoDSA). The first survey was conducted in 2007, and the second in 2012.

Survey objectives

The 2007 survey was developed with the objective of evaluating directors' approach to, and understanding of, sustainable development. This was part of a process to develop a sustainable development policy and strategy for IoDSA.

The 2012 survey sought to elucidate a more granular understanding of the drivers and obstacles to directors acting courageously for ethical and sustainable business in South Africa. This survey was based on the eight core messages that emerged from the 2011 IoDSA Annual Business Update Conference – themed 'Courageous Leadership'.

Survey design

Although the surveys were undertaken with different objectives, they were complementary and had areas of overlap. The 2007 survey was located within the paradigm of the Five Capitals model of sustainable development (Forum for the Future, 2011). The issues comprising the survey were purposefully selected from all of the five capitals and were sufficiently generic to be relevant to all boards and board members.

The 2012 survey interrogated to what extent the eight requirements of courageous leadership exist within the IoDSA membership companies across all sectors, what the obstacles are to achieving these requirements, what approaches might be most effective in overcoming the obstacles, and identified the leadership drivers currently in play for South African directors. These eight requirements (Ramalho, 2011) are:

- *Build a vision and live by it*—the need to understand who you are as a leader and what you stand for, within a business that operates as part of society
- *Understand what the new kind of leader is—and consciously transform yourself*—a new type of leader is needed with emotional intelligence, who lives their vision, and can do so under complex pressures
- *Build relationships with government*—developing pragmatic relationships built on trust, through contributing to debates and through actively pursuing wrongdoers in every sector
- *Build relationships with the unions*—needing to reach a better and more pragmatic accommodation with even militant labour
- *Build skills*—prioritizing skills development within a business risk framework, rather than relying on government programmes
- *Support small business and entrepreneurs*—particularly focusing on procurement policies to support small, medium, and micro enterprise (SMMEs) as the 'engines of job creation'
- *Put ethics first*—leadership is the most powerful force influencing ethics, through formal reporting and especially leading by example, and actions being consistent with the 'rules'
- *Build out from pockets of excellence*—leveraging excellence for ongoing business success and for the greater benefit of broader society, on which business ultimately depends.

The main sections of the two surveys are listed in Table I.

A variety of response formats were used in both surveys for reliability and to obviate respondent fatigue. These included categorical responses for demographic questions; ordinal (Likert-type) rating scales of agreement, importance, and frequency; partial rank ordering of items in order of importance; and binary associations between, for example, personal values and corporate outcomes.

For the 2012 survey, the findings were explicitly investigated to determine hurdles to, and enablers of, their implementation. A reasonable consistency of understanding of the terminology among the population of directors could be assumed, thereby addressing construct validity. A literature survey was used to identify words and phrases that support the eight core messages of courageous leadership. For example, emotional intelligence was 'deconstructed' into its commonly recognized components, as per the literature, which factors were included in the survey. It is relevant to note that several of these factors pertain to more than one of the core messages.

Table I

Sections comprising the 2007 and 2012 IoDSA surveys

2007 survey	2012 survey
• Demographics of the participant • The time frame boards have in mind (explicitly or implicitly) when making decisions on specific issues (*i.e.* their decision horizons) • The priorities boards associate with the issues above (*i.e.* decision priorities) • Opinions regarding non-financial risk, governance, and the role of the IoDSA	• More detailed demographics of the participants • The extent that board decisions reflect social and environmental values and considerations, and include social and environmental costs • The extent to which the respondents' board colleagues exhibit particular characteristics, associated with the eight identified requirements of courageous leadership for sustainable development • The top 10 rank-ordered elements that contribute most to effective courageous leadership • The biggest obstacle that is most relevant to each of the requirements for courageous leadership at board level • Rating specific mechanisms in terms of their effectiveness in assisting directors to be courageous leaders • Matching a series of personal values to particular business outcomes

Data collection and participation

The 2007 questionnaires were distributed by e-mail to all members of the IoDSA, and responses were returned either by e-mail or by fax. The 2012 survey was administered using the *SurveyMonkey* online survey software, with IoDSA members receiving a hyperlink to the survey via an e-mail.

The samples in both surveys represented a relatively small proportion of the membership of the IoDSA, but were nevertheless sufficiently representative of the diversity of membership for an exploratory study of this nature. The demographics of the participants in each of the surveys are given in Table II.

As evident in Table II, participants were from a broad range of industries, and not exclusively the mining industry. The results of the survey are therefore considered to have broad relevance, although mining and related issues have been highlighted for the purposes of this paper.

Data analysis

The demographic categorical data was analysed using descriptive statistics and charts to give a summary and profile of the survey participants.

Likert-type ordinal survey data is typically analysed by assigning numeric values to each of the response options. However, a more reliable method of estimating the means and spreads of responses to each survey item has been shown to be the normal distribution fitting algorithmic approach (Stacey, 2005) particularly for small samples. Using this technique, the means and spreads of responses were estimated using an iterative mathematical optimization algorithm to find the best-fitting distributions to the survey data, without the errors associated with assigning specific numeric values to each of the response categories.

For the rank-ordered and partially rank-ordered survey data, an optimization methodology was applied that makes it possible to estimate the means and spreads of survey responses; this is referred to as the 'shotgun stochastic search algorithm' (Stacey, 2006). This methodology is similar to the normal distribution-fitting algorithm in that it searches iteratively for the best-fitting distributions to the survey data, in this instance using a numeric modelling technique rather than mathematical optimization. The methodology is unique in its ability to analyse partial rank-ordered responses data.

The binary response data was summarized in a cross-tabulation of rows and columns. Correspondence analysis is an analytical technique used to present graphically the associations between the rows and columns in a cross-tabulation of research data. The output of the correspondence analysis is a two-dimensional chart, which in this study was used to illustrate the association between the personal values and the corporate outcomes.

Discussion of results

Board perspectives on sustainable development: social, environmental and economic priorities

Overview of 2007 results

Sustainable development requires that social and environmental considerations are part of all business decision-making, should form part of the measures of business success (Institute of Directors, 2009), and link to economic outcomes. Because of the prevailing paradigm that prioritizes economic success, this requires board-level 'courageous' leadership. It is shown in Figure 1 that in 2007, only 15.8 per cent of directors considered natural capital to be of above-average importance, while 39.4 per cent considered social capital issues to be of above-average importance.

Other observations with respect to the relative importance of the five capitals were that financial capital was predictably the highest priority (60.4 per cent), closely followed by

Table II

Summary of demographics of participants of the 2007 and 2012 IoDSA surveys

Variable	2007	2012
Sample size	83	221
Economic sector		
Primary (*e.g.* mining, agriculture, fishing and forestry)	16%	14%
Secondary (*e.g.* manufacturing and construction)	20%	19%
Tertiary (*e.g.* services, retail, education, and technology)	64%	67%
Role		
Executive	70%	70%
Non-executive	30%	30%

Perceptions of the impact of board members' individual perspectives

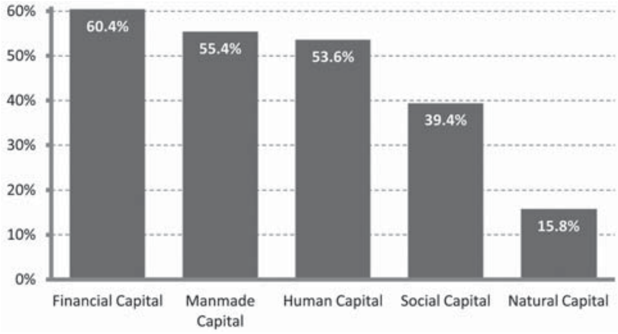

Figure 1—Proportions of directors regarding capitals being of 'above average' importance

human capital. It is acknowledged that the relative importance of the capitals fluctuates with varying external pressures, including the regulatory environment. Human capital was interpreted in the South African context as being a high priority due to the various charters and regulatory emphasis on this issue. The low relative priority of social capital could be interpreted as being due to an attitude that social issues external to the businesses were not within the direct control of companies.

When assessed at a more detailed level, the top five priorities for boards were, as expected, financially driven. These five priorities are listed in Table III.

Environmental issues

In contrast, environmental issues were first mentioned in position 31 out of the 39 priorities. The ranking of relative importance of issues specific to environmental concerns is given in Table IV.

The relative importance of energy use, water, and waste/pollution suggested a poor appreciation of the strategic importance of these issues. Climate change is a critical issue, and should also be considered to be a consequence of energy use and source.

With respect to natural capital, an understanding of how environmental issues contribute to business success was clearly lacking, although viewing them as being longer term was appropriate. It is possible that, because they are long term, environmental issues are treated as less important than the immediate financial delivery imperatives of business.

Social issues

Within social capital, Black Economic Empowerment was rated the most important issue, which is unsurprising given the status of the regulations. External communications was rated relatively important with a relatively short decision time horizon, typically being a proactive response with reputational and marketing implications. Job creation was viewed as being 'incidental' to business; macroeconomic objectives related primarily to unemployment. Business alone cannot address this, and government support and incentives are needed, not just regulation and prescription. Community investment and community health was perhaps seen as being of higher priority than community relations because of the action-orientated nature of most businesses *i.e.* the company could do something active in relation to the first two.

Community relations were perhaps seen as being more an operational issue than a strategic one. The very low priority of human rights (position 39 out of 39) perhaps reflected the feeling that this was something outside of business's control.

Overview of 2012 results

In the 2012 study, participants were asked to indicate the extent that board decisions typically reflect various issues; the results are illustrated in Figure 2.

Nearly two-thirds of respondents perceived that board decisions often or almost always took into account social values (specifically relating to business opportunities) or included social issues in all decision-making. Values relating to the environment, and environmental issues in general, featured slightly less prominently. The relative positioning of social and environmental costs mirrored this, whereby social costs were perceived to be internalized more often than environmental costs.

In contrast to the orthodox business view, which holds sustainable development to be mostly a threat, approximately three-quarters of the respondents indicated that board

Table III

Top five relative priority issues for boards

Relative position	Issue
1	Profitability
2	Shareholder value
3	Return on Investment
4	Black Economic Empowerment
5	Government policy

Table IV

Relative priorities for boards of environmental issues

Relative position (out of 39)	Issue
31	Energy use
32	Water
33	Raw materials (use & sourcing)
34	Biodiversity
36	Waste / pollution
37	Climate change
38	Land access

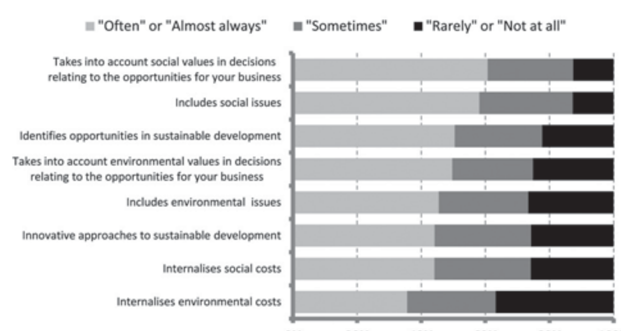

Figure 2—Consideration of social and environmental issues in board decisions

decisions regarded sustainable development to at least 'sometimes' include opportunities. Innovative approaches to sustainable development appeared to display a similar profile, featuring fairly regularly in board decisions.

Of concern however, are the responses that indicate that social and environmental aspects were typically considered 'rarely' or 'not at all' in board decisions. At least a quarter – and up to approximately one third – of the respondents indicated that board decisions rarely or never 'take into account environmental values in decisions relating to the opportunities for your business', 'include environmental issues', 'have innovative approaches to sustainable development', 'internalize social costs', or 'internalize environmental costs'. While a minority percentage, this potentially represented a substantial number of board decisions that seemingly excluded social and environmental considerations. A detailed breakdown of social and environmental issues was not undertaken in the 2012 survey.

Governance, values, and ethics

2007 survey

The levels of agreement among participants pertaining to the so-called 'non-financial risk' and governance statements included in the 2007 survey are illustrated in Figure 3.

It can be seen that there was strong agreement that non-financial issues affect company value and strategy, both directly and indirectly, although there may be a need for clarity of terminology with respect to non-financial issues *versus* sustainable development issues. Clearly, participants understood (>70 per cent) that corporate governance is not only a financial issue, but must be related to all aspects affecting company value. This could be interpreted as an 'in-principle' agreement, rather than a demonstrable deliverable.

Some differences were observed between the Executive and Non-executive responses. Ten per cent of Non-executives felt that corporate governance was applicable to only financial issues, while the number for Executives was 35 per cent.

It is particularly noteworthy that in 2007, only 14 per cent of participants agreed that board decisions were always consistent with their personal values. When the Executive and Non-executive split was examined, an even more disturbing picture emerged: only 8 per cent of Executives felt that board decisions were consistent with their personal values.

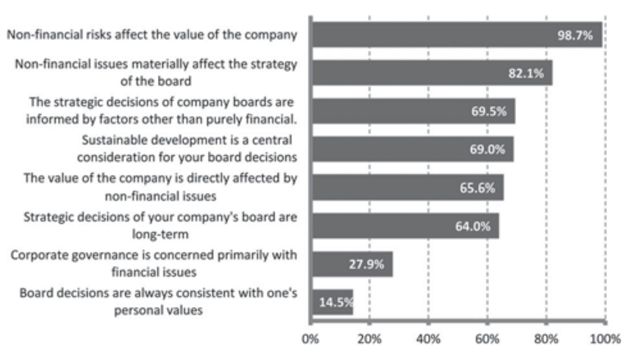

Figure 3—Levels of agreement with non-financial risk and governance statements

2012 survey

The King Code of Governance (King III), implemented in 2010, stipulates that sustainability, strategy, and governance are inseparable. The Code requires that boards operate ethically, through sound systems of governance, and that organizations are run on the basis of values, to deliver sustainable development. The Code also requires that organizations adopt the stakeholder inclusive model of governance (Institute of Directors, 2009).

This paradigm presents challenges to businesses operating in the prevailing orthodox economic model: the IoDSA 2011 conference recognized this in its use of the term 'courageous leadership'. Figure 4 demonstrates the relative evidence of various characteristics in respondents' board colleagues and their perceived importance in contributing to this 'new' model of business.

Encouragingly, six factors were deemed to be both relatively important and evident. These were: standing up for what is right, long-term view, trusted by people, actions consistent with words, thoughtful in decision-making, and contributes to decision-making. Conversely, four factors that were perceived to be relatively important for courageous leadership were relatively less evident, namely: expresses unpopular perspectives, manages relationships well, takes responsibility for failures, and innovative about sustainable development.

Of most interest are the following apparent contradictions in these findings:

➤ The apparent importance and evidence of standing up for what is right (a principle) could be belied by the relative positioning of supporting concrete actions. In support of standing up for what is right, it could be expected that 'actions consistent with words', 'express unpopular perspectives', and 'take responsibility for failures' would also be relatively evident. These actions, although relatively absent, are simultaneously deemed to be relatively important for courageous leadership. In a similar vein, it is noticeably less important to 'point out rule breaking', which action is inconsistent with the intention of standing up for what is right

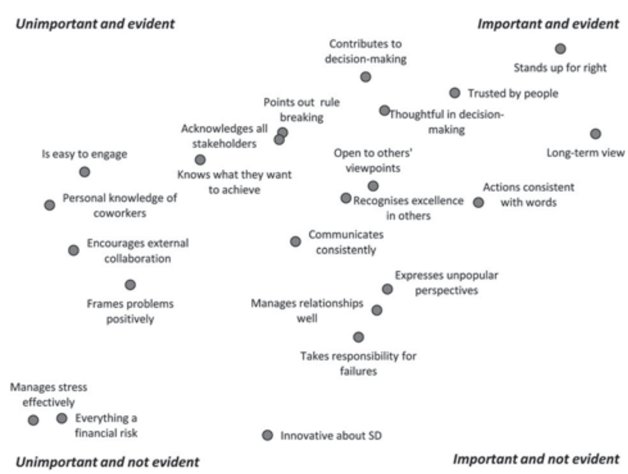

Figure 4—Relative importance and evidence of elements of courageous leadership

- Being trusted by people is seen as both relatively important and relatively evident. In apparent contradiction, however, being 'easy to engage' is one of the lowest ranked elements in terms of importance, although still relatively evident. The new leadership paradigm recognizes explicitly that trust is earned, largely through engagement with others in a way that demonstrates one's integrity with one's values. In a worst-case scenario, this could suggest that engagement is being done for its own sake or perhaps for regulatory compliance, rather than to genuinely develop relationships built on trust. The reported view that board colleagues are trusted by people is not matched by the popular perception of the trustworthiness of business leaders – in this context, particularly relevant to mining companies
- Being innovative about sustainable development, while relatively important is the least evident attribute among board members. This may suggest a lack of understanding regarding sustainable development, or perhaps to some extent, companies being at a loss about how to tackle what seem to be insurmountable problems of global significance. Alternatively, or perhaps in addition, it may be that initiatives such as the Global Reporting Initiative (GRI), the codification of Integrated Reporting, and the plethora of various compliance codes has resulted in a 'tick-box' mentality towards sustainable development (Axelrod, 2012). Such compliance-driven initiatives seem to have eroded the understanding of the need for what is termed 'wrenching change' (World Business Council for Sustainable Development, 2010) in the business response to sustainable development
- The relative low importance of encouraging external collaboration may be indicative of (i) excessive workloads and/or severely overstrained business resources, (ii) an ivory tower mentality, (iii) being out of touch with the needs of other stakeholders, or (iv) a lack of acceptance of the stakeholder-inclusive model described in King III. This could be a contributory factor to the apparent polarization between business, government, and labour. This is of significant concern given the international recognition of the need for radical cooperation both within and across business sectors, and between all sectors of society, to achieve 'green growth' (World Business Council for Sustainable Development, 2010; Martinez-Fernandez *et al.*, 2013). In apparent contradiction to the finding on external collaboration, acknowledging stakeholders (again, an in-principle statement) is ranked as fairly evident
- It was acknowledged at the IoDSA conference that directors' emotional intelligence or emotional quotient (EQ) is important for courageous leadership. Through the survey it would appear, however, that demonstrable behaviours that provide tangible evidence of high EQ are perceived as relatively absent, and less important. Of specific relevance are the factors of 'expressing unpopular perspectives', 'managing relationships well', 'taking responsibility for failures', 'framing problems positively', and 'managing stress effectively', all of which are deemed to be relatively absent. EQ factors that are deemed to be evident, yet (erroneously) unimportant in delivering on courageous leadership are 'easy to engage', 'knowing what they want to achieve', and 'acknowledging all stakeholders'. In support of this apparent contradiction, it is worthwhile noting the positioning of 'manages stress effectively' in relation to the fact that there is a strong negative correlation between EQ and measures of stress (Higgs and Lichtenstien, 2011) *i.e.* higher EQ means lower stress
- Knowing what directors want to achieve ranked fairly low on the importance scale, yet building and living by a vision is seen as very important. Perhaps this is indicative that people do not link their personal vision as a leader to building an organizational vision, or that they do not perceive the importance of their personal behaviour in leading the behaviour of others (van Knippenberg *et al.*, 2004). It could conceivably be further evidence of the prevalent and destructive compartmentalization between personal values and business roles that was demonstrated in the 2007 IoDSA survey, and supported by the literature (Bakan, 2005).

At best, the findings in this section may be indicative of a lack of understanding and/or unrealistic expectations in board members. It may be that board members are fully aware of the schism between their personal values and business expectations, but feel that there is no choice in this matter if they are to maintain their positions. It is also conceivable, however difficult it may be to acknowledge, that the results suggest a level of denial and/or self-deception in board members (Langevoort; 2004, Tenbrunsel and Messick, 2004). It is the latter possibility that is of the most concern, insofar as it has been found to be a primary cause of leadership failure (Arbinger Institute, 2002). This assumption could further be supported by the profusion of apparent inconsistencies and contradictions between stated intent and action.

The 2012 survey attempted to further interrogate the link between values and business outcomes. The King III Code requires that organizations operate out of a base built on values, not only economic value. The Code identifies four core values for directors – responsibility, accountability, fairness, and transparency. Research has shown that there is a link between personal values, emotional intelligence (Higgs and Lichtenstien, 2011), and leadership. Values are highly personal and complex constructs; the survey nonetheless attempted to elicit whether there was some common understanding about which values are perceived to deliver on specific desired business outcomes, in the context of sustainable development and courageous leadership. Figure 5 illustrates the perceived associations between personal values and business outcomes.

When assessing the results, two main themes relating to business outcomes were identified: that of people (at a personal level and as a collective in 'business') and the time dimension (long-term and short-term). Business outcomes are presented as dots in Figure 5, while values are represented by red diamonds. The darker blue ellipses in

Figure 5 indicate one interpretation of possible associations between the stated business outcomes and values, although other patterns of 'clustering' may be intuitively valid.

The following observations are worth further interrogation:

- Contemporary governance and business performance outcomes such as 'financial success', 'minimizing business risk', and 'small business footprint' are fairly logically associated with the contemporary governance values of 'accountability', 'responsibility', and 'transparency'. These business outcomes are short-term, which is consistent with the current focus on shareholder value delivery
- The value of 'inclusivity' may be associated with 'executing an effective strategy', 'maintaining a market', 'maximizing opportunities' and 'creating a long-term vision'. The apparent deficit of other associated values (at board level) may be indicative that these outcomes are perceived as traditional management functions rather than leadership functions
- Empathy is very strongly associated with issues relating to people
- Enthusiasm is very strongly associated with long-term issues
- Honesty (because it is closest to the origin or centre-point) is perceived to influence business and people outcomes equally
- That 'inclusivity' is not more closely associated with 'building trust with all stakeholders' seems somewhat anomalous in light of contemporary approaches to sustainable business, as well as the stakeholder inclusive model espoused in King III. This warrants further interrogation
- 'Improvement in human wellbeing', 'retaining excellent employees', and 'making a social contribution' are logically associated with the values of 'empathy', 'fairness', and 'respect'
- It would seem to be a paradox that 'transparency' is seen to be only tenuously associated with 'collaboration'. This could reflect the unintended consequences of high levels of regulation and codification of transparency initiatives.

Figure 5—Perceptual map of the associations between personal values and business outcomes

Enablers of and obstacles to board decision-making for sustainable development

Overview

That the leaders of organizations set the tone, define the culture, and determine performance priorities is well documented (Church, 1997; Mitroff and Denton, 1999; Lowney, 2003; Bakan, 2005; Bouquet and Birkinshaw, 2008; World Business Council for Sustainable Development, 2010; Marcus, 2012; Goldstein, 2013; Roberts, 2013). The previous sections highlight that this initial research demonstrated that environmental and social considerations lag financial imperatives, and that while intentions are good, action to deliver social and environmental benefit receives less attention at board level. Logically, this can translate into poor environmental and social performance on the ground. While practical and technical solutions to tangible performance issues are required, given the link between board leadership and organizational performance, the gaps at board level need to be filled, and enablers need to be improved.

Obstacles

Table V presents the obstacles to implementing courageous leadership identified in the 2012 survey, ranked in order of the perceived importance of each of the eight key elements of the 2011 conference.

Directors' perceptions of self and associated issues therefore rank as the most prevalent obstacle to delivering courageous leadership. 'Maintaining the director's image' is seen as an obstacle to three of the eight core messages. 'Being a lone voice' is an obstacle to two of the core characteristics. This supports the previous observations of the poor evidence of actual 'courageous' actions, rather than the relatively abundant evidence of good intentions towards environmental and social issues in board members.

Similarly, poor company values are seen to work against a director putting ethics first, and building a vision and living by it. This is a profoundly disempowered position in which directors appear to find themselves. Academic, business, and popular writings all agree that the tone is set at the top: company culture is dictated by the board. It is of special concern that despite their own role in setting company culture, directors feel that the company's values, which underpin the culture of the organization, impede the enactment of their personal values. To some extent, this disconnect is mirrored in the presence of 'poor reporting to the board on problems' in the top three: the board determines the culture of reporting as being honest and transparent, or not. That it is perceived by directors to impede their pursuit of courageous leadership reflects an apparent lack of recognition of their role in creating the culture. These findings are of particular concern given that 70 per cent of the respondents were executive directors. It may also be construed as evidence of the structural constraints imposed by the historically constructed culture of the organization.

'Understanding the new leader and the need to transform oneself' was seen to be relatively unimportant in creating courageous leadership. This could be explained by the fact that two of the three obstacles to this element of courageous leadership are highly personal issues related to perceptions of the self (maintaining the director's image and being a lone

Table V

Perceived obstacles to courageous leadership

Rank-ordered element for courageous leadership	Obstacles to courageous leadership
Put ethics first	Maintaining director's image Being a 'lone voice' Poor company values
Build a vision and live by it	Maintaining director's image Board colleagues peer-pressure Poor company values
Support small business and entrepreneurs	Regulatory requirements Poor reporting to the board on problems
Build skills	Focus on short-term financial issues Executive performance criteria
Understand what the new kind of leader is and consciously transform yourself	Maintaining director's image Pressure from shareholders Being a 'lone voice'
Build out from pockets of excellence	Executive performance criteria
Build relationships with the unions	Perceptions of being weak Decisions exclusively legally framed Goes against the culture of the organization
Build relationships with government	Regulatory requirements Decisions exclusively legally framed These issues are not seen as relevant to business

voice). That these very human characteristics are evident in directors should not be surprising, and yet there is an unrealistic tendency to suggest that directors must be able to compartmentalize their personal and corporate lives (Langevoort, 2004).

'Put ethics first' was also reported as being very evident in respondents' colleagues responses. This is somewhat contradicted by the finding that 'being a lone voice' impedes putting ethics first: logically, if generally directors were indeed putting ethics first, those trying to do so would not feel that they were a lone voice. Similarly, if the majority of the board was 'standing up for what is right', directors would not feel themselves to be a lone voice in pursuit of this. Finally, if board colleagues are standing up for what is right and putting ethics first, it is unclear how 'board colleague peer pressure' could be an impediment to 'building a vision and living by it', as reflected by respondents. This tends to support the possibility that directors are to some extent in denial about the real difficulties that they face, or is potentially evidence of the structural constraints prevalent in the global and South African business climate.

Relationships with government and unions appear to be inhibited by different factors. The common impediment of the legal framework is logically consistent with the current socio-political climate in South Africa. This is almost a 'double blow' with respect to building government relationships: the impression is created that there is no room to manoeuvre because of the legal and regulatory framework. Most surprisingly, government relations were not seen as relevant to business – or perhaps that business cannot change the government – which might impede leaders from taking up difficult issues *i.e.* demonstrating courage.

Relationships with unions, however, take on a much more personal flavour. That leaders might be perceived as 'being weak' if they try to build relationships with unions confirmed the personal issues already noted. It is again logically consistent that such leaders may not have built an organizational culture that would be open to such relationships.

Economic pressures on the company (shareholder pressure and focus on short-term financial issues) play a role in impeding two of the eight elements. Measures of executive performance are seen to inhibit skills development and building out from pockets of excellence.

Finally, two obstacles – 'threat to board position' and 'vulnerability to manipulation' – did not feature prominently in the responses. This could be indicative that board members do not feel that their positions as directors are in any way under threat. This contradicts the results of further informal research since 2012, which indicates that fear of being ostracized, including losing positions on boards, impedes directors' ability to voice contrary opinions.

The cumulative result of these findings suggests real liability risks to directors, with respect to the legal requirement for formal dissention if boards make decisions that directors believe to be fundamentally wrong.

Enablers

Respondents rated various mechanisms in terms of their perceived effectiveness in assisting directors to be courageous leaders. Table VI presents the rank-ordered responses from the most to the least enabling mechanisms.

It is notable that 'disclosure of wrongdoing at all levels' (ranked second overall) was ranked first by executives and fourth by non-executives. Similarly, 'internal codes of conduct/ethics' was ranked third by respondents under the age of 50 and first by respondent over the age of 50. Finally, 'internal codes of conduct / ethics' was ranked third by respondent with 10 years' experience or less as directors and ranked first by those with 11 or more years of experience as directors.

That codes of conduct or ethics are seen as the priority enabler is of great concern. Many of the relatively recent business collapses were most notable for the fact that the

Table VI

Ranking of enabling mechanisms for courageous leadership

Rank	Enabler
1	Internal codes of conduct/ethics
2	Disclosure of wrongdoing at all levels
3	Transforming the company culture
4	Ethics training for the board as a group
5	Advising shareholders on ethics
6	Personal coaching for board members
7	Advising shareholders on social and environmental value
8	Improving individual understanding of social issues
9	Informing customers/clients on ethics
10	Improving individual understanding of environmental issues
11	Informing customers/clients on social and environmental value
12	Programmes to build individual self-awareness
13	Training on group dynamics
14	Changing internal reporting requirements
15	Educating analysts on social and environmental value
16	Educating analysts on ethics
17	Sector-level agreements

companies had very strong codes of ethics, which the board members actively chose to override or ignore. The ineffectiveness of a reliance on codes of ethics to deliver on ethical behaviour is supported extensively in the literature (Tenbrunsel and Messick, 2004; Langevoort, 2004).

The recognition of the importance of disclosing wrongdoing at all levels is laudable. This statement of intent is, however, again contradicted by the observations of the apparent relatively low importance of board members actively 'pointing out rule-breaking', and the low evidence of 'taking personal responsibility for failures'. Similarly, this is contradicted where 'poor reporting to the board' was seen as an obstacle to courageous leadership.

'Transforming the company culture' was seen as the third most important enabling mechanism for courageous leadership. This would seem to be consistent with the finding that company culture (including values and reporting) is an impediment to putting ethics first, building a vision and living by it, and supporting SMMEs.

Ethics training for the board was reflected as the fourth most important enabling mechanism: of concern is that traditional ethics training has been found to fail in delivering ethical behaviour (Tenbrunsel and Messick, 2004).

That social issues were ranked relatively higher than environmental issues is consistent with the pattern of the research.

It was also observed, and is consistent with the other sections of the survey, that mechanisms that relate to individual responsibility and accountability for courageous leadership were perceived to fall lower on the ranking scale than those involving group or collective responsibility. Phrases containing the words 'individual' or 'personal' were ranked in Table VI at sixth, eighth, tenth, and twelfth.

Finally, it was perceived that engaging shareholders was more important to deliver on courageous leadership than engaging analysts. This is consistent with the finding that pressure from shareholders was seen as an obstacle to transforming oneself into the new kind of leader that is required. It could also be that engaging shareholders is in fact easier than engaging analysts. The personal image issues could also play a role in impeding such external engagement.

Concluding remarks

Much has been done in the global mining industry and in South Africa to address safety issues, including fatalities. Evidence that leadership values, perceptions, and actions have played a vital role in these achievements to date has been presented in the academic (Marcus, 2012) and popular literature (Bakan, 2005). It is not unreasonable to suggest, therefore, that a similar focus on directors' values, perspectives, and priorities in relation to other social matters and environmental concerns would result in on-the-ground improvements.

'In-principle' statements relating to social and environmental concerns, as well as ethical behaviour, ranked high in both the 2007 and 2012 survey findings. The 2012 findings suggest, however, that action to implement these apparently important considerations lags intent.

In the current context of societal expectations of mining companies to operate in a manner that contributes to social development and limits environmental impacts, ranking of environmental issues on a par with society issues would have been in keeping with societal expectations. Therefore, it seems somewhat ironic that in both surveys, social issues ranked consistently higher in importance than environmental issues.

Directors are nonetheless first and foremost human beings, subjected to the same aspirations, fears, insecurities, good intentions, and (at times) failure to deliver on those good intentions as others. Very real and human characteristics, such as personal issues, and a sense of individual powerlessness in the face of seemingly insurmountable global problems, as well as local obstacles, either organizational or externally imposed, could explain apparent contradictions.

Directors largely understand what is required to deliver courageous leadership for sustainable development, and have admirable intentions in this regard. These intentions include the need to put ethics first, and stand up for what is right.

The identified need for a new type of leader is perceived to be least evident in board colleagues, and of low importance in delivering on courageous leadership. This may be because directors currently view themselves as courageous, although not necessarily in the sense articulated in the conference outcomes.

Sustainable development issues are being raised at board level through considerations of social value and environmental issues.

There appears to be strong reliance on existing leadership and ethics frameworks to deliver sustained value. There is little acknowledgement of the importance of personal transformation in delivering courageous leadership. Codes of ethics, despite their widely publicized failure to deliver ethical behaviour, are deemed to be the most enabling courageous leadership mechanism.

Personal issues relating to maintaining the director's image and being a lone voice are the greatest obstacles to two of the most crucial factors in creating responsible and sustainable businesses, namely putting ethics first and building a vision and living by it. Although the role of high levels of emotional intelligence, self-awareness, and the ability to engage people at a personal level in delivering simultaneously on aspects of sustainable development and business imperatives is supported in the literature, these behaviours are relatively lower in evidence.

There could be a degree of denial and/or self-deception evident in directors (a prominent cause of leadership failure), related to what they think they are doing, compared to what they are actually doing. That this may be the case is strengthened through cross-linked correlations in the survey, and the prevalence of apparent inconsistencies between statements relating to intent and those relating to action. This could point to an unfortunate sense of individual disempowerment in our business leaders.

It might be inferred from the responses that board members do not see the direct link between their personal perspectives, values, and behaviour, and that of the company or board. This is supported in the literature (Bakan, 2005). Conceivably, these results could also point to a lack of understanding of the role of directors' behaviour in creating a strongly ethical and sustainable business culture.

External factors in the South African business environment are seen to impede a number of elements required for courageous leadership to deliver sustainable outcomes.

At the broadest overview level, the results of the surveys could be seen to represent a perspective of 'business (and leadership) as usual'. This may be a matter of perception: directors may perceive that the factors included in the survey are already being tackled, and therefore constitute 'business as usual'. The findings of the survey would also suggest that senior business leaders feel embattled, indeed overwhelmed, in the prevailing South African socio-economic and political climate.

Differences observed between the primary, secondary, and tertiary sectors were appropriate to the sector; no significant diversions from the above were observed. Similarly, no statistically significant differences were observed between responses of Executive and Non-executive directors. This raises questions about the roles adopted by Non-executives, especially in terms of the longer-term direction of companies.

These findings suggest that there is a need for creating greater awareness among directors of the inconsistencies, paradoxes, and sustainable development dilemmas of board decision-making. Following awareness, there will be a need to give directors the skills, confidence, and support to fulfil their directors' mandate with personal integrity and deliberately based on values. Finally, it is recommended that the status quo of values-based decision-making at board level, as required by the King III Code, be evaluated and disseminated on a regular basis.

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120 YEARS OF TECHNICAL EXCELLENCE 1894 - 2014

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SAIMM DIARY

2015

CONFERENCE
Mining Business Optimisation Conference
11–12 March 2015, Mintek, Randburg, Johannesburg, South Africa

CONFERENCE
Accessing Africa's Mineral Wealth
24–25 March 2015, Emperors Palace Hotel Casino Convention Resort, Johannesburg, South Africa

CONFERENCE
5th Sulphur and Sulphuric Acid 2015 Conference
7–10 April 2015, Southern Sun Elangeni Maharani, KwaZulu-Natal

CONFERENCE
Mining, Environment and Society Conference
12–13 May 2015, Mintek, Randburg, South Africa

CONFERENCE
Mine to Market Conference 2015
24–25 June 2015, South Africa

CONFERENCE
The 8th Southern African Base Metals Conference
6–8 July 2015, Zambezi Sun Hotel, Victoria Falls, Livingstone, Zambia

SCHOOL
School Production of Clean Steel
13–14 July 2015, Emperors Palace, Johannesburg, South Africa

CONFERENCE
Virtual Reality (VR) and spatial information applications in the mining industry Conference
15–17 July 2015

CONFERENCE
MinProc 2015 Conference
5–8 August 2015, Western Cape, South Africa

CONFERENCE
The Tenth International Heavy Minerals Conference
11–14 August 2015, Sun City, South Africa

CONFERENCE
The Danie Krige Geostatistical Conference
19–20 August 2015, Johannesburg, South Africa

CONFERENCE
WORLDGOLD Conference 2015
28 September – 2 October 2015, Misty Hills, Gauteng, South Africa

SYMPOSIUM
International Symposium on slope stability in open pit mining and civil engineering
12–14 October 2015, Cape Town Convention Centre, Cape Town

CONFERENCE
Young Professionals 2015 Conference
20–21 October 2015, Mintek, Randburg, Johannesburg, South Africa

CONFERENCE
Nuclear Materials Development Network Conference (AMI)
28–30 October 2015, Nelson Mandela Metropolitan University, North Campus Conference Centre, Port Elizabeth

SYMPOSIUM
23rd International Symposium on Mine Planning & Equipment Selection MPES 2015
8–13 November 2015, Sandton Convention Centre, Johannesburg, South Africa

New Concept Mining

Integrated systems of support