Technical risk assessment techniques and practice in mineral resource management with special reference to the junior and small-scale mining sectors

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Synopsis

The junior and small-scale mining sectors in South Africa play an important role in the livelihoods of numerous communities. Mining presents an opportunity, in the post-1994 democratic era, for many individuals to obtain access to much required empowerment and socio-economic development. These sectors are, however, not without numerous characteristics that pose problems for operators, legislators, and other role-players. Mining is inherently risky, with operators experiencing frequent difficulties and challenges throughout the life of mine. Opportunity exists, and needs to be enhanced, for junior and small-scale prospects and operations to include technical risk assessment techniques in documentation presented in search for funding, and in optimizing monthly planning and longer-term functioning.

The focus here is to explore how the risk management cycle may currently be applied to a mineral resource suitable for exploitation by the junior and small-scale mining sectors. No management process can create additional value in the ground, but various available mechanisms can go a long way to quantifying the inherent risk that exists, highlighting the need to manage the risks and hopefully allowing the entrepreneur access to the intrinsic opportunities of the emerging mining sector in South Africa.

Introduction

The junior and small-scale mining sectors have emerged to be a potentially important role-player within the South African mining sector. This work sets out to address certain implications of mineral resource-related risk for this sector. Mineral resource management (MRM) is a concept developed by large multinationals, but is often not holistically embraced by the junior and small-scale sectors. For successful mining outcomes, the ability to combine and holistically appraise the impact of risk, especially within the MRM environment, is critical. The ability to tailor solutions for the small and junior sectors is paramount to the success of these sectors.

Junior and small-scale mining

In the Australian and Canadian context junior mining companies primarily identify, explore, and delineate new mineral deposits. Once this is achieved, the entire or only a portion of the prospect is sold to a major or multinational company for mine development (Cooper, 2004). In South Africa, however, an entirely different approach is taken to 'junior mining'. South African junior mines are envisaged to be important role-players in the newly emerging black economic empowerment mining sector, which would benefit the historically disadvantaged sections of the community. In the current dispensation such juniors often acquire marginal deposits, as outliers to the much larger well-understood deposits mined by the majors (AngloGold Ashanti, Anglo Platinum, Impala, Harmony, Goldfields, to name a few). Examples of current junior mining companies include Sebilo Resources, Retsibogile Mining and Nozala Diamonds.

Small-scale mining has been defined in a variety of ways. The term 'small-scale mining' is often interchanged with 'artisanal mining' or even 'artisanal small-scale mining'. Artisanal and small-scale mining encompasses all mining operations that, by virtue of their size and overall turnover, etc, are categorized as small. Small-scale mining also sometimes includes illegal miners or the West African, South American 'garimpero's' or 'galamsey'. In the South African context the boundaries between each category are not distinct, hence the confusion that is often expressed. The concept of small-scale mining as applied here is therefore fully defined below.

The concept of risk

The Complete Wordfinder (1993) defines risk as 'a chance or possibility of danger, loss, injury or other adverse consequences', while risk within an operational environment is

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defined by Kerzner (2001) as 'a measure of the probability and consequence of not achieving a defined goal'. The King Report on Corporate Governance (Institute of Directors, 2002) defines risk as 'uncertain future events that could influence the achievement of a company's objectives'. The Institute of Directors (2002) states that these 'could include strategic, operational, financial and compliance objectives' and that 'some risks must be taken in pursuing opportunity, but a company should be protected against avoidable losses'. Conversely, opportunity can be viewed as the likelihood of doing better than a specified goal. Achieving an outcome, therefore, represents the most likely scenario in terms of the interaction of risk and opportunity factors evaluated.

Specific to the mining sector, Agricola (1556), in his famous treatise on mining, *De Re Metallica*, refers to the need for understanding the geology of a particular deposit for successful mining, while Krige in 1955, also developed many aspects of mining risk in his work on risk analysis in mining ventures. The mining industry in South Africa exhibits some unique characteristic factors when compared with other industrial sectors. These factors (Table I) result in a very interesting and challenging sector, which underpins the entire South African economy.

The South African mining sector since 1994

Prior to the democratization of South Africa in 1994, junior and small-scale mining had been largely ignored or regarded as a troublesome activity that did not contribute towards the attainment of national objectives. The practice was largely confined to the alluvial diamond sector. Furthermore, an exclusionary legislative framework restricted access to minerals rights and active participation in the minerals sector to a small privileged proportion of the country's population and greatly favoured the entrenched mining houses. With the establishment of a new government, a realization occurred that junior and small-scale mining could be a vehicle for creation of economic activity in remote communities, a mechanism of job creation, and a basis for skills development that could be transferable to other sectors of the economy (McGill, 2004).

The new governance framework for the granting of prospecting and minerals rights is fundamentally friendlier towards the needs of junior and small-scale operators. This framework is present firstly within the Mining Charter and also supported by the Minerals and Petroleum Resources Development Act 28 of 2002. The objectives of the new government policy, supported by the newly developed legislative framework, are to attract greater participation by individuals from historically disadvantaged backgrounds into responsible mining activities that are appropriate to national interests. In addition, this policy should facilitate integration, through legitimizing, of illicit mining operations into the regulated formal sector of the economy. It is envisaged that enhanced levels of partnership between big and small business will develop during the journey towards sustainable community development centred on mining operations.

Table I

Characteristics of the South African Mining Sector

Typical characteristics
High risk but also high reward
Capital intensive procurement
Price taker
Cyclical profits and losses
Remote locations
Finite life of a non renewable resource
Reclamation and rehabilitation liabilities
Recently implemented state ownership of the mineral resource

There remain major challenges, many of these in common with other sectors of the economy, in supporting the transition of small-scale mining for poverty reduction from the second economy into the formal economy of the country, where it can contribute optimally to the national benefit. The intention is therefore to ensure that the nation's mineral wealth can be transformed optimally into other forms of capital that will support the sustainable development of communities. Appropriate regulation of small-scale mining is vital to avoid the erosion of value in the mineral resources or even the creation of significant net liabilities due to irresponsible mining activity. In terms of the current legal and administrative framework, inadequate provision is made for assisting the small-scale mining sector in the identification, quantification and management of mineral resource-related risk.

The small-scale mining sector

Small-scale mining is an essential activity in many developing countries, as it provides an important source of livelihood, particularly in regions where economic alternatives are critically limited. This form of mining is a livelihood strategy adopted primarily in rural areas. In many cases, mining represents the most promising, if not the only, income opportunity available (MMSD, 2002; Hilson, 2002; McGill, 2004).

Most formal definitions attempt to categorize mines in terms of one or more physical criteria. These criteria may include: mineral type; annual production (tons mined or minerals produced); the value of commodity produced or capital invested; or the number of people employed (Peake, 1998). In effect, nations develop their own definitions as to what constitutes smallness depending upon their mixes of sociological, geographical, financial, and technical factors. Following are two examples of efforts to define small-scale and the problems, constraints and omissions in the definitions are apparent:

- *Ghana*—Small-scale mining refers to operations of individual Ghanaians or organized groups of Ghanaians (4–8) or cooperatives (>10), which are entirely financed by Ghanaian resources at a certain time limit, and carried out on a full-time basis using simple equipment and tools (MRF, 2005, p. 1).
- *United Nations*—Small-scale mining is any single unit mining operation having an annual production of unprocessed materials of 50 000 tons or less as measured at the entrance of the mine (MRF, 2005, p. 1).

This can be compared to a formal definition as provided by the South African Department of Minerals and Energy (DME), Table II.

Table II

Current DME classification (Sihlali 2004)

Category	Employment	Turnover (R)	Gross Assets (R)
Micro	<5	150 000	100 000
Very small	6–20	3 million	1.8 million
Small	21–49	7.5 million	4.5 million
Medium	<200	30 million	18 million

Small-scale mining is often a poverty-driven activity, practised by the poorest of the population sector and the practice is regularly migratory in nature (Ghose, 2003). This is particularly true in the context of the South African alluvial diamond sector. When undertaken as a subsistence activity, growth opportunities will not exist and escape from the cycle of poverty is considered unlikely (Peake, 1998). Literacy levels of small-scale miners are low and often mining is conducted in below-standard safety, environmental and occupational health conditions. It is commonly associated with informal, undercapitalized and under-equipped operations. It does, however, have the potential to enrich and economically empower disadvantaged communities (Drechsler, 2001). The United Nations Development Programme (UNDP) believes that to improve the livelihoods of the small-scale miners, alternative livelihood opportunities need to be developed and the entire sector needs to be formalized. For this reason, an in depth knowledge of the underlying resource/reserve that will underpin such developments is essential.

An important realization is that some orebodies may not lend themselves to small-scale mining practices. This lack of suitability could be attributed to depth, mineralogical complexity, or mode of extraction required. The South African mining sector cannot afford to lose the big players and the two sectors (large and small) need to develop side by side. Often junior and small-scale mining entrants require money 'now' and long-term impacts, cash flows, and risks to MRM-related decisions are not seen as important.

In South Africa, provinces with relatively high levels of small-scale mining activity are the Northern Cape, NorthWest, Mpumalanga, and KwaZulu-Natal. It must be remembered that operating conditions are constantly fluctuating, and it is expected that the current formalization process for small-scale miners at the DME will result in a more up-to-date regulations, especially after the promulgation of the Minerals and Petroleum Resources Development Act (MPRDA) (2002).

Studies have revealed that the small mines category contributes 1.1% to mining sector employment and 2.5% to sector revenue (Noetstaller *et al.*, 2004). A more current figure relating to small-scale diamond miners considers some 1 000 miners, with about 25 000 people being employed by the sector as a whole. The purchasing power of the community is estimated to be in the order of R7.7 billion per annum (Coetzee, 2004).

Mining is a very technical and costly endeavour. As certain initiatives require only limited start-up capital, prolonged financial support is often neglected (Hilson, 2002). If such operations are going to perform throughout a reasonable life of mine, increased access to funding mechanisms could result in the ability to upgrade equipment and improve efficiencies. However, the limited duration of the two-year small-scale mining permit may restrict the level of funding available to operators. Not many financing mechanisms are available for potential operators as a result of the inherent risk in investing in mines with shorter life-cycles. This ultimately means that less capital is available for technical assistance in the form of contractors or consultants. Often, only the legal requirements, such as survey, are covered by the junior operators. As result, most aspects of MRM, which could result in sustaining an operation over a longer period, are being ignored.

It is recommended here that initially the function of MRM for the small-scale sector should reside with the state as the owner of the minerals and that the state should develop the sector to the level where the MRM responsibility could be passed on to the operators. In addition, it could be the function of the small-scale mining directorate within the DME to support MRM-related capacity-building initiatives. In the following paragraphs some of the risk identification, quantification and alleviating techniques, relating to different parts of the risk management cycle, will be presented to provide examples of possible applications within this sector.

Mineral resource management for the small operation

Harrison (2000, p. 1) states that MRM refers to 'professionally (managing) the exploitation of mineral resources or reserves to meet company objectives'. MRM is therefore an integrated activity, including the application of sound management principles that maximize the value of the mineral asset, in order to grow shareholder wealth (Macfarlane, 2000). In recent times a change in organization structure to embrace this holistic approach has resulted in a more process-driven and value-added approach to MRM. In this instance MRM incorporates the mine-based disciplines of survey, evaluation, geology and planning in a holistic entity rather than treating them as separate functional domains. On smaller operations the need for such disciplines is no less important. Functionally, most of the MRM-related decisions become the responsibility of a single mineral resource practitioner, rather than an entire department.

To be effective, MRM requires a system that will identify, quantify, and manage the risks associated with the orebody. An industry example within the junior mining sector is provided by Minnaar and Theart (in press) who deal with the exploitability of the feldspar from pegmatite deposits in the Namaqualand region. To be able to do this the person responsible for MRM needs to possess the requisite skills and competencies to undertake quantitative risk management and to report accordingly.

In the overall organizational picture MRM has a role to play in corporate governance. Corporate governance provides the guidelines and platform for companies to operate internally and interact externally. The Institute of Directors (2002, p. 18) states that 'Corporate governance, is essentially about leadership'. The extent to which companies adopt and demonstrate good principles of corporate governance will

affect investment decisions (OECD, 1999). This premise is particularly relevant for junior operators within the South African context seeking financing, and the ability to display sound corporate governance practices will go a long way securing funding.

The South African Code for Reporting of Mineral Reserves and Mineral Resources (SAMREC) provides guidance and standardize the reporting practice that the mining industry must adhere to. The true challenge involves how this code could be applied to the small and junior mining sectors, as smaller operations can often not meet the required density of data required for proper resource/reserve classification due to the inhibitive costs in obtaining such data (frequently required long before production and a revenue stream commences). They therefore operate with much higher resource-risk profiles. Producing high ore grades is obviously not as significant, riskwise, as intersecting low grades and discontinuities in the orebody. Owing to the lack of background data it is very difficult to predict grade distributions accurately. Risk reduction should be addressed as a continuous process. Financial strength and associated grade trends during 'good times' should be used to reduce the risk of the mining of the remaining resources.

Finally, it is prudent for mining role-players to establish where the MRM functionality resides in junior and small-scale operations. Ultimately, the strategic responsibility lies with the board of directors or the mine owner. At an operational level MRM competency may be provided by a consultant to the operation, or an independent consultancy firm. The obvious proviso is that the operation can afford such expenses. For many of the smaller operations this is not possible, resulting in issues related to MRM largely being ignored, to the detriment of the optimal exploitation of the deposit and future of the mine. In such situations, annual MRM sessions could possibly be facilitated by the South African science councils and/or the Chamber of Mines and other interested stakeholders to address these issues in a structured way, for the benefit of all junior and small-scale mines.

Risk management

The risk management cycle

Dealing with risk requires that risk management be viewed as part of dynamic, repetitive processes rather than just a static management activity or being completely ignored. There are three distinct phases to successful risk management. These include (Toll, 1994):

- Risk identification: both internal and external to the operation
- Risk analysis: using any of a variety of techniques and
- Risk response: based on the identification and analysis, a response to the risk can be formulated prior to the problem occurring.

All business development initiatives involve elements of risk. The appropriate identification and management of these risks should be seen as the key to effective and sustainable growth, if effectively managed. Risk identification, as the first phase of the risk management cycle, can be completed by consulting objective (past experience) and/or subjective (knowledgeable experts) sources (Kerzner, 2001). Various different risks can also be identified during the life-cycle phases of a project or operation. Risk management assists with the improvement in decision-making as the entire cycle/process (risk identification, assessment, and response/management) contributes towards a greater understanding of all risks and potential opportunities and losses. The risk management process is as much about identifying opportunities as it is about avoiding loss exposure.

Risk quantification/analysis techniques

Menell, in his address to the Application of Computers and Operations Research in the Minerals Industries (APCOM) Conference (Cape Town, 2003), observed that 'tools without purpose are toys', while Rozman and West (2001, p. 501) state that 'no single tool exists, which combines the many and varied uncertainties in a mining operation' (or project). This evidence supports the fact that risk analysis and quantification are exceptionally difficult within a mining framework. Various methodologies have been applied over time and continue to evolve as understanding of the overriding uncertainties increases.

Some of the more widely applied risk assessment techniques in the MRM arena are provided in Table V, which also provides comment on their applicability to the junior and small-scale mining sectors. The overall size of the operation and/or deposit need not be a reason not to adopt certain of these methodologies. In fact, because of the greater element of risk in smaller mines the need to begin applying such techniques is critical to ensure success. Risk analysis quantifies exposure and losses to prescribed circumstances so

Table III

Summary of risk areas that affect the MRM function and possible analysis techniques

Risk area	Methods of analysis
Business risk High level of economic uncertainty exists Dynamic, constantly changing business environment	Cash flow models (scenario planning) Discounted cash flow models Sensitivity analysis Monte Carlo simulations
Natural risk Geological uncertainty More difficult to quantify and dependable on availability, relevance and quantity of information	Geotechnical risk assessment Conditional simulation Other techniques based on repeatability and variance of sampling results

that probabilities of future losses or opportunities can be projected (Terblanche, 2002). In addition, one should not lose sight of the overriding business objectives, which is the most important aim of risk analysis, and thus predicting the likelihood of a planned profit to be achieved over a given period of time (Simonsen and Perry, 1999). Essentially, this process provides answers to the following fundamental queries:

- What can happen?
- How likely is it that it can happen?
- What are the consequences if it does happen?

Certain techniques are possibly more applicable to smaller operations. One such technique is the use of a risk matrix. A practical application of the risk matrix process was undertaken in the selection of a suitable or appropriate small-scale mining method for a travertine deposit (McGill, 2003). Travertine comprises deposits of fresh water limestone formed by precipitation of calcium carbonate from hot or cold mineral springs. It is very soft and often quite porous. The two critical criteria assessed in the evaluation of potential mining methods were the overall cost and the applicabiliy to small-scale mining (SSM). The mining methods were ranked accordingly (Table IV). The criteria for each method were rated from 1 to 5, i.e. low to high ranking.

These methods can be applied adequately to the junior and small-scale sectors, as each of the matrices is designed specifically for the particular operation. Table V provides a summary of the various stages of the risk management cycle, the various techniques available per stage and then commentary on the applicability of each technique for the junior and small-scale mining sectors. It would prove beneficial to many smaller mines to apply these easy techniques.

Conclusion and recommendations

The junior and small-scale mining sectors in South Africa already contribute to the livelihoods of communities, particularly rural communities in a few provinces. In such instances junior and small-scale operations form the central node of numerous other add-on opportunities and developments. It is therefore in the interest of the development of South Africa to continue supporting and nurturing this sector.

The practice of risk management has been applied to most areas of general business operation e.g. production and human resource management. The application of risk management to technical areas is complex. Because geology is not an exact science, uncertainty is inherent in each stage of grade predictions for resource and reserve estimation. This activity is therefore prone to errors in the form of over- and under-estimation of commodity grades (Glacken, 2002). Low levels of sound geological and evaluation data on many junior and smaller operations equate to very high levels of resource risk.

One of the aims of MRM is to minimize the overall resource related risk. Methods to quantify geological and technical risk are varied, as is the level of potential application in the junior and small-scale sectors. For some aspects of risk it may be acceptable to rank variables by relating the probability and the consequence of failure and representing the relationship on a probability-impact matrix. The relationship between cause and risk is also important. By removing of obvious causes, the likelihood of the risk occurring will be reduced. As Pitzer (1998, p. 58) states, 'unknown causes of unknown risks usually constitute the unexpected'. For the average junior and small-scale operator avoiding the 'unexpected' in terms of resource risk, equates to being aware of the mineral resource and reserve being exploited and through capacity building, where required, being able to quantify the risk accordingly.

The level of risk acceptability is generally determined by a risk-benefit analysis (Dowd, 1997). This approach compares the cost of a project or operation with the value of benefits generated. The greatest benefit to junior operators will result in lower levels of resource risk and, consequently, a greater ability to obtain funding. Other approaches to risk management available to the junior and small-scale mining sectors include: decision tree analysis; assessing the impact of uncertainty on finances via a discounted cash flow model; and sensitivity analysis. Certain methods mentioned in Table V may be best undertaken by technical consultants on behalf of mine management. These methods include 3D seismics, geological modelling and conditional simulation.

Obviously, the greatest hurdle for many junior and small-scale operations is the cost associated with obtaining these technical services. The DME's small-scale mining board is such an avenue that exists for junior and small-scale operators to apply and request that technical feasibility and mine works programmes are completed on their behalf by relevant science councils. In effect, this service equates to a consultancy service where the technical fee is paid by the government on behalf of the successful applicant. The result is that limited capacity building and skills transfer in related areas and disciplines occurs. The operators remain dependent on outside individuals and other organs of the state for financing outcomes and decisions relating to their own permitted or licensed areas. It is recommended that the

Table IV

Matrix for determining of a mining method for a potential travertine deposit (McGill, 2003)

	Cost	Applicability	Comments
Channelling	4	5	Suitable for travertine mining, but high capital cost
Chain saw	5	2	Not suitable for SSM due to size and capital costs
Stitch drilling	2	5	Suitable for SSM, but need suppliers and affordable expanding clay/cement
Wire saw	3	4	Suitable for SSM but expensive if diamond-tipped equipment is used
High pressure water jet	2	3	Suitable for travertine mining since the quarry is next to the river, but method needs to prove its applicability and reliability. Environmental constraints

Table V

Risk and the-scale mining sector

Stage of risk management cycle	Technique available	Applicability to junior and small-scale mining
Risk identification (types of risk)	• Management risk • Financial risk • Country risk • Operational risk • Technical risk • Resource risk	All these risk types will interact with each other and have individual influences on the overall success of operations or projects within the junior and small-scale mining sectors. Of greatest importance to the particular sectors is the impact of technical and resource risk. High levels of resource risk severely affect the alluvial diamond sector
Risk quantification/analysis	• Risk classification (matrices) • Hazop studies • Fault/decision-tree analysis • Sensitivity analysis • Expert judgement • Classical statistical techniques • Monte Carlo simulation • Conditional simulation	• Very applicable and easy to implemen—recommended • Owing to limited process complexity, most operations may not obtain any value from applying this method • A useful tool to quantify risk and probability substantially in various scenarios—recommended • Where the detail in a DCF allows the use— recommended • Potential strategic method for obtaining input from stakeholders • High level of application possible—recommended • Requires large quantities of data and computation • Requires large quantities of data and computation but potential exists for junior operations
Tools for managing MRM risk	• Bayasian approach • Discount rate in a DCF • Grade tonnage curve • Geological modelling • 3D seismics • Mining due-diligence studies • Reconciliation	• Technique loosely applied currently to infer potential by operations adjacent to larger established operations • Evidence reveals that not much variation exists in discount rate applied but the DCF remains a critical tool for evaluation purposes—recommended. • Potential exists for the 'larger' junior operators within the gold, platinum and iron-ore sectors, for example • Very useful method to graphically obtain an understanding of various mineral resource aspects, recommended especially for more structurally complex deposits. Use of relevsant consultants encouraged • Expensive technique but allows high levels of confidence for geological understanding and mine planning. Acquisitions of old-order rights from majors could involve the purchase of such data • Integral to the holistic understanding of the operation, most commonly completed on behalf of an operation by technical consultants—recommended, especially if funding is required • A good measure for the level of confidence in grade estimates but requires high levels of data, role for a relevant consultant, but remains a highly recommended approach
Risk control techniques	• Risk avoidance • Risk reduction • Risk prevention • Risk transfer/sharing	The application of a variety of these methods is recommended. The application of the planning domain example can provide useful quantified information.

science councils (Council for Geosciences, CSIR Mining Technology, and Mintek) play a greater role in the provision of capacity building, as well as in the research and development of technical techniques on a platform to enhance the small-scale mining sector's position. Two examples of current capacity-building initiatives include: the Mine Qualifications Authority-funded SSM training school at Mintek that provides entry level skills training on commodity-specific areas (Mutemeri, 2005); and the development of a board simulation by CSIR Mining Technology, which demonstrates in a practical manner the range of decision making required throughout the mine value chain as well as the actual impact of these decisions on the underlying orebody and cash flow. Technical research and development solutions that have been developed by the science councils to reduce risk in portions of the mine value chain include the stepping pump concentrator developed at CSIR Mining Technology and the I-goli mercury-free gold-refining technique at Mintek (Mutemeri, 2005). In addition, universities should be encouraged to promote and maintain training and research in the mining-related disciplines of geology, geophysics, geostatistics, mining engineering and metallurgy, for example, as viable career options.

Finally, there are many different voices in the junior and small-scale mining sectors in South Africa. Many independent interest groups, organizations and stakeholders are practitioners and advisors to this sector. Confusion still exists over clear definitions of the concepts of artisanal, small-scale and junior mining; legislative constraints exist; and limited technology and skills transfer occurs. Within the working environment small-scale activities often develop in response to poverty situations, operations are often migratory and overall skills level and understanding low, while junior operations struggle to obtain leverage to bridge critical financing hurdles.

Certain critical challenges undoubtedly exist for the South African government, and the servicing organizations and science councils. With the increased need for assistance, mostly financial and capacity building in nature, the key will be to deliver these services so as to enhance and uplift the development of the community. Junior and small-scale mining has the ability to reduce poverty and augment

technology transfer, but only through formal and focused channels. This discussion creates a platform by describing the characteristics of the sector and dealing with minerals resource management issues in particular. The overall aim was to highlight techniques to reduce mineral resource-related risk, which, in turn could make these prospects or operations viable for financing and/or investment opportunities. No process can create additional value in the ground but these mechanisms can go a long way to quantifying the inherent risk that exists and, one hopes, to allowing the entrepreneur access to the intrinsic opportunities of the emerging mining sector in South Africa.

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