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Mineral resource risk assessment in the BHPBilliton capital investment process

M.P. MULLINS*, C.G. CAREY*, and D. HODSON†
**Project Development Services, Johannesburg, Marshalltown, South Africa*
†Mineral Resource Development, Project Development Services, Melbourne, Australia

BHPBilliton is a large (US$32bn market capitalization) diversified mining group. Significant organic growth is planned through the development of a number of mining, processing and oil and gas projects, totalling some US$5.2bn over the next three years. The investment standards underpin the capital approval process, and incorporate the requirements for range and risk analysis of key input variables, including mineral resources.

Public reporting codes for mineral resources and ore reserves (such as JORC) stipulate deterministic reporting of estimates, but are generally silent on any requirement for range or risk assessment, although they acknowledge the risk and uncertainty in the production of resource estimates. In contrast, public reporting of petroleum reserves allow for the use of either deterministic or probabilistic estimation, and for the latter, mandate the level of confidence required for proven versus probable reserves.

Conditional simulation techniques, popular in the petroleum industry, provide an ideal tool for range and risk assessment of the range of outcomes of key resource parameters, such as tonnages and grades. Examples of a diamond deposit and of a porphyry copper deposit are presented.

The understanding and quantification of mineral resource risk through a technique such as conditional simulation provides quantified information on the potential upside or downside. These techniques should be more widely utilized in the high-risk minerals extraction industry.

Keywords: mineral resources, conditional simulation, risk, capital investment standards, BHPBilliton.

Introduction

The merger that created BHPBilliton from two large diversified mining groups in mid-2001 was part of a decade-long industry consolidation. In 1990, the top 5 metals and mining companies accounted for less than 25% of the total equity value of the US$150bn industry; in 2002 the top five companies account for 50% of the US$235bn industry (Gilbertson[1])

BHPBilliton has a market capitalization of about US$32bn, and its divisions are organized into seven Customer Sector Groups (CSGs): Aluminium, Base Metals, Carbon Steel Materials (iron ore, manganese and coking coal), Stainless Steel Materials (nickel and chrome), Energy Coal, Petroleum, and Diamonds and Speciality Products. The net asset value (NAV) and geographic spread of these assets are shown in Figure 1.

The BHPBilliton project pipeline

Organic growth from a strong project pipeline underpins the company growth strategy, with sanctioned projects amounting to about US$5.2bn of capital investment (US$2.9bn committed in FY2002) since the merger of BHP and Billiton. These projects range from Aluminium (Mozal 2, Hillside 3) to Base Metals (Escondida Phase IV) to Petroleum (Ohanet, Minerva) (Figure 2).

The capital approval process has been institutionalized, and is underpinned by capital investment standards and toolkits.

The capital approval process

The investment system applies to major investments, defined as those projects where the BHPBilliton share of the investment is greater than US$100 million. The system provides a common framework ('operating system') and approval processes for the range of investment types that the company is likely to undertake, with consistent terminology, tools and techniques.

An Independent Peer Review (IPR) process has been established, and forms an integral part of the investment approval. The IPR provides assurance that investment opportunities are robust and have been subjected to independent, rigorous and consistent analysis. The investment review process is not only essential for satisfying corporate governance requirements but also provides the opportunity to further value-add by drawing on the experience of the independent peer reviewers.

A critical requirement to delivering on the investment objectives is a full understanding of the risks associated with the investment opportunity. In providing the ranges of outcomes for measurable parameters such as ore reserves, operating costs and capital costs, both the downside and upside can be managed and exploited. This approach is adopted throughout the investment management process.

Mineral resource risk assessment

There are a number of ways that resource risk can be

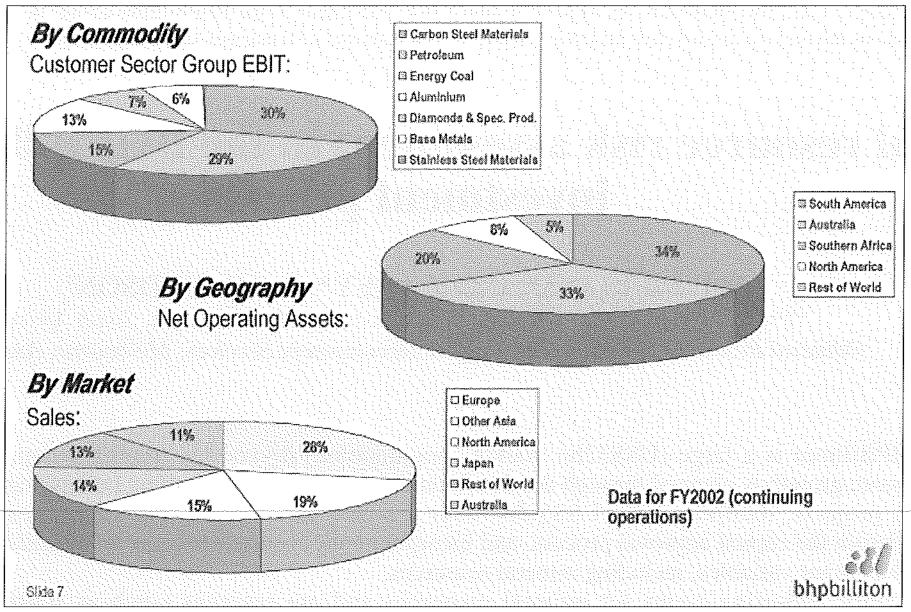

Figure 1. BHPBilliton net asset value by commodity, geography and market

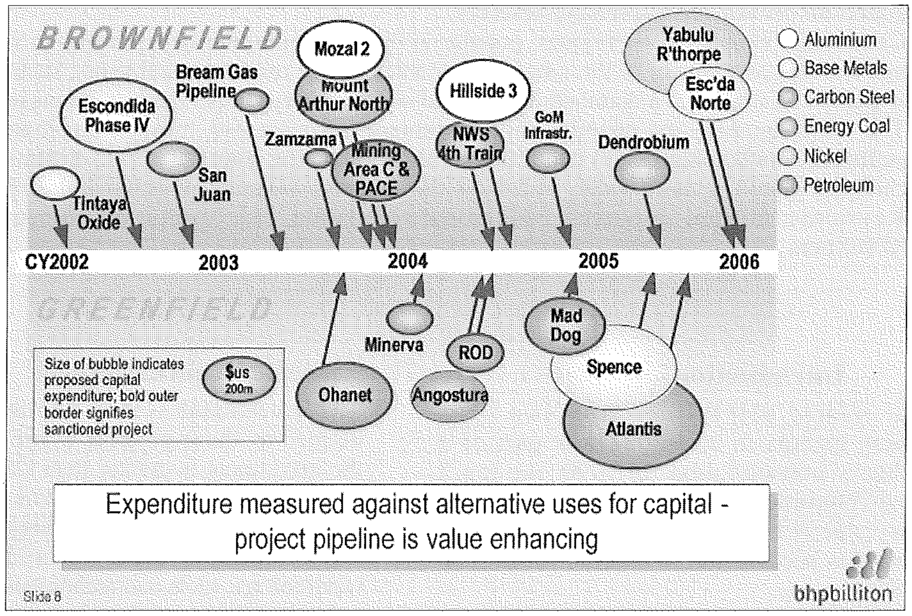

Figure 2. The BHPBilliton project pipeline

assessed, both subjectively and quantitatively. Resource modelling frequently depends on subjective interpretation of measured data (much of which inherently contains errors), and there is thus often strong opposition to quantifying this subjective information.

Resource estimation in the minerals industry is almost exclusively deterministic, where a single best estimate of reserves is made based on known geological, engineering, and economic data. An alternative method of estimation is called probabilistic when the known geological, engineering, and economic data are used to generate a range of estimates and their associated probabilities.

Quantitative resource risk assessment can be looked at in a number of ways.

- ***Sensitivity analysis*** *of key variables*

  This is widely used, and provides good information on the sensitivity of the outcome (usually NPV) to changes in the input parameters. Sensitivity analysis is based on a deterministic estimate.

- *Reporting quantitative* ***confidence levels for resource classes***

  At this stage this is rarely used in public reporting, but is gaining more popularity in corporate in-house reporting (Mwasinga[2]). This is also based on deterministic estimates.

- *Calculating the* ***range of possible outcomes*** *for key variables such as tonnage and grade.*

  Probabilistic-based estimation of mineral resources is standard practice in the petroleum industry, but to date, has had limited application in the minerals industry.

The international framework for reporting of mineral resources and ore reserves

The globalization of the resource industry has been accompanied by the development of resource and reserve public reporting codes in the major countries associated with the raising of mining capital (Yeates[3]) These codes have been led by the JORC Code in 1989 in Australia, and followed by the SAMREC Code (March 2000) in South Africa, the CIM Code (August 2000) in Canada, and the Reporting Code (October 2001) in Europe. JORC has produced revisions of its Code in 1996, 1999, and a new revision is due out in 2003. All these reporting codes have adopted a similar framework for reporting, with some local variations. None of the codes require the reporting of risk or uncertainty in mineral resource estimates, although it is believed that JORC 2003 will introduce certain requirements. JORC classifies mineral resources on the basis of confidence in the estimates, but makes no requirement to report the confidence levels applied (subjective or otherwise).

In contrast to public reporting codes on minerals, which emphasize deterministic estimates, reporting codes for petroleum emphasize the risk and uncertainty aspects. The Society for Petroleum Evaluation Engineers' (SPE) reserve reporting code emphasizes that estimation of reserves is done under conditions of uncertainty.

The SPE Code further states that if deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate (50% for probable reserves). The SPE Code thus not only allows the use of either deterministic or probabilistic estimation methods, but also determines the level of confidence required for proven versus probable reserves, when using the probabilistic method of estimation.

The BHPBilliton investment standards

BHPBilliton reports its mineral resources and ore reserves according to the current version of the JORC Code, which thus forms an integral part of the internal project standards.

A number of requirements, additional to JORC, are specified in the investment standards. One of these is the requirement to report the range of possible outcomes for key outputs (such as tonnes and grade) as well as a discussion of likely ranges to be expected for items such as continuity, orebody geometry, boundaries, and contacts. The methods used to quantify these ranges of outcomes need to be described. The technical risks associated with the study should also be quantified and discussed.

Although the requirement for range assessment is mandated, the methodology used to comply with these minimum requirements is not. The standards at this stage do not mandate the reporting of mineral resource confidence levels.

Range analysis and risk assessment

A number of techniques are available for risk assessment, ranging from subjective judgement, to classical statistical techniques, to Monte Carlo and spatial Monte Carlo techniques, such as conditional simulation.

Current range measures such as grade-tonnage curves and sensitivity analysis, suffer from the fact that they are still based on single, deterministic resource estimates. In addition, sensitivity analysis often ignores the correlation between variables (e.g. between cutoff grades and operating costs).

Geostatistical simulation is a spatial extension of the concept of Monte Carlo simulation (Vann, *et al.* 2002[4]) that attempts to reproduce the range of grades present in the sampling data as well as the spatial variability described by the variograms. If the simulations also honour the data themselves, they are said to be 'conditional simulations'.

Resource estimates produced by kriging may be quite good locally, but show a pronounced smoothing effect when viewed globally. This smoothing results in a poor reproduction of the extremes of the assay values, and these models thus provide little scope for assessing risk. Instead of producing a single, average case model, conditional simulation produces a number (typically 20 to 200) of equiprobable models, based on close-spaced nodes. The range of conditional simulation models thus provide an ideal platform for assessing risk, and for evaluating options, such as grade control strategies.

Recent advances in hardware, software, and simulation techniques have made it feasible to apply conditional simulation routinely in the mining industry to communicate uncertainty and enhanced understanding of risk.

Introduction to conditional simulation

A number of techniques are available for performing conditional simulations. A critical analysis of the positive and negative aspects of the various techniques is beyond the scope of this paper; for this the reader is referred to Vann[4] and Thomas[5]. According to Thomas, the choice of technique depends on the style of mineralization and its associated continuity, and the statistical behaviour of the mineralization.

The sequential gaussian simulation (SGS) is an efficient method widely used in the mining industry. The algorithm, in very simple terms, defines a random path through all grid nodes (including the conditioning samples). Kriging of the nodes in the path helps generate a local distribution. A new value is then drawn from this local distribution. This is added to the nodes in the random path and the next node is simulated (and so on).

Each simulation is equiprobable, however, slight deviations from the original histogram occur in the simulation process, and this reflects in the results, particularly where a high-grade tail exists. A disproportionate amount of metal contained in this tail will result in simulations with higher and lower average grades. The range of simulations will depend on the variogram properties, and the data density. Blocks located in poorly informed zones will vary widely from one simulation to another, whereas blocks located in well drilled areas will vary little, due to the conditioning effect.

The generation of a number of simulations (typically 20 to 200) provides a distribution of grade estimates for each block. These distributions can be used to calculate various probabilities of occurrence. For example, the 10th worst ranked simulation of 100 runs could be described as the 10% chance that the average grades are not lower than this distribution. Uses of this feature are in quantifying:

- Global resource or reserve risk
- Pit optimization (and NPV) risk
- Phase pit risk
- Mine scheduling risk.

The following examples illustrate the application of conditional simulation to grade risk. However, the technique is also being developed to quantify volume risk through simulation of geological boundaries.

Ekati Diamond Mine™

The Ekati Diamond Mine™ came into production in 1998, and originally sourced production from a single kimberlite pipe. Production has been expanded to 11 ktpd, and is being sourced from multiple kimberlite pipes. Ekati currently produces about 4% of the world's diamonds by volume, and about 6% by value.

A sequential gaussian simulation was undertaken to assess the resource risk with depth at a particular kimberlite pipe. The parameter chosen for this simulation exercise was diamond grade, expressed in carats per tonne. Individual simulations of the 2.5 × 2.5 m nodes show a pronounced 'salt-and-pepper' effect, with indistinct clustering of higher grades in the northern half of the pipe. The simulation average shows this clustering a bit better, as shown in Figure 3.

In order to quantify the resource and scheduling risk, level averages were calculated for the mean grade, a pessimistic case, and an optimistic case. These are shown in Figure 4, together with 25 of the simulations completed. The individual simulations are more tightly clustered in the upper levels of the pipe, and become more scattered in depth, reflecting the decline in sample density. The pessimistic case shows a systematic increasing deviation from the realistic case with depth. The optimistic case shows a more complex relationship with the realistic case.

As mining progresses downwards in a level-by-level fashion, the level grades are a direct reflection of scheduling risk. Increasing risk is apparent, as expected, with depth; however, the quantification of this risk allows the incorporation of the pessimistic, realistic, and optimistic grades directly into a number of cash flow projections. Risk management then can be undertaken, incorporating changes in scheduling, additional drilling, etc., in order to ensure that cash flow projections remain within acceptable levels of risk.

Spence porphyry copper

Spence is a porphyry copper deposit located 50 km southwest of Calama in northern Chile, that is currently undergoing a feasibility study. The orebody can be subdivided into a north, a central, and a southern domain, with the majority of the leachable copper mineralization present as oxides or as secondary sulphides. Twenty-five

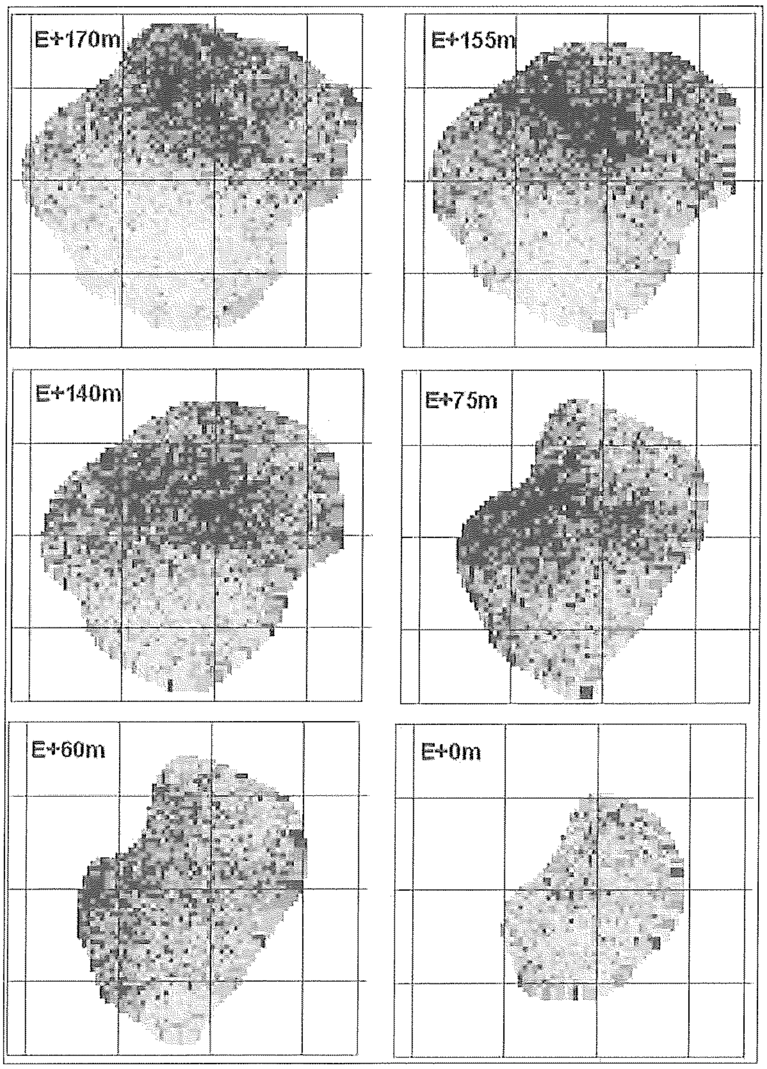

Figure 3. Simulation averages for six level plans

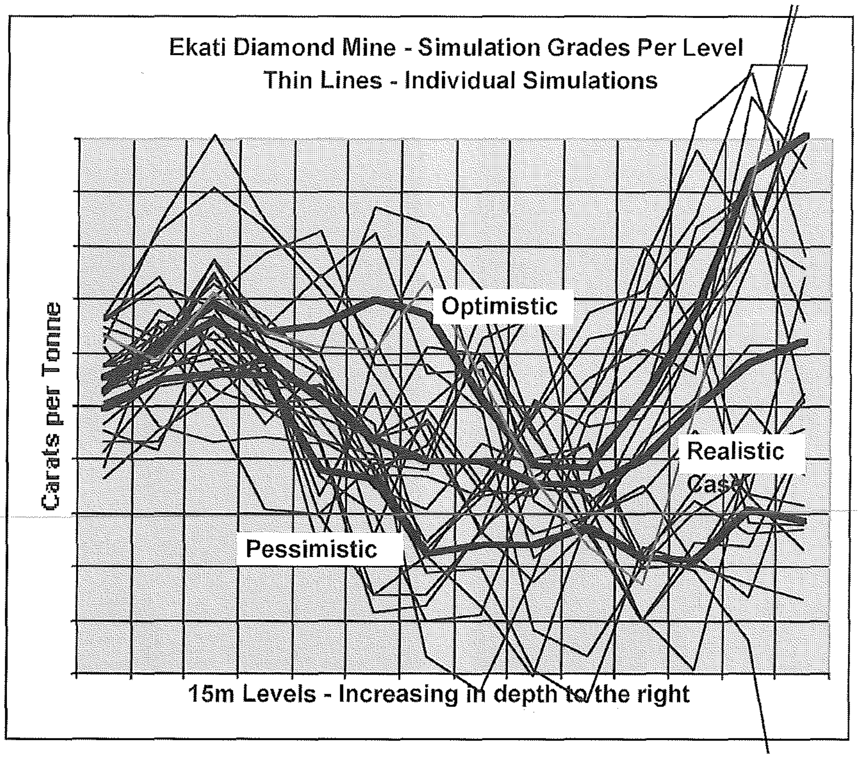

Figure 4. Conditional simulation level grades

simulations were run per domain using the SGS algorithm in Snowden's Maximisor® software with post-processing of results in Supervisor®, Vulcan and Excel.

When viewed on a bench average basis, there are limited differences between simulations. However, plots of the grade estimates show variation in certain areas, as shown in Figure 5. Certain areas are highlighted (dark circles), showing differences between the optimistic and pessimistic cases, especially in the Central sector. The distribution of high and low variability can reflect the drill grid, with a checkerboard distribution of least variability focused on drillholes and sampling, moving outwards from these areas to centres of higher deviation.

The conditional simulations were re-blocked to the kriged estimate block size. The resources within each phase pit were then extracted, and the simulations ranked according to metal content within each individual pit. The median simulation for each pit was then assigned a metal deviation of 0%, and all other simulations were recalculated according to percentage metal deviation from the median simulation. The percentage metal deviation from the median simulation is considered to be a measure of metal production risk. The results are shown in Figure 6. Consideration of these results indicates a low risk associated with pits 1 to 4 and 6 respectively. Pit 5, and to a lesser extent 7 and 9 (i.e. late in mine life) show higher risk and would probably require further drilling going forward.

Discussion and conclusions

This paper has focused on range analysis as a means of quantifying mineral resource risk. Although deterministic and probabilistic resource estimation methodologies are allowed in public reporting of petroleum reserves, there is no mention of probabilistic methodologies in the mineral reporting codes.

The internal BHPBilliton standards require range analysis, as part of the overall project risk assessment. The range of possible outcomes of key input parameters such as grades and tonnages needs to be described and quantified.

Conditional simulation has been presented as an ideal methodology for fulfilling these requirements.

The example at Ekati shows how risk, not surprisingly, increases as drilling density decreases. However, the technique shows how this risk can be quantified, and the resulting grades incorporated into cash flow modelling. At Spence, the visual risk shown in optimistic versus pessimistic simulations has been demonstrated, as well as the phase pit risk, quantified in terms of metal production deviation from the mean.

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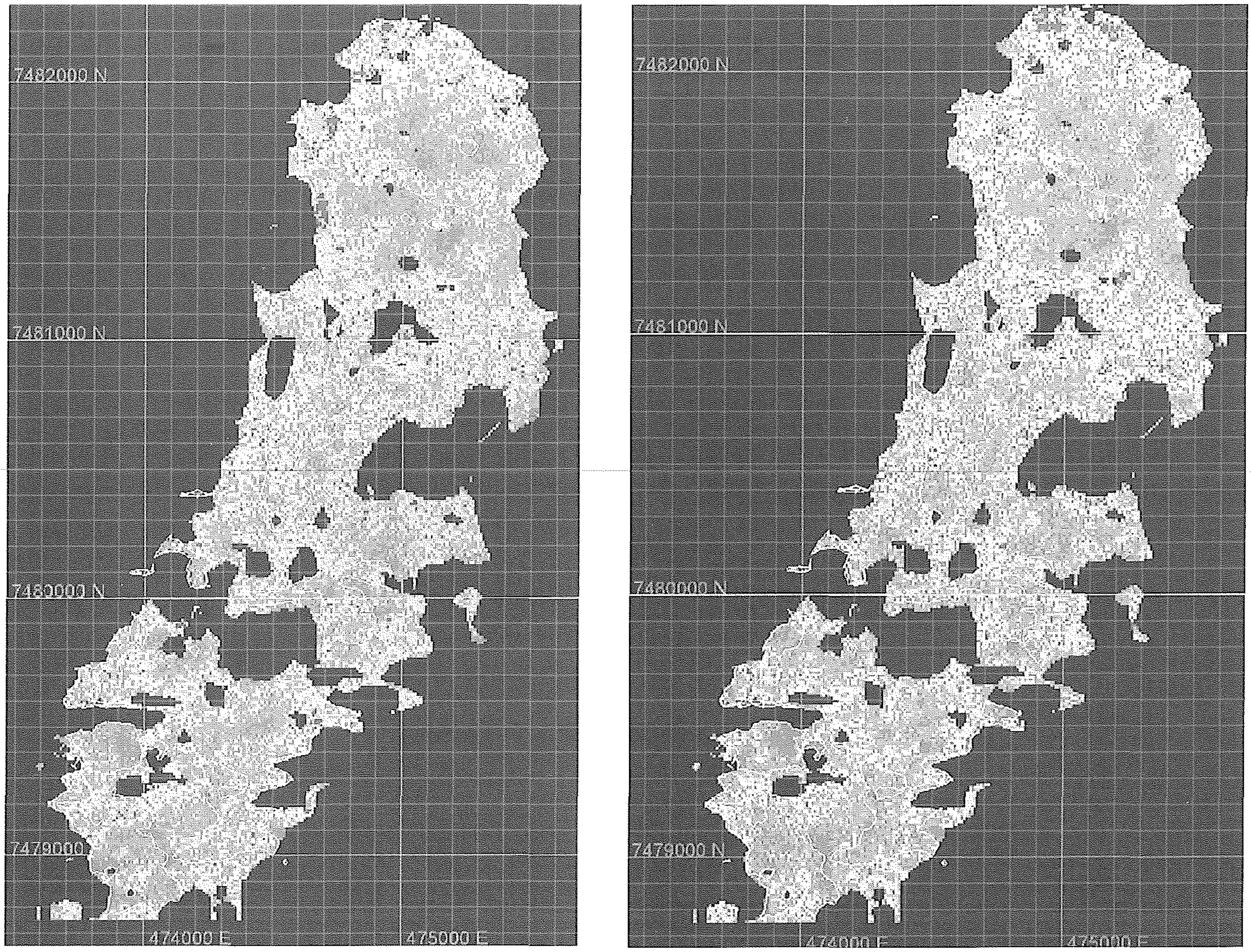

Figure 5. Spence conditional simulations. Left—pessimistic case, right—optimistic case

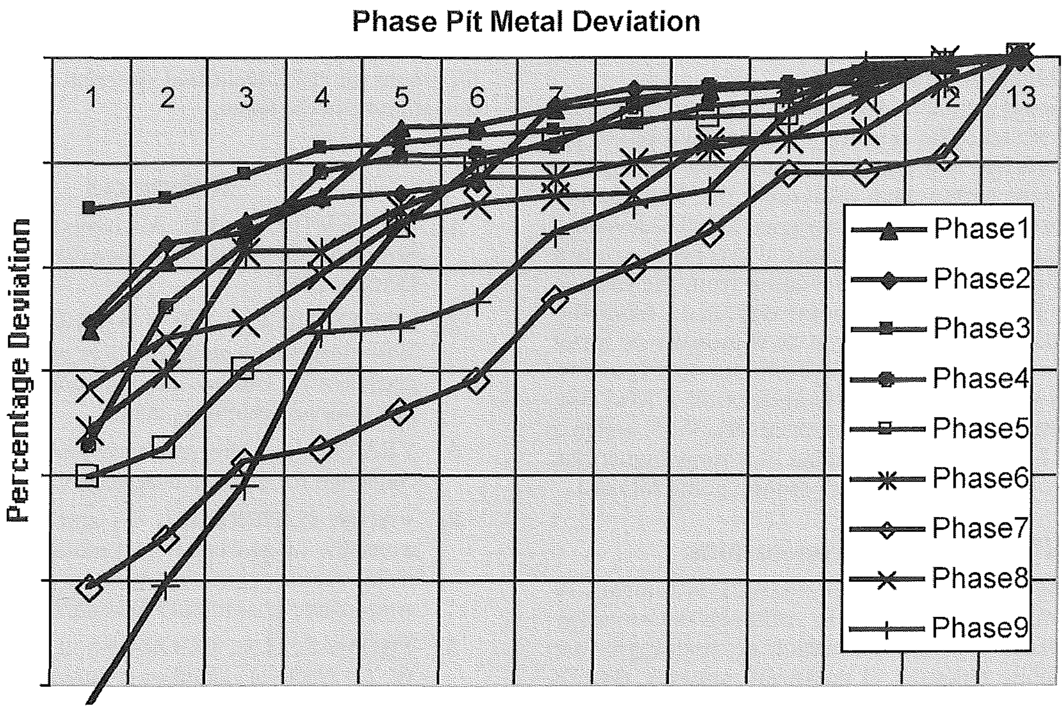

Figure 6. Spence phase pit metal deviation