Grab sampling for underground gold mine grade control

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Synopsis

Geologists in some underground gold mines collect grab samples from broken ore piles or trucks as a method of grade control. It is often known as muck sampling. Generally, the goal of grab sampling is to try and reconcile the mined grade at the ore source to the predicted grade and/or predict the mill feed grade. The mass of the sample collected is limited by health and safety issues, as well as by the capacity of the laboratory to process the samples within a given time frame. In general terms, grab sampling is known to be problematic because samplers tend to oversample the fines, and/or pick out high-grade fragments; surface sampling of piles does not test material within the pile; muck piles in development drives/faces are likely to be zoned due to the blasting sequence; high or low-grade material may preferentially segregate in the pile during mucking; the five per cent mass reject size of the material in muck piles is very large from underground blasting; some correlation usually exists whereby the larger fragments are enriched or depleted in the critical component of value; and the average error made in estimating the true stockpile grade is likely to be high. The method is prone to chronic fundamental sampling, grouping and segregation, delimitation, and extraction errors. Substantial warnings must be given about the use of grab sampling for grade control in gold mines. The method may appear to work sometimes, which can be attributed to a fine gold particle sizing and more disseminated distribution. As with all sampling methods, its appropriateness must be determined by ore characterization and heterogeneity testing to ensure the method suits the ore type.

Introduction

Ore and waste must be defined effectively to ensure an economically optimized mill feed in all mining operations. Grade control is essential for efficient mine operation, with key performance indicators including: effective definition of ore and waste (and marginal ore if required); correct delivery of ore and waste to their designated destination; optimized feed grade to the mill; minimal dilution; and maximum recovery. The process of grade control, broadly comprises data collection (e.g. sampling), integration, and interpretation; local resource/reserve estimation; stope design; and supervision of mining and stockpile management, which leads ultimately to reconciliation.

The requirement for high quality samples has been long recognized, where sampling programmes must be representative, unbiased, safe and operationally timely.[4,5,15,16,26]

Gold veins often pose problems during sampling because of their erratic grade distribution, which is often compounded by the presence of coarse gold particles.[7,8,10,17] Consideration should be given to the implications of the gold particle sizing and uneven distribution of gold requiring larger and close-spaced samples in order to be representative; partition of gold between sulphide-locked and free categories; geological versus assay cut-offs; and stringers/disseminations that require sampling beyond vein margins.[12,13]

Any sampling strategy should provide quality information on gold grade and its relationship to geology. Samples should be collected in such way as to minimize sampling errors (e.g. fundamental sampling (FSE), grouping and segregation, delimitation and extraction errors); ensure effective bagging and labelling; and be located in mine 3D space.

Geologists in some underground gold mines collect grab-samples from broken ore as a method of grade control. It is often known as muck or broken rock sampling. Generally, the goal of grab sampling is to try and reconcile the mined grade at the ore source to the predicted head grade. Additionally, the samples may be used to verify prior *in situ* estimates of grade such as those derived from face samples, sludge holes or diamond drilling. It is often used because of access issues (e.g. non-entry stopes), safety (e.g. to avoid

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unsupported backs) or lack of other sample data. On surface, grab sampling is often used to monitor the grade of stockpiles prior to blending and/or feeding to the plant.

There is relatively little published material on the topic of grab sampling usage for grade control. This paper reviews some of the key issues in applying this method to sampling in underground gold mines and presents a series of case studies.

General considerations

Collecting grab samples

Grab sampling involves collecting a large sample (or series of smaller samples that are later combined) from the muckpile at a face or drawpoint, or from tram cars or trucks transporting the ore from these points (Figure 1).

Samples are generally collected either by hand or shovel by a geologist, field technician or miner (Figure 2). Non-scientific protocols usually define a sample mass and number of samples per blast or per truck, etc. Time pressures and carelessness can lead to missed samples, for example where only one out of six tram cars is sampled, or where no trams were sampled.

The mass of individual samples is usually in the range of 1 kg to 5 kg. The sample mass is limited in practical terms by health and safety issues, as well as by the capacity of the laboratory to process the samples within a given time. Realistically, sample sizes required to be representative of broken rock piles are likely to be in the range of 100 kg to 20 t or more.

Published case studies

There are relatively few detailed studies of grab sample application reported in the literature, though a number of sources report the method.

One approach to muckpile grab sampling that has been employed at the mines in Val d'Or (Quebec, Canada) is the 'string and knot' method.[1] The broken ground from each blast at the face is transported to surface and spread over a concrete pad. Three or four strings, with knots at 0.5 m intervals, are then placed over the pile at 3 m intervals. At each knot a sample is taken and its weight recorded, along with the position of the knot. Each sample is assayed and the result weighted by the relevant weight to obtain the overall grade. In this way, it is hoped that a more representative grade is obtained. A similar method is also used for tram car sampling. A knotted string, as above, is placed diagonally across each 10 t truck and samples taken at each knot position. These are combined and then composited on the basis of pairs of trucks. The weight and grade of each composite sample is then used to obtain a weighted grade for the current round. Comparisons of the two methods indicate that the pad method is more reliable, but it is considerably more time consuming, involving more handling of the ore. The mean and variance values of a large number of weighted pad grades are lower than those found from the truck sampling. The string and knot is difficult to apply underground, since the material is still segregated after blasting. The method merely allows for regular sample collection; it does not result in an improved sample.

At the Dome mine (Ontario, Canada), one handful of ore was taken from each of six 3 t tram cars and combined to make a composite sample.[22] After crushing, a 1.5 kg to 2 kg sample was split from the original sample and sent for testing. The result was meant to be representative of 20 t of broken ground. In addition, grab samples were also taken from cut-and-fill stopes during mining. Rogers[22] notes that much of the gold at Dome was concentrated in quartz, which yielded fine high-grade product after blasting. Grab sampling was known to overstate grade, particularly where high quantities of visible gold existed in the ore.

Annels[1] notes that at the former Kerr Addison mine (Ontario, Canada), muck sampling practice varied with ore type. 'Flow ore', which consists of carbonatized lavas and interlayered tuffs impregnated with pyrite and gold, sampled by taking one lemon-sized piece from each of up to 15 cars (5 t) and then combining them into one composite which was taken to be representative of 75 t or less. In the case of 'green carbonate ore', however, which is fuchsite bearing and derived from ultramafic volcanics and invaded by auriferous quartz veins, the nuggety gold content was taken into

Figure 1—Underground at a drawpoint in the Macassa gold mine, Canada, showing the challenges of grab sampling material from longhole stope drawpoints

Figure 2—Collecting 50 kg 'grab' samples from a development stockpile using a portable -10 mm screen at the Bendigo mine site. Each white bucket held 25 kg of sample

account by taking three pieces of rock from each of no more than five cars at a time. Fifteen pieces were therefore taken to represent 25 t. This differential approach clearly recognizes that veins within a mine have variable ore characteristics.

Vallée[25] reports the fragment weight method which can be used to sample material from stope drawpoints. At the Opemiska mine (Quebec, Canada), narrow gold sulphide veins were exploited; mining was undertaken with either shrinkage or longhole stoping. In the longhole stopes, a wall dilution of 35% to 40% was added to the ore. As the walls are massive and mostly barren, they contributed large fragments that required removal to the waste pass. The material from the vein structures is more friable and the mineralization is concentrated into the fine fraction. Accordingly, the sampling procedure aimed to estimate the proportion of fragments of various sizes taking a portion from each size class: small hand size (maximum dimension 125 mm); medium double-hand size (<50 kg); large (>50 kg); and blocks (500 kg or more). In practice, the small to large classes were sampled. Fines samples were taken, whereas the larger blocks were not sampled. The mean grade was calculated by weighting of the various assays according to their estimated proportions. This method attempts to account for the potential differences in fragment size and grade. Although appropriate, there are likely to be differences in the fragment size grade relationship throughout the mineralization, not least in high grade versus low grade zones.

Grab sampling was used at the Tarnagulla mine (Victoria, Australia).[7,8] Studies undertaken in 1989 involved grab sampling from rail trucks to estimate the grade of two trial mining parcels of 250 t and 350 t respectively. Two 1 kg samples were taken out of each truck at the shaft station. These were bulked together to make a 10 kg to 15 kg sample, which was then pulverized and split to 1 kg for screen fire assay. Correlation with mill grades were +8% and -18%, respectively, for a mean grade of 7.1 g/t Au for both lots. In this case the correlation with the mill reconciled grades was reasonable and based on 20 to 25 composite samples. The mined material was from a low-grade zone of the reef and known to contain less coarse gold than the high-grade shoots (30 g/t Au: ~60% of gold greater than 300 microns in size). In addition, stoping was via air leg methods which tend to yield a 'finer' rock fragment size range.

The Pajingo mine (Queensland, Australia) applies grab sampling to determine the grade of surface truck dumps prior to milling.[23] Truck dumps were either 20 t or 30 t, and a day's production from each source is trucked to separate bays for sampling. The grab sample assays are averaged per bay to determine the mean grade. A trowel is used to collect around 3.5 kg of material from around and over each dump, taking at least five increments. Any rock fragment on the trowel was included in the sample. In general, it was found that the grab samples understated grade by about 4%. Gold at Pajingo is very fine grained (between 5 microns and 120 microns, with a mean of 40 microns) and relatively disseminated through the quartz carbonate veins.

Potter, Sheriff, and Collins report the use of grab samples from trucks at the Sand Queen mine (Western Australia).[20] A composite of 8 kg to 10 kg is taken from each truck made up of individual 0.5 kg samples. The veins contain a substantial proportion of coarse visible gold. The grab sample grades are used, together with geological information and face samples, to classify ROM stocks. The authors note that the grab samples overstate grade due to the concentration of gold in fines and under-sampling of diluting waste blocks.

Millar and Cheatle report the use of grab sampling at the Musselwhite mine (Canada).[18] Samples for ore headings and stopes are collected by scoop operators with a minimum of one sample for every three trucks of ore (approximately one sample per 90 t ore). Assays are entered into a database and used for daily stope grade estimation, in conjunction with face chip data. Musselwhite gold mineralization is noted to be low nugget effect (20%), with most gold associated with microfractures in sulphides.

At the high grade underground Kencana mine (Gosowong, Indonesia), grab sampling is used to monitor the grade of surface stockpiles to allow blending of mill feed.[2] For each 200 t lot, eight grab samples are taken from the pile representing approximately 25 t per sample. Initial grabs were of the order of 0.5 kg each and over a six-month reconciliation period were 7.5% higher than the mill. A larger 1.5 kg sample regime was introduced, which subsequently reduced the bias to around 3.5%. Bias was attributed to undersampling of coarse >6 cm fraction which is depleted in gold relative to the fines fraction. The overall reasonable performance of grab sampling can be attributed to the high-grade and more disseminated nature of the Kencana mineralization. Local variability can be high, however, particularly in the Bonanza Zone (mean grade 187 g/t Au) when compared to the Main Zone (mean grade 23 g/t Au).

Grab sampling and bias

The accuracy of grab samples has frequently been questioned due to the presence of large biases in the method.[5,19,26] Bias can be due to the natural tendency of the sampler to be drawn to richer fragments or to the fact that fines are often enriched in metal, particularly in high-grade gold mines (Tables I and II).[4] The tables show granulometric analyses for two different gold ore types. Each bulk sample was approximately 25 t and screened to provide the data given. The sulphidic ore contains very fine (<20 microns) disseminated pyrite-locked gold particles that are not liberated during blasting and hence show a relatively even grade distribution through the fractions (Table I). The other ore type was

Table I

Muckpile granulometric analysis of a sulphidic gold ore. Each assay group represents the mean of twenty individual assays

Size fraction	Grade 1 (g/t Au)	Grade 2 (g/t Au)	Grade 3 (g/t Au)	Grade range of all assays (g/t Au)
-3 mm	4.5	4.4	4.9	2.6–5.8
+3 to 6 mm	5.5	5.6	5.8	4.0–7.6
+6 to 15 mm	6.3	6.1	6.7	3.0–10.2
+15 to 25 mm	5.9	5.1	5.4	2.4–8.9
+25 to 50 mm	6.3	6.4	6.7	3.8–12.2
+50 mm	2.9	6.5	6.0	1.0–11.00

Table II

Muckpile granulometric analysis of a coarse gold ore. Each assay group represents the mean of twenty individual assays

Size fraction	Grade 1 (g/t Au)	Grade 2 (g/t Au)	Grade 3 (g/t Au)	Grade range of all assays (g/t Au)
-3 mm	47.7	51.5	85.5	6.2–95.8
+3 to 6 mm	28.4	33.7	38.2	13.0–59.0
+6 to 15 mm	9.7	12.8	23.1	7.4–41.4
+15 to 25 mm	14.7	11.5	18.5	11.4–28.0
+25 to 50 mm	12.8	6.7	9.1	4.2–44.7
+50 mm	4.3	1.8	3.3	1.0–22.8

characterized by coarser gold hosted in quartz. Fraction assays were much more variable and there was more gold located in the fines (Table II). In this case, grab sampling commonly overstated grade by 25% to 35% and was the cause of reconciliation problems, whereas in the first case grab sampling worked well. The fine gold ore required a 150 kg grab sample from broken ore to be taken, whereas the coarse gold ore required closer to 3 t for a representative sample (assuming a FSE of ±15% at 90% confidence level).

The main problem is that the material in muckpiles, or the material loaded into tram cars, is rarely sufficiently mixed to be representative of the block of ground from which it was drawn. This problem is exacerbated by the fact that in development headings, detonator time delays eject material sequentially from the face, initially, from the centre and finally from the edges. Therefore the muckpile will be zoned with the last material blasted on the top. Also, material collected will be from the surface of the pile and rarely from its interior.

In longhole stoping, the last material to be fired will generally be from the hangingwall and footwall of the stope and may be entirely dilution (i.e. low grade or barren). In narrow orebodies extracted by the longhole method, minimum stoping widths may require a significant amount of edge dilution, which will generally end up on top of the pile.

Additional issues result from the use of water underground to suppress dust. Sprinkler systems or water jets spraying onto a muckpile results in the exacerbation of fines segregation at the pile base. In some cases, spraying can lead to gold loss into drive or stope floors.

In order to obtain a reliable sample, a large quantity of broken rock would have to be collected on a regular day to daily basis and transported to surface for assay. This is generally impracticable in a mining situation. Sampling would have to be throughout the pile which is impossible and hence tram car sampling is the preferred option.

The amount that should ideally be taken is dependent on the size of the largest fragments in the pile and on the nature of the contained mineralization (i.e. with reference to the Gy sampling equation: Gy, 1982). The latter includes whether the gold is coarse and more evenly distributed and proportions of fine particles.

Generally, the coarser the rock fragments and the coarser and more localized the gold, the larger the sample that is required. For example, at Bendigo a 120 t development round would require a sample of at least 10 t in size to be collected (based on very coarse gold),[17] whereas at Cononish (Scotland) a sample of 300 kg is required (fine gold, less than 100 microns)[12] assuming an FSE of ±15% at 90% confidence level.

In some deposit types, even very nuggety systems, exhaustive grab sampling over long periods of time (at least months) can provide a reasonable grade prediction. The Wattle Gully mine (Victoria, Australia) operated between 1934 and 1969; historical records exist of grab samples taken from trucks during the period 1956 to 1968.[14] Some 1 500 samples were taken, which were believed to be between 3 kg to 4 kg in size (~4.5 t to 6.0 t). The estimated representative sample size for Wattle Gully broken, stope ore is estimated to be between 5 t and 10 t (assuming an FSE of ±15% at 90% confidence level).[13] The weighted mean grab sample grade of the 1 500 samples was 11.6 g/t Au, compared to a production reconciled head grade of 11.1 g/t Au (from 312 000 t). Individual sample grades were highly variable, ranging from less than 0.05 g/t Au to 2,800 g/t Au. Clark and Thompson[14] report that 'assays of grab samples taken daily from muck piles mined in each working place [at Wattle Gully] are not indicative of the true grade of each pile and sampling cannot be used for daily grade control'.[3] Grade control at Wattle Gully was reported to be controlled by geology and understanding how certain vein textures and mineralogy indicated economic gold grades.[14] Given the comments of Clark and Thompson, the role of grab samples at the mine was unclear, though the results on a stope by stope basis were likely to identify any grade trend.

Case studies

Bendigo mine, Victoria, Australia

The Kangaroo Flat mine is operated by Bendigo Mining Ltd. Modern reevaluation began in 1993, culminating in underground exploration and development in 1998. During August 2006 to May 2007 operations yielded 176 000 t at a grade of 5.4 g/t Au. Following the reemphasis on exploration in late 2007, BML announced, in November 2008, that trial mining of the Gill Reef yielded 36 829 t ore at 8.1 g/t Au. In January 2009, BML stated that it had treated 27 700 t at 6.2 g/t Au in Q3 2008 and 30 600 at 10 g/t Au in Q4 2008. It subsequently reported production of 40 552 t at 8.2 g/t Au in Q1 2009 and 27 800 t at 9.4 g/t Au during April to May 2009.

The Bendigo goldfield is hosted in black-shale dominated upward-fining turbidite cycles. Gold mineralization is hosted in quartz veins which form as reefs located in the apex of the crest of the folds and associated with faulting. Mineralization is well known to contain substantial quantities of very coarse gold and have a high nugget effect. This requires specific approaches to sampling. Gold particles are characterized by their very coarse nature, ranging from below 100 microns to over 10 000 microns in size.[17] In some instances, 60% of the gold occurs in particles greater than 1 000 microns in size.

Underground evaluation was undertaken between 1998 and 2006. During this period, there was a need for a cost-effective and rapid sampling system that could be used to determine the grade potential of development material. Bulk samples and trial ore parcels were known to give the most representative estimate of grade, but are costly in terms of time and money. Some operations have utilized sampling systems based on so-called micro bulk samples, which are generally less than 1 t in weight.[15,21]

During 2000 to 2001, the company accessed the St Anthony's Reef on the 450 South Drive. At this time, 3 kg to 5 kg grab truck samples were taken during development. The technique was able to define the presence of a high-grade area, but did not directly correlate with actual bulk sample (120 t) grades (i.e. picked up the trend into a high grade zone, but did not correlate with the 'true' grade). In this case, the grab samples considerably understated the bulk sample grades.

To address the challenge of representivity and to provide between discrimation between ore and waste more effectively, the company devised a 'micro' bulk sampling circuit. The micro bulk sample consisted of approximately 100 kg of rock, made up from two 50 kg samples taken from each on reef development round. The grades from the two samples were averaged to give a total grade. Initial sampling was undertaken underground prior to mucking. However, safety issues forced sampling to be undertaken from surface stockpiles (Figure 2). These samples were effectively grab samples taken from development ore.

Only the -10 mm fine fraction was sampled, which by a granulometric study was shown to contain an approximate 50% increase in gold content due to preferential fracturing of the quartz during blasting. By taking a biased fine-fraction sample, there was an increased chance of encountering coarse gold particles, and hence representing the grade potential of the mineralization. Four 25 kg samples were taken from opposite sides of the muck pile. A similar purposively biased methodology is reported for drawpoint sampling at the Ridgeway copper gold mine (Queensland, Australia).[24]

Each sample was processed at an on site gravity facility, based on a mobile Knelson Concentrator unit.[17] The gravity concentrate was immediately panned, any coarse gold removed, weighed and then reconciled with the sample weight to give a rapid semi quantitative grade. Following the removal of coarse gold, the remaining concentrate along with a sample from the tailings is sent for assay. The assay values for the concentrate and tailings are then recombined with the value obtained for the coarse gold removed in order to determine a head grade.

This approach is not rigorous from a sampling theory standpoint, with the grab sample being both too small and purposively biased to the -10 mm fraction. Micro bulk (grab) sampling, together with detailed geological mapping and observed occurrence of visible gold in the face became a useful tool in the delineation of the reefs. With sample turnaround times as low as two hours, a sampling system such as this has some advantages. It provides a measure of ore/waste definition, metallurgical information on gravity recovery, and gold particle size and distribution in a timely manner. It must be stressed that the micro bulk samples did not provide accurate values of *in situ* grade.

Production began in 2006 and following a reevaluation period, began again in 2008. This type of sampling has not been continued, with preference for a more geologically controlled grade proxy (scorecard-based) method for development faces and drill core.[9,15] The new approach is both cheaper and quicker, and provides a more realistic call grade range for each face.

Gold Pig mine, Western Australia

The Golden Pig mine was operated by Sons of Gwalia Limited and is located in the Yilgarn goldfields of Western Australia. It operated for more than 100 years, producing 2.25 Mt of ore at about 6 g/t Au for some 430 000 oz Au. The mine is now closed.

The deposit is situated on the eastern edge of the Southern Cross Greenstone Belt, which is a sequence of mafic and ultramafic rocks with intercalated banded iron formations (BIF) and sediments. Mineralization is mainly stratabound, within tight to isoclinally folded and sheared quartz pyrrhotite diopside BIFs. Gold is also located in shear zones containing lodes with high grade shoots. The Taurus (Lode) shear zone contains localized pods of high grades.

The mine often experienced problems reconciling grade control with resource model grades. A sampling study was undertaken on the Taurus Lode during 2001 to 2002.[21]

ROM grab samples were used to estimate a grade for each stope pile, and this value was compared to the reserve estimate for the individual stope. Samples were taken from ROM piles, with two grab samples taken from each truckload. For example, if the pile consists of 6 truckloads, 12 samples were taken. In general, individual sample fragments 'no larger than hand sized' were taken. Sample masses were generally 'half a bag full' of between 2.5 kg and 5 kg. The ROM pad was sampled twice daily, on the night and day shifts.

To test the variability of subsequent ROM pile samples, 40 repeat samples were taken from 2 ROM piles, and the grades compared (Table III). The samples were taken in the same manner as normal at the mine, and the samples were sent to the same assay laboratory. The ROM pile tested contained 7 truckloads, so 14 individual samples were taken.

Table III

Comparison of original ROM and repeat samples from Golden Pig mine

	ROM grade (g/t Au)	Repeat grade (g/t Au)	% Difference
Mean	15.1	5.3	183
No. of samples	14	40	-
Minimum grade	0.7	0.03	2333
Maximum grade	111.0	81.9	36
Variance (g/t)^2	810	187	720

In addition to this, 40 repeat samples were also collected. The mean grades for the two sample datasets are shown in Table III.

Table III shows that the mean grades from the repeat samples are significantly lower than the original mean grades. The original grades are being heavily influenced by the erratic nature of the ore, with a single high grade sample having a big effect on the overall grade assigned to the pile. Taking numerous larger samples reduces this effect and reduces the overall grade.

The individual sample grades were up to 111 g/t Au. If any 14 samples are taken from the ROM pile, the average grade for those 14 samples will be highly variable. If the ROM pile contains the 54 samples (i.e. the 14 original plus 40 repeat samples) and an exhaustive number of 14 sets taken, the number of possible outcomes is great. The 14 samples with the lowest grades produce an average grade of 0.7 g/t Au, but the highest 14 samples produces a grade of 25.2 g/t Au. If the lowest 14 samples had been picked, the pile would have been discarded as waste, but if the highest 14 had been chosen, the pile would have been sent to the mill as ore.

A modelling study extracted 250 groups of 10 samples randomly from the 54 sample database to investigate likely outcomes. Some 20% of samples were below a cut-off grade of 3.5 g/t Au and would have resulted in the ore being misclassified as waste.

Ore characterization work was undertaken, including heterogeneity testing and mineralogical determination.[21] The tests indicated that coarse gold was present within the ore, and often in quantities of greater than 10% above 100 microns. Visible gold was not common, though there was evidence of gold particle clustering leading to a local pseudo coarse gold effect.[11]

The ROM pile grab sampling has been shown to produce a high level of variability (Table III). It was estimated that around 1 t of ROM stock needed to be taken for every 100 t. This is clearly impractical from both a collection and assaying perspective.

A similar study was undertaken on the Haddons Lode (BIF-type mineralization) and resulted in less, but still high variability (a range of outcomes between 0.5 g/t Au and 6.5 g/t Au). Characterization again indicated quantities of coarse gold in the ore. Modelling showed that 70% of the samples were below a cut-off grade of 3.5 g/t Au, indicating a high probability of misclassification. The original mine-based samples indicated a grade of 3.9 g/t Au, whereas the additional test sampling indicated 2.5 g/t Au.

This example demonstrates the substantial risk involved when sampling surface ROM piles to determine whether rock is sent to the mill as ore or stockpiled as waste. The probability of misclassification was higher in the Haddons Lodes compared to the Taurus Lode.

Hadleigh Castle mine, Queensland, Australia

The Hadleigh Castle mine lies near Charters Towers, Queensland. It extracted 180 000 t per annum at a grade of 7 g/t Au between 1997 and 2005.[6] The gold-bearing veins of the district cut post tectonic Ordovician and early Devonian granitoid plutons of the Ravenswood Batholith. The veins are emplaced by brittle fracture associated with reverse faults/shear zones.

The quartz sulphide-gold veins form a gently to moderately dipping (40°) array in granitoid rocks. Lodes are composed of a narrow vein (<1.0 m) or array of several veins. The sulphide assemblage is dominated by pyrite, with lesser, dark, iron-rich sphalerite, galena and scarce chalcopyrite. Gold is mostly interstitial and intergranular, commonly in microfractured pyrite grains; the grain size range is approximately 5 microns to 50 microns. Visible free gold is rare, occurring in particles up to 1 mm in size.

Development faces were regularly called visually and assigned to the appropriate grade range. Material of uncertain grade or awaiting face-sampling results was sent to a 'resample' stockpile pending assays or grab sampling and then reclassified.

Muckpile grab sampling of both underground development and surface truck piles was seen as an effective method of monitoring likely mill-feed grade. The 12 kg to 15 kg grab samples were considered to reflect a 'bulk' grade better than face samples. In general, the grab sample grades underestimated mill grades by 10% to 15%. This consistent error was linked to undersampling of the gold rich fines from the muck pile.

The finer nature of broken ore from the air leg stopes made them more amenable to this type of sampling. In this instance, grab sampling was seen to work relatively well, especially in air leg stopes where dilution and rock particle sizes were less. The method was more problematic in longhole stopes.

Gwynfynydd mine, Gwynedd, United Kingdom

Gwynfynydd is located in North Wales, UK. Since production was first recorded in 1863, about 50 000 oz Au has been recorded from the mine. The mine is currently closed, but the gold belt is being reevaluated by Victorian Gold Limited. The Gwynfynydd mine contains a number of east northeast trending, quartz sulphide dominated veins hosted by Cambrian metasediments. Gold distribution within the reefs is extremely erratic and related to a complex interplay of lithogeochemical and structural controls. Localized rich pockets (sub shoots), yielding kilogrammes of gold, are sparsely distributed through the structures. Gold assays between the rich pockets are low and in some areas fall below 0.1 g/t Au.

During the last period of operation (1991 to 1999), grab sampling was initially undertaken from rail-bound ore trucks with 2 kg to 4 kg samples taken from every truck. All samples were combined to give a 12 kg to 18 kg total weight, jaw crushed to -5 mm and split to 4 kg. The sub-sample was sent for 50 g charge triplicate traditional fire assay and/or one 1 kg screen fire assay.

A comparison of sample data (face, grab and development bulk) was made from the working area of the mine between 1995 and 1998. The samples represent the ore shoot low-background grade domain (>0.1-5 g/t Au). High grade, visible gold zones were not sampled due to the extreme abundance of visible gold. The gold within the low grade domain is mostly coarse (sometimes visible up to 1 mm). Standard face chip samples typically both over- and underestimate grade. The grab sample data generally showed a reasonable correlation with 25 t bulk sample grades (±20%), when extremes were removed from the data.

Estimates of primary sample size, required for Gwynfynydd broken low-grade ore stocks between 0.5 t to 1.5 t, depending on the maximum particle size present and grade.[11]

The conclusions drawn at Gwynfynydd were that development bulk sampling always provided the best way to estimate the likely mineable grade.[7] However, during mining, grab sampling did provide an indication of grade trends. This relationship held only while working within the low grade domain of the ore shoot. Grab sampling was abandoned in favour of a 100 kg micro bulk sampling method, based on face panel samples and geological control.[15]

Macassa mine, Ontario, Canada

The Macassa mine is operated by Kirkland Lake Gold Incorporated. Between 1980 and 1995, the mine produced between 75 000 oz Au to 95 000 oz Au per annum from the No. 3 Shaft. During this period and earlier, the mining focus was on conventional cut-and-fill and shrinkage stoping methods. Since the early 1990s, 50% to 70% of production had come from longhole stopes. Annual production is around 75 000 oz Au, based on a head grade of 14 g/t Au.

Mine series rocks at Kirkland Lake are tuffs, conglomerates and syenite porphyries. The gold mineralization and most of the mine are preferentially hosted in the syenites. Gold mineralization is located along breaks (major faults) and associated splays as quartz veins ranging from a 5 cm to 2 m in width. Veins may be of single, sheeted or stacked morphology. Gold is usually accompanied by 1% to 5% pyrite and sometimes is associated with molybdenite and/or telluride minerals, and is sometimes visible.

Routine grade control samples are taken from development faces, conventional (air leg) stope backs and longhole muckpiles. Development samples are used for resource estimation and in stope grab samples for reconciliation monitoring.

Within conventional ‘entry’ stopes, chip samples are taken from the stope backs as each lift progresses. In the longhole ‘non access’ stopes, grab samples are taken from either the stope muck pile or from muckers (Figure 1). One to two kg samples are collected and placed in plastic bags and submitted to the mine assay laboratory. In practice, each sample is estimated to represent 20 t to 25 t of ore.

Screening tests undertaken in 1993 indicated that fines carried higher gold grades and revealed that a disproportionate amount of fines were being collected, resulting in a higher-grade bias. This is a typical effect of this sampling type, and lead to the use of a ‘grade factor’ to reduce the average grade and reconcile mine production with the mill.

The use of grab samples for grade control in longhole stopes is considered to be problematic. Experience shows that the results are generally biased and can provide misleading information. The methodology was abandoned in 1997 for all access stopes, but continued for non access longhole stopes.

It was understood that to fully abandon grab sampling would leave the mine geology team with no method to monitor longhole stope grade. The situation was made worse by the narrow nature of the veins. A purposively biased sampling approach, where only quartz vein material is collected from the muck pile, was recommended. Little or no gold is hosted in the wallrocks unless micro-veining is present. The sample result can then be diluted by the proportion of host rock at a grade of 0 g/t Au. The relative proportion of quartz vein versus host rock will need to be determined from the development faces prior to stoping and an allowance made for stope width. For example, a 10 cm vein represents 2% of a 2 m stope, and with a grab sample average grade of 124 g/t the diluted muckpile grade would be 6.2 g/t Au.

Empire Ranch mine, north America

The Empire Ranch mine is located in North America. During the period 1992 to 1996, the mine underwent a period of evaluation, development and mining. The mining programme yielded 42 000 tonnes of ore at a mill recovered grade of 37 g/t Au (estimated 41 g/t Au head grade). At the start of evaluation, it was known that the mineralization was dominated by coarse gold and had a high nugget effect. A series of sampling tests were undertaken to gain a clearer picture of the variability inherent for different sampling techniques.[21]

Greenstone and slates host the subvertical vein system, which is composed of massive to laminated quartz, with minor quantities of pyrite, galena, and sphalerite. Vein widths vary from 0.8 m to 1.5 m, with an average of 1.1 m. The gold is coarse grained with 40% of the gold reporting to the +1 000 micron fraction, 88% to the +450 micron fraction and 98% to the +100 micron fraction. As a result, at least 90% of the gold was recoverable by gravity methods.

Economic grades are located within moderately to steeply plunging ore shoots that are traceable for approximately 50 m along strike and up to 150 m up dip. Within the large scale ore shoots, smaller high grade sub shoots were encountered for up to 10 m along strike and dip. All veins contain low grades ranging from 0.1 g/t Au to 1 g/t Au, with the ore shoots historically containing recoverable grades of 30 g/t Au to 45 g/t Au. Grades within the small sub shoots were generally around 250 g/t Au, contributing up to 45% of the gold to the overall ore shoot metal inventory.

Detailed sampling tests were undertaken during the development of the stope 02/N2 raises. Four kg samples were taken from every round blasted, prior to entire rounds being processed as bulk samples. Comparisons show strong variability with the grab samples giving between +275% and -75% of the bulk sample grades. Some 80% of grab samples overstated grade by at least 15%.

The 02/N3 stope (1 500 t block) was developed on all four sides. Selected development rounds were processed as bulk samples yielding a mean grade of 38 g/t Au (diluted to stoping width). Each face was chip sampled (mean grade 49 g/t Au) and development rounds grab sampled (mean grade 63 g/t Au). During stoping, each bench floor was grab sampled yielding a mean grade of 86 g/t Au. The final estimated head grade from the stope after processing was 46 g/t Au. Each grab sample had a mass of 2 kg to 3 kg. Both the development grab and stope grab samples overstated the stope grade (37% and 87%, respectively). This overstatement was due to the high concentration of gold into the fine fraction. For the stope samples, the proportion of fines in the stope muckpile was higher due to the blasting regime used.

A granulometric study on 5 t of stope ore revealed that 71% of the gold was hosted in the -6 mm fraction (35% of the total mass), whereas in development ore 50% of the gold was hosted in the -6 mm fraction. Coarse gold particles were located on the grain boundaries of quartz and preferentially liberated into the fine fraction during blasting. This led to issues of gold loss during broken stope ore recovery.

As a result of this study, grab sampling was not used at the mine with reliance placed on face channel samples and careful geological control during mining. On a sample by sample basis, grab sampling was highly unreliable. Twin channel face samples and careful geological mapping was found to be a better method for calling grade and understanding gold distribution.

Discussion

Key problems with grab sampling

In terms of the theory, grab sampling from muck piles is problematic because:

- Samplers tend to over sample the fines, and/or pick out high grade 'looking' fragments
- Surface sampling of piles does not test material within the pile
- Muck piles in development drives/faces are likely to be zoned due to the blasting sequence
- High or low grade material may preferentially segregate in the pile during mucking
- The 5% mass reject size (screen size that that rejects 5% of the total stockpile mass) of the material in muck piles is very large; generally in the order of 10 cm to 20 cm from underground blasting, but may be +50 cm in some stoping operations
- Some correlation usually exists whereby the larger fragments are enriched or depleted in the critical component of value
- The average squared error made in estimating the true stockpile grade (sampling error variance) is likely to be high, even with large samples.

Recommendations

The general recommendation when considering the application of grab sampling is to be very careful. Where possible, an alternative method such as predicting the grade from *in situ* samples is likely to be a better option.

Grab sampling has been known to work in more 'homogeneous' low nugget effect mineralization styles (e.g. some massive/disseminated base metal deposits), but in heterogeneous high nugget effect systems such as gold (especially with coarse gold present) strong bias is likely. If grab sampling is the only option, the following approaches are recommended to understand error:

- Carry out tests to investigate whether there is a relationship between fragment size and the grade(s) of interest. For a complete stockpile, or a least several bucket loads that are deemed representative of the ore size distribution, establish the size distribution of the material and identify the screening sizes that split the stockpile mass into say five or more size ranges. Analyse multiple samples from each fraction (at least 10) to determine the variability of the grade distribution
- Carry out heterogeneity tests and mineralogical characterization on the ore to establish the key sampling parameters and gold deportment.[12] From this work, establish what sample size is required to achieve the minimum level of sampling precision that can be accepted for the sampling
- During mucking, collect increments from the stockpile (e.g. from each bucket, drawpoint, etc) targeting the size fractions established in the first step and using the sampling masses identified in the second step. For the larger fragment sizes, collect chips from the lager rocks to achieve the required mass, while for the smaller fractions use a screen to exclude oversize and/or undersize material. Collect duplicate samples as a quality control step for say 1 in 10 stockpiles
- Assay the samples from step 3 and mass weight the results from the screen testing in step 1. Monitor the precision of the results through duplicate sampling.

One of the greatest issues with grab sampling is the size of the primary sample that is required. The few kg of sample that are usually collected over a pile is generally inadequate and leads to a large FSE (potentially to ±500% or more). In the most challenging of cases (e.g. nuggetty gold), it is likely that tonnes of material are required for each sample. This raises the issue of how to collect and assay the samples and the required assay charge size. In this case, the options are usually either sample size and fragment reduction via a sampling tower or total processing through a plant.

Final comments

The case studies presented indicate that the use of grab sampling for underground gold mine grade control must be undertaken with care (Table IV). The method is prone to chronic FSE and grouping and segregation, delimitation, and extraction errors (Table V). Key attributes of the method are given in Table VI.

Considering the case studies presented, Table VII shows an analysis of grab sampling based on deposit characteristics and mining method. Theoretical sample sizes required are generally large, so practical application must be supported by testing to determine precision and accuracy as noted previously.

Grab sampling may be effective where gold grades vary little between size fractions (e.g. fine disseminated gold that is locked in sulphides) and where both the ore and waste break into pieces of approximately equal size. In many gold mines, despite best efforts, the mine geologist should expect precision to be poor and ore/waste misclassification high unless the operation can afford to crush its ore before

Table IV
Summary of case studies presented

Operation (mining method)	Gold grade and particle sizing	Application of grab sampling ROM grade	Effectiveness of grab sampling to determine
Bendigo (longhole stoping and jumbo development)	Very coarse gold up to 1 cm particles with localized clusters. Liberation of coarse gold during blasting.	Grab sampling of -10 mm fraction from surface stockpiles. Was generally able to define grade trends within the reef.	Poor— purposively biased method to determine grade trend. Quantitative estimate of grade via calibration with 120 t bulk sample results.
Empire (air leg stoping and development)	Very coarse gold up to 1 cm particles with localized clusters. Liberation of coarse gold during blasting.	Grab sampling of development piles and stopes to define ore versus waste for mill feed.	Poor—shows typical variability expected when tonnages of broken rock are sampled.
Golden Pig (longhole stoping and jumbo development)	Rare coarse gold to 1 mm particles. Association with sulphides which liberate during blasting.	Grab sampling of surface stockpiles to define ore versus waste for mill feed.	Poor—shows typical variability expected when large tonnages of broken rock are sampled.
Gwynfynydd (air leg stoping and development)	Coarse gold up to 5 mm particles with localized clusters. Liberation of substantial gold during blasting.	Grab sampling of development piles to define ore versus waste for mill feed.	Poor—shows typical variability expected when tonnages of broken rock are sampled.
Hadleigh Castle (longhole and air leg stoping, with jumbo development)	Very fine gold, generally sulphide grain locked. Minimal to no gold liberation during blasting, except in liberated sulphides.	Grab sampling of surface stockpiles and stopes to define ore versus waste for mill feed.	Moderate—shows a reasonable correlation with mill output. Fine and more disseminated gold distribution, assisted by finer more consistent air leg stope blast product. Poorer results were seen for longhole stope ore.
Macassa (longhole stoping and jumbo development)	Generally fine gold with rarer coarse gold up to 5 mm particles. Some liberation of gold during blasting.	Grab sampling of development piles to define ore versus waste for mill feed.	Poor—shows typical variability expected when tonnages of broken rock are sampled. Challenge of sampling vein material which can be less than 50% of the muckpile.

Table V
Sampling errors and their impact on grab sampling

Sampling error	Error effect during grab sampling
FSE	Relates to collection of a sample that is generally too small for the lot and is biased to the finer fractions
GSE	The muckpile bears a natural segregation particularly of fines that settle to the pile base
DE	Routine grab samples sample only the surface of the muckpile. Large tracts of the pile go effectively unsampled
EE	The poorly delimited sample does not extract all the rock fragments within the sample zone due to differential fragment sizes

sampling. Grab sampling must, therefore, be used with extreme caution as in many cases it can be best described as a random process.

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Table VI

Grab sampling attributes

Attribute	Comment
Logistics and planning	Easy: relatively easy to undertake
Frequency of collection	High: numerous small (<5 kg) samples can be collected
Geological quality	Poor: little geological information
Hazard exposure	Low-high: depends upon sampling location; risk with multiple small samples as composite high mass results in manual handling issues
Flexibility of method	High: can be undertaken quickly and at short notice
Cost	Low: relatively easy and quick to collect, cost principally sample preparation and assaying
Sample quality	Poor: prone numerous sampling errors (see Table V)
Value proposition	Low: strong likelihood of bias, and thus ore/waste misclassification

Table VII

Summary of gold deposit types versus grab sample performance from air leg and longhole stoping methods

[1]Ore type	[2]Style	Example	[3]Indicative nugget effect	*In situ* gold particle sizing diameter (dL)	[4]Gold liberation constant (K)	[5]Indicative sampling sample size (M_S) for air leg methods	[6,7]Theoretical indicative sample size (M_S) for longhole methods	[6,8]Theoretical indicative for standard industry practice	[9]Grab sample performance
1	Mesothermal veins, lodes & disseminations	Bendigo, Empire, Gwynfynydd & Wattle Gully	>50% (generally >75%)	Mostly coarse gold dominated (>>100 µm) with localized clustering	>>100 µm often to 1,000 µm,	>1,000 g/cm$^{1.5}$ (potentially to over 100,000 g/cm$^{1.5}$)	5-145 t [1-30 t]	10-300 t [2-70 t]	Poor: >±30%, often positive bias though can be negative depending on dilution effects
2	Mesothermal veins, lodes & disseminations	Dome, Golden Pig, Hadleigh Castle & Macassa	>50%	Occasional coarse gold, dominated by finer more disseminated gold (<100 µm)	<200 µm	<1,000 g/cm$^{1.5}$	<5 t [<1 t]	<10 t [<2 t]	Moderate: ±15-30%, often positive bias
3	Epithermal veins, lodes & replacement/ disseminations	Kencana, Musselwhite & Pajingo	<50% (generally <30%)	Fine gold dominated (<<100 µm)	<75 µm	<250 g/cm$^{1.5}$	<1 t [<250 kg]	<2 t [<500 kg]	Good: ±15%. Bias may still be positive

Notes

[1]Type defined for the purpose of this Table, not based on any other classification scheme.

2Mesothermal systems generally more challenging from a sampling and evaluation perspective than epithermal systems; though the reverse can sometimes be observed.

[3]As indicated by variographic analysis.

[4]As defined in the Gy equation for FSE.

[5]As defined in the Gy equation for FSE (K). Based on ROM grade of 8 g/t Au, lower grades will result in a higher K value.

[6]Mass dependent upon level of dilution in the muckpile, more dilution leads to lower grade and more sample mass required.

[7]Based on a confidence level of 90% and FSE ±15% and [70% FSE ±20%]; with dN of 15 cm and ROM grade of 8 g/t Au. Lesser grades will require larger sample mass.

[8]Based on a confidence level of 90% and FSE ±15% and [70% FSE ±20%]; with dN of 25 cm and ROM grade of 8 g/t Au. Lesser grades will require larger sample mass.

[9]Based on typical four to eight 2-4 kg grab samples from a 25 t to 100 t muckpile.

References

1. ANNELS, A.E. *Mineral Deposit Evaluation: A Practical Approach*. Chapman and Hall, London. 1991. 436 pp.

2. CARSWELL, J.T., YULIA, K., LESMANA, D., and STEAMY, K. Grade control sampling quality assurance/quality control in a high-grade gold mine—Gosowong, Indonesia. *Proceedings of the 7th International Mining Geology Conference*, Perth, Dominy, S.C. (ed.). Melbourne. The Australasian Institute of Mining and Metallurgy, 2009. pp. 283–290.

3. CLARKE, P.E. and THOMPSON, I.R. Operating experience at Wattle Gully in relation to the Central Victorian gold mining area. *Proceedings of the 8th Commonwealth Mining & Metallurgical Congress*—Australia and New Zealand, vol. 6, 1965. pp. 323–338.

4. DOMINY, S.C. Sampling and Estimation of Gold Deposits, unpublished research report, University of Greenwich, Chatham and Welsh Gold PLC, Dolgellau. 1997. 230 pp.

5. DOMINY, S.C. Sampling—a critical component to gold mining project evaluation. *Proceedings of the Project Evaluation Conference*, Melbourne. The Australasian Institute of Mining and Metallurgy, 2007. pp. 89–96.

6. DOMINY, S.C., HODKINSON, I.P., and KIDD, R.G. Meeting the challenges of narrow-vein gold mining: Hadleigh Castle gold mine, Charters Towers, north Queensland, Australia. *Transactions of the Institute of Mining and Metallurgy,* vol. 108, 1999. pp. A192–A205.

7. DOMINY, S.C., ANNELS, A.E., JOHANSEN, G.F., and CUFFLEY, B.W. General considerations of sampling and assaying in a coarse gold environment. *Transactions of the Institute of Mining and Metallurgy*, vol. 109, 2000. pp. B145–B167.

8. DOMINY, SC., JOHANSEN, G.F., CUFFLEY, B.W., PLATTEN, I.M., and ANNELS, A.E. Estimation and reporting of mineral resources for coarse gold-bearing veins. *Exploration & Mining Geology,* vol. 9, 2001. pp. 13–42.

9. DOMINY, S.C. and JOHANSEN, G.F. Reducing grade uncertainty in high-nugget effect gold veins: application of geological and geochemical proxies. *Proceedings of the PACRIM Congress*, Adelaide. Melbourne. *The* Australasian Institute of Mining and Metallurgy, 2004. pp. 291–302.

10. DOMINY, S.C. and PETERSEN, J.S. Sampling coarse gold-bearing mineralisation—developing effective protocols and a case study from Southern Greenland. *Proceedings of the 2nd World Conference on Sampling and Blending*, Sunshine Coast. Melbourne. The Australasian Institute of Mining and Metallurgy, 2005. pp. 151–165.

11. DOMINY, S.C. and PLATTEN, I.M. Gold particle clustering: a new consideration in sampling applications. *Transactions of the Institute of Mining and Metallurgy*, vol. 116, 2007. pp. B130–B142.

12. DOMINY, S.C., XIE, Y., and PLATTEN, I.M. Characterisation of in-situ gold particle size and distribution for sampling protocol optimisation. *Proceedings of the Ninth International Congress on Applied Mineralogy, Brisbane*. Melbourne. The Australasian Institute of Mining and Metallurgy, 2008. pp. 175–185.

13. DOMINY, S.C., XIE, Y., and PLATTEN, I.M. Gold particle characteristics in narrow vein deposits: implications for evaluation and metallurgy. *Proceedings of Narrow Vein Mining Conference*, Ballarat. Dominy, S.C. (ed.). Melbourne. The Australasian Institute of Mining and Metallurgy, 2008. pp. 91–104.

14. DOMINY, S.C., PLATTEN, I.M., EDGAR, W.B., CUFFLEY, B.W., and TOWSEY, C.A.J. Application of mine records to reduce project risk during the evaluation of historical goldfields. *Proceedings of the Project Evaluation Conference*, Melbourne. Melbourne. The Australasian Institute of Mining and Metallurgy, 2009. pp. 145–161.

15. DOMINY, S.C., PLATTEN, I.M., FRASER, R.M., DAHL, O., and COLLIER, J.B. Grade control in underground gold vein operations: the role of geological mapping and sampling. *Proceedings of the 7th International Mining Geology Conference*, Perth, Dominy, S.C. (ed.). Melbourne. The Australasian Institute of Mining and Metallurgy, 2009. pp. 291–307.

16. GY, P.M. *Sampling of Particulate Materials—Theory and Practice*. Elsevier, Amsterdam, 1983. 431 pp.

17. JOHANSEN, G.F. and DOMINY, S.C. Development of sampling protocols at the New Bendigo Gold Project. *Proceedings of the 2nd World Conference on Sampling and Blending*, Sunshine Coast. Melbourne. The Australasian Institute of Mining and Metallurgy, 2005. pp. 175–183.

18. MILLAR, R. and CHEATLE, A. Musselwhite mine—The history of a giant gold deposit. *Proceedings of the 7th International Mining Geology Conference*, Perth, Dominy, S.C. (ed). Melbourne. The Australasian Institute of Mining and Metallurgy, 2009. pp. 231–238.

19. PITARD, F.F. *Pierre Gy's Sampling Theory and Sampling Practice*. CRC Press: Boca Raton, 1993. 488 pp.

20. POTTER, D., SHERIFF, C. and COLLINS, P. Significance of geological control on assay data in the narrow, high-grade gold quartz veins at the Sand Queen mine, Comet Vale, Western Australia. *Proceedings of Narrow Vein Mining Conference*, Ballarat. Dominy, S.C. (ed.). Melbourne. The Australasian Institute of Mining and Metallurgy, 2008. pp. 71–78.

21. ROBERTS, L.S., DOMINY, S.C. and NUGUS, M.J. Problems of sampling and assaying mesothermal lode-gold deposits: case studies from Australia and North America. *Proceedings of the 5th International Mining Geology Conference*, Bendigo. Dominy, S.C. (ed.). Melbourne. The Australasian Institute of Mining and Metallurgy, 2003. pp. 387–400.

22. ROGERS, D.S. The discovery, evaluation and development of gold occurrences at the Dome mine, South Porcupine, Ontario: A working model for Archaean-type deposits. *Applied Mining Geology—Problems of Sampling and Grade Control*, Denver. Metz, S.C. (ed.). New York. Society of Mining Engineers, 1984. pp. 7–29.

23. SIMS, D.A. Sampling practices at Vera Nancy gold mine. *Proceedings of the 4th International Mining Geology Conference*, Coolum. Melbourne. The Australasian Institute of Mining and Metallurgy, 2000. pp. 35–42.

24. SMART, G., RUTTER, J. and NOPPÉ, M.A. Inves-tigation of alternative drawpoint sampling at Ridgeway mine, NSW, Australia. *Proceedings of the 2nd World Conference on Sampling and Blending*, Sunshine Coast. Melbourne. The Australasian Institute of Mining and Metallurgy, 2005. pp. 227–231.

25. VALLÉE, M.A. *Guide to the Estimation of Gold Deposits*. Canadian Institute of Mining and Metallurgy, Montreal. 1992. 300 pp.

26. VALLÉE, M.A. Sampling quality control. *Exploration & Mining Geology,* vol. 7, 1998. pp. 107–116. ◆