PINCOCK perspectives

Consultants for Mining and Financial Solutions | ISSUE NO. 83 — March 2007

Does It Pan Out?

Sampling and Metallurgical Testing of Base and Precious-Metal Ore Deposits

INTRODUCTION

Sampling and metallurgical testing of ore deposits is often a haphazard process, particularly in the early stages of a project. This is to be expected since exploration is, intrinsically, stepping into the unknown, and the associated metallurgical testwork must follow suit. For all that, it is worthwhile thinking ahead and having a general plan in mind to guide metallurgical sampling and testwork, recognizing that the project may well have be cut short should early exploration and metallurgical testing not pan out.

In the event that initial assays and metallurgical testing appear promising, then early planning will pay off, particularly since both are part of a continuum rather than a stepwise process and it is usually difficult to recognize when a project is changing from early assessment to definitive evaluation.

In attempting to give a structure to the planning process, it is worthwhile breaking the process into a series of components. The following areas have been outlined in this article:

- Sampling
- Mineralogical definition and assaying
- Special assays and reagent consumptions
- Test procedures
- Test sequencing

This article is limited to base and precious metal ores, so as to minimize the options, but the general principles are applicable to other deposits.

SAMPLING

Table 1 (page 4) shows a series of possible sample sources and the type of metallurgical testing to which they are applicable.

One caution worthwhile mentioning in discussing sampling for metallurgical testing of sulfide minerals is the need to ensure that samples are not dried at too high a temperature, which might cause surface oxidation of sulfide minerals. About 105^{0}C is a good target. For such minerals, particularly if the deposit is in the tropics, it is also worthwhile using sealable plastic bags, purging the bags with nitrogen, and storing them in a freezer to minimize further oxidation.

Another aspect of sampling that needs emphasis is clear definition of where the samples come from; specifically, their location in three-dimensional space. This is critical when it comes to later auditing of testwork where one of the tasks is determining whether the samples are reasonably representative of the deposit. It is best to include such information in the main body of the report rather than as an appendix, so it is less likely to be lost.

Trenches, Adits, Declines, and Shafts

The first listed source of samples in Table 1, that for trenches, adits, declines, and shafts can provide large bulk samples of coarse rock. Accordingly, there is no limitation for the applications of these samples; they can be used for all types of metallurgical testing and are particularly useful for large-scale testwork, such as pilot-plant programs. They are also especially useful for tests that require coarse rock, such as coarse-rock gravity separation tests (jigging and heavy media separation (HMS)), and for heap leaching.

Drill Core

The second source of samples, diamond-drill core, is the most common and is generally applicable to all tests, depending on the core diameter. The commonly available core size is generally two to three inches in diameter and this core is usually split, using one half to provide samples for assaying, leaving half core for geological logging and for posterity. With some forethought the splits from the half core taken for assaying, which are usually crushed to about minus half inch before initial splitting, are

CALENDAR

- **Asia Mining Congress 2007**
  March 27 – 30, 2007
  Grand Hyatt
  Singapore, Singapore
  e-mail: joan.ong@terrapinn.com

- **The Natural Resource Summit of the Americas 2007**
  April 2 – 3, 2007
  Atlantis Resort
  Paridise Island, Bahamas
  e-mail: john@premierconferences.com

- **APCOM 2007 International Symposium on Application of Computers and Operations Research in the Mineral Industry**
  April 24 – 27, 2007
  Hotel Sheraton San Cristobal
  Santiago, Chile
  e-mail: info@apcom2007.com

- **Mining World Russia 2007**
  April 25 – 27, 2007
  Crocus Expo
  Moscow, Russia
  e-mail: oleg.netchaev@ite-exhibitions.com

- **CIM Conference & Exhibition**
  April 29 – May 2, 2007
  Palais des Congrès de Montréal
  Montréal, PQ, Canada
  e-mail: jmdemers@cim.org

- **ArMinera 2007: VI International Mining Exhibition**
  May 2 – 4, 2007
  Centro Costa Salguero
  Buenos Aires, Argentina
  e-mail: info@viewpoint.com.ar

- **2007 Elko Mining Explo – 22nd Annual Mining Expo**
  June 4 – 8, 2007
  Elko Convention Center
  Elko, Nevada
  e-mail: matt@elkocva.com

kept and these can be a useful source of metallurgical samples.

A factor that can be the cause of consternation with the use of drill core is that the assays of the metallurgical samples may not match those of exploration where different parts of the core are used. Since core is not homogenous, core on one side may have a different grade then the opposite side. This disparity is, of course, more likely if the sections of core used for metallurgical testing are relatively short.

Occasionally, large-diameter core are drilled, specifically to provide metallurgical samples. These are usually for heap-leach testing where large quantities of representative samples are required for leaching at coarse sizes.

Drill Cuttings

Drill cuttings provided by reverse-circulation drilling can provide samples for any metallurgical tests where the testing incorporates slurrying of the ore; this includes all tests except comminution testing, coarse gravity separation, and heap leaching. In using drill cuttings it is sometimes questionable as to just how representative the samples are, but they can still be useful, particularly for initial metallurgical testing.

Assay Pulps

Assay pulp rejects are usually fairly fine, of the order of ten mesh or less. Such samples may come from diamond-drill core or from drill cuttings and serve well for all metallurgical tests where coarse sizes are not required.

MINERALOGICAL IDENTIFICATION AND ASSOCIATION

There is often a question as to how extensive mineralogical identification and association needs to be, particularly in the early stages of a project. Often such studies are initially done in conjunction with geology and are often of little use for metallurgical assessment. They are often heavy tomes with hundreds of microphotographs and ponderous text that have little application or helpful insight into metallurgical processing.

There is also some of the same tendency to plunge into obscure and tangential mineralogical studies related to metallurgical testing too early in the testwork program, before some idea of possible mineralogical difficulties become evident. Mineralogical studies are usually expensive and it is usually wise to wait until initial metallurgical testing gives some idea of how these studies should be directed.

Once some idea of a probable ore processing scheme is established, then mineralogical studies can provide both guidance as to appropriate ore processing parameters and reasons for poor response to some processing methods. Studies of ore, concentrates, middlings, and tailings should provide assessment of the parameters listed in Table 2 (page 4). These parameters are discussed in the succeeding paragraphs.

Major Mineral Types and Distribution

The mineralogical studies need to identify and quantify the major gangue and valuable mineral types present. Doing this manually is laborious and it is difficult to establish the distribution of the minerals. However, with the development of computerized methods, such as QemSCAN, it is possible to identify and quantify the minerals in numerous samples easily so that average values and ranges of mineral content can be clearly determined.

Particle Size and Intergrowth

Determining appropriate grinding size parameters requires an assessment of size of the valuable mineral particles and the form and extent of intergrowth of valuable minerals of different types with each other and with gangue minerals. This is usually done manually and requires observation of numerous samples of ore, concentrate, middlings, and tailings to establish a clear assessment of reasonable grinding size parameters.

ASSAYING

Along with mineralogical studies, assays of the valuable metals, major elements, and deleterious elements are required. A listing of such elements is presented in Table 3 (page 4). As indicated in the table all of these analyses are helpful for the ore, concentrates, and tailings. The middlings generally only need analyses of the valuable metals.

In the initial testwork the analyses can be limited to the valuable metals and then, in more definitive testwork, broadened to include the major and deleterious elements. The latter two groups of analyses can be provided by relatively-inexpensive multi-element X-Ray Fluorescence (XRF) and Inductively-Coupled Plasma (ICP) analyses. Where difficulties in the testwork are encountered, analyses of the major and deleterious elements can provide indication of what elements may be the cause of problems.

SPECIAL ASSAYS AND REAGENT CONSUMPTIONS

Table 4 (page 4) shows a listing of special assays and reagent consumptions and types of deposit to which they are applied. As shown on the table they are applied to just three of the six types of deposits considered in this article.

Special Assays

Once a process is established for a deposit, it will sometimes be necessary to do special assays to establish the type of mineral present, particularly if there are mixes of mineral types that require different ore processing methods. As indicated in Table 3, acid-soluble analyses are done for oxide and secondary copper ores, and cyanide-soluble analyses are done for secondary copper and oxide gold ores. Such analyses are often included in the suite of assays done by exploration and it is helpful to ascertain the need for such assays early in a project so they can be done in parallel with the other assays. These assay values are sometimes included as part of the geological block models.

Reagent Consumptions

Reagent consumption is often a major factor in determining the economic viability of a deposit. Accordingly, where reagent consumption is significant, it should be tested on a good proportion of the exploration samples. High reagent consumption can occur in calcite-bearing oxide copper ores and in copper-bearing and partially-oxidized gold ores. In some instances estimated reagent consumptions can be derived indirectly from chemical analyses, which is usually less costly than direct testing of the samples. As for the special assays, reagent-consumption values are sometimes included as a component of geological block models.

TEST PROCEDURES

Table 5 (page 4) shows a listing of test procedures applied to the six types of ore deposit considered in this article. A discussion of each of test groups is provided in the following text.

Comminution

Practically all ore types have to be at least partially reduced in size in any ore processing method. The first three listed procedures in Table 5: abrasion, crushing impact, and Bond

Work Index, are usually applied universally, even though the ore may not be crushed, since it does give an idea of the abrasion characteristics, hardness, and toughness of the ore which are useful in deciding on process alternatives. These tests are usually done shortly after it is established that the ore can probably be processed, with more extensive tests done later, as part of definitive testing. Where large variations in the Bond Work Index occur, extensive testing, often in a more basic form, may be undertaken and the results incorporated in the geological block model.

Where semi-autogenous (SAG) milling is a possibility, then testing of this aspect is normally done using a McPhearson mill or by doing JK drop tests. Often pilot-plant tests are also required. All these SAG mill tests require large and/or coarse samples. The one process in which SAG mill tests are not required is for oxide copper deposits since such ores are processed by heap leaching, where SAG milling is inapplicable.

Gravity

Testing of gravity processes is grouped in two categories: coarse rock and fine rock.

Testing the application of gravity separation for coarse rock (generally minus 2 inches, plus ¼ inch) is done using heavy liquids. This tests the applicability of the ore to jigging and to heavy media separation (HMS). As indicated in Table 5, such testing is limited to sulfide ores.

Testing the application of gravity separation for fine rock (generally less than 20 mesh) is done on shaking tables. Such testing is limited to the recovery of metallic gold and so is usually only applied to copper/gold sulfide ores and to oxide gold ores.

Flotation

Flotation testing for the types of ores listed is generally limited to sulfidic mineralization, so this testwork does not apply to oxide copper and oxide gold deposits.

Flotation tests begin with simple rougher flotation, move on to open-circuit inclusion of cleaner flotation, and then to locked-cycle tests, as confidence in processing strategy and the viability of the deposit rises.

Oxidation

As indicated in Table 5, there are four types of oxidation testing applied to the ores considered. Atmospheric oxidation, which is done by sparging oxygen into close-to-boiling slurry, is applied only to secondary copper ores and so is of limited application. Roasting is also limited to one ore type, in this instance, refractory gold ores.

Autoclave oxidation may need to be tested on several ore types; however, the principal application is for refractory gold ores. It is only occasionally applied to base-metal sulfide ores, where its use is limited to copper sulfide concentrates and then only for the special situation where the low-strength acid generated can be used at the same site. Another infrequent application is for secondary copper ores.

Biological oxidation can be used for some refractory gold ores; accordingly, testing of this process is often required to assess this alternative for this ore type.

Slurry Leaching

Testing of slurry leaching is divided into two groups: without oxidation and post oxidation.

Testing without prior oxidation is limited to oxide copper and oxide gold ores, though it is seldom applied to the former unless the ore is exceptionally soft and friable. Testing of oxide gold ores using bottle-roll tests is extremely common.

Testing of slurry leaching post oxidation is applied to base-metal sulfides, secondary copper, and refractory gold ores. In the case of base-metal sulfides it is limited to copper ores and, since oxidation of these ores is seldom practiced, it is not a common test requirement.

Heap Leaching

Heap leach testing is widely applied to oxide copper and oxide gold ores; for these ores the leaching is simple and direct. In the case of secondary copper ores, tests require the introduction of bacteria which are a fundamental part of the leaching process.

Solid/Liquid Separation

In the latter stages of testing of processes involving slurries it is necessary to conduct sedimentation and filtration tests on many of the intermediate and final process streams to provide information for sizing of thickening and filtration equipment.

TEST SEQUENCING

Table 6 shows a simple outline of the timing of metallurgical testwork together with the sampling, the testing, and the objective of the testing. The testing is grouped as initial and final testing and is further discussed in the following text.

Initial Testing

The initial testing of a deposit normally starts with taking random samples which are subjected to simple amenability-level flotation or leach tests. These tests assess whether any of the ore types considered in this article, with the exception of refractory gold ores, can be directly processed. Leach tests identify the presence of refractory gold ore since the ore will not leach or only to a marginal degree.

As indicated in Table 6 (page 4), random sampling and simple tests generally continue in the next stage but can now begin to establish principal processing parameters such as recovery and reagent consumption and start to identify the presence of different ore types.

The final stage of initial testing is usually the collection of a crude bulk sample, the testing of which establishes the process outline, some testing of comminution parameters and, where needed, the application of gravity and oxidation processes.

Final Testing

In this stage it is normal to obtain one or more representative bulk samples and proceed to fine tune the process and fully establish all of the processing parameters required for plant design. Once this is done, the process is then tested, in simplified form, to check the application of the intended process to a variety of ore types, to a range of ore grades, and to a variety of locations within the intended mining area.

CONCLUSIONS

Hopefully, the ideas presented will provide a guide for those engaged in developing and managing metallurgical testwork programs. However, each deposit is unique and so one cannot be too rigid in structuring these programs. Yet, applying forethought and planning can keep the work on track and, with luck, the project will pan out.

This month's article was provided by Richard Addison, one of PAH's ore processing engineers who grew up with a pan in hand and the sound of stamp mills in his ears. He is forever on the lookout for gold in them thar hills! *dick.addison@pincock.com*

TABLE 1
Sample Sources

	Comminution Testing	Slurry Processing	Coarse Gravity Separation	Heap Leaching
Trenches/adits/ declines/shafts	√	√	√	√
Drill core Small diameter	√	√	√	
Large diameter	√		√	√
Drill cuttings		√		
Assay pulps		√		

TABLE 2
Mineralogical Identification and Association

	Ore	Concentrates	Middlings	Tailings
Major mineral types and distribution	√	√	√	√
Particle size and intergrowth	√	√	√	√

TABLE 3
Assaying

	Ore	Concentrates	Middlings	Tailings
Valuable Metals				
Copper	√	√	√	√
Lead	√	√	√	√
Zinc	√	√	√	√
Molybdenum	√	√	√	√
Gold	√	√	√	√
Silver	√	√	√	√
Major Elements				
Iron	√	√		√
Sulfur	√	√		√
Silica	√	√		√
Carbonate	√	√		√
Problematic Elements				
Antimony	√	√		√
Arsenic	√	√		√
Bismuth	√	√		√
Cadmium	√	√		√
Carbon	√	√		√
Chlorine	√	√		√
Copper	√	√		√
Fluorine	√	√		√
Magnesium	√	√		√
Manganese	√	√		√
Mercury	√	√		√
Selenium	√	√		√
Tellurium	√	√		√

TABLE 4
Special Assays and Reagent Consumptions

	Oxide Copper	Secondary Copper	Oxide Gold
Special Assays			
Acid soluble	√	√	
Cyanide soluble		√	√
Reagent Consumption			
Acid	√		
Lime			√
Cyanide			√

TABLE 5
Test Procedures Applied

	Base-Metal Sulfides	Copper-Gold Sulfides	Oxide Copper	Secondary Copper	Oxide Gold	Refractory Gold
Comminution						
Abrasion	√	√	√	√	√	√
Crushing impact	√	√	√	√	√	√
Bond work index	√	√	√	√	√	√
SAG milling tests	√	√		√	√	√
Gravity						
Coarse rock (heavy liquid)	√	√				
Fine rock (tabling)		√			√	
Flotation	√	√		√		√
Oxidation						
Atmospheric				√		
Roasting						√
Autoclave	√			√		√
Biological						√
Slurry Leaching						
Without oxidation			√		√	
Post oxidation	√			√		√
Heap Leaching						
Direct			√		√	
Biologically assisted				√		
Solid/Liquid Separation						
Sedimentation	√	√	√	√	√	√
Filtration	√	√	√	√	√	√

TABLE 6
Test Sequencing

	Sampling	Testing	Objective
Initial	Random	Simple flotation or leach	Establish processability
	Random	Simple flotation or leach	Determine rough processing parameters and existence of different ore types
	Crude bulk	Variety of tests	Establish process
Final	Representative bulk	Fine tuning proposed process	Establishing proposed process
	Variability Testing		
	Variety of ore types	Simple testing of proposed process	Applicability of proposed process
	Range of grades	Simple testing of proposed process	Applicability of proposed process
	Variety of locations	Simple testing of proposed process	Applicability of proposed process

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