PROCEDURE FOR CHARACTERIZATION OF CARBONACEOUS MATTER IN AN ORE SAMPLE WITH ESTIMATION TOWARDS ITS PREG-ROBBING CAPACITY

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ABSTRACT

Carbonaceous matter (c-matter) in sulphide ores can adversely affect the process of gold recovery during cyanidation due to its ability to adsorb, or preg-rob, gold from a cyanide leach solution. This paper describes a standardized procedure for characterization of c-matter in an ore sample providing detailed information on its composition, maturity and preg-robbing capacity. The procedure utilizes the following complementary analytical techniques in conjunction with several chemical tests and assays: SEM/EDX, Raman spectroscopy and TOF-SIMS. Results of the test can be used as a predictive tool to estimate the impact the c-matter will have on the gold recovery process. A comparison between predicted preg-robbing behaviour and cyanidation test results are presented.

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INTRODUCTION

Autoclave pressure oxidation (AC POX) of refractory sulphide ores and subsequent cyanidation is a common technology used to liberate the sub-microscopic gold in these types of ores. A major obstacle for effective gold recovery during this process is the presence in the ores of an active carbonaceous matter (c-matter) which has the ability to adsorb, or preg-rob gold from the cyanide leach solution. Carbonaceous matter present in the Carlin type carbonaceous sulphide ores has shown varying degree of preg-robbing activity [1-3]. In that regard it is important to develop technology and procedures for: the evaluation of the preg-robbing capacity and direct quantitative determination of the surface gold preg-robbed on the carbonaceous matter.

Surface micro-beam analytical techniques such as TOF-LIMS (Time of Flight Laser Ionization Mass Spectrometry) and TOF-SIMS (Time of Flight Secondary Ion Mass Spectrometry) were first introduced for characterization of sorbed gold species on c-matter from CIL tails samples by Dimov et al [4]. Recent development and introduction of a new generation of cluster liquid metal ion sources (Bi^{3+} and Au^{3+}) to the TOF-SIMS instrumentation have led to a dramatic improvement of the detection sensitivities and ability to identify complex compounds with minimum fragmentation. The TOF-SIMS technology provides non-destructive elemental and molecular surface analysis and allows for simultaneous detection and imaging of the distribution of surface metallic gold and gold compounds on individual carbonaceous particles. The quantification of the TOF-SIMS data is based on element and compound specific standards with established detection limits for surface metallic and compound gold in the low ppm range [4].

While it is now possible to quantitatively evaluate and speciate the surface gold preg-robbed on carbonaceous matter from process stream products, it is equally important to develop predictive tools for characterization and assessment of the preg-robbing behaviour of carbonaceous matter in an ore sample. The capacity of carbonaceous material to preg-rob may vary between ores as well as within a single ore body. Currently, as there is no single parameter which can be used to fully describe the preg-robbing capacity of an ore, recovery operations are continuously challenged by this highly variable and significant characteristic.

This paper describes a routine standardized procedure used for characterization of carbonaceous matter in ores. The procedure combines the use of several analytical techniques, tests and assays in order to provide complete information on all the variables affecting the preg-robbing capacity of the carbonaceous matter, namely its composition, maturity and surface area. Standardized doping tests provide an estimate on the maximum preg-robbing capacity. Normalized preg-robbing indices are introduced which more accurately describe the preg-robbing capacity of carbonaceous matter across a set of samples and allow for comparative analysis between different ores or between composite samples within the same ore body. Results from characterization of c-matter in different ore samples and comparison between predicted preg-robbing behaviour and cyanidation test results are presented.

CHARACTERIZATION OF THE COMPOSITION OF CARBONACEOUS MATTER BY SEM/EDX

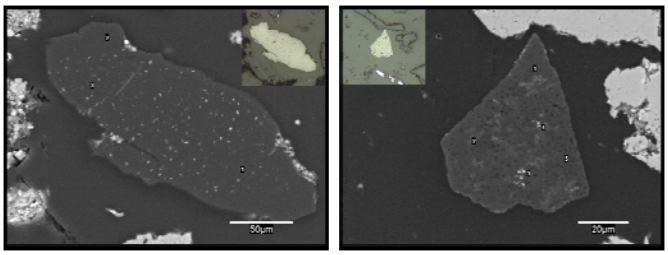
Carbonaceous materials within ore samples are most commonly identified and classified by microscopic examination of cross section grain mounts. For the most part the identification is limited to total carbonaceous material (TCM), grains which consist primarily of carbon with or without inclusions. What is not revealed in this type of examination are other grains which can contain various proportions of carbonaceous material.

Scanning electron microscopy coupled with energy dispersive x-ray analysis (SEM/EDX) is an effective tool for evaluating the various types of carbonaceous materials identified in an ore. Detailed examination of feed ores or various stream products by SEM/EDX can provide valuable information regarding the nature of the carbonaceous materials within the sample. Moreover the samples can be examined in both cross section and as grain mounts, the later providing information regarding surface

coatings or can identify fragments of carbon on the surface of gangue grains. This type if information can be invaluable when reconciling carbon balances between analytical results and those estimates based on optical microscopy.

Two different types of carbonaceous material are usually identified in the carbonaceous ore samples:
i. Total carbonaceous material (TCM) particles which consist of almost 100% carbon and
ii. Disseminated carbonaceous material (DCM) particles: quartz (or other gangue) particles with different degree of finely disseminated carbonaceous matter which will appear black or grey under optical stereoscope. The distribution of the carbonaceous material on these grains is patchy and shows very high variability from grain to grain or from ore to ore.

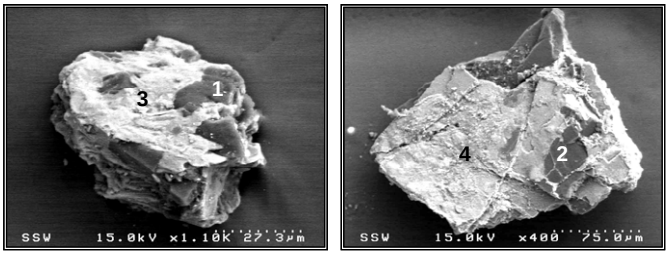
SEM images of optically identified TCM particles (insets) from a feed ore are show in Figure 1. The backscattered electron images (BSE) reveal some variability in composition. EDX analysis of the dark areas on the grains indicates compositions dominated by C, whereas the lighter regions contain variable proportions of Si and Al along with C or, as in the case of Figure 1-B higher proportions of O and Fe. Note the BSE image in B also clearly shows the grain to be porous.



	C	O	Al	Si	S	Fe	As
A Spot 1	80.9	7.2	0.3	0.6	1.9		
A Spot 2	90.4	7.1	0.2	0.5	1.9		
A Spot 3	89.2	7.8	0.3	0.7	1.9		
B Spot 1	85.9	6.8	0.7	0.7	2.5	1.2	2.1
B Spot 2	84.7	7.8	0.6	0.7	2.6	1.3	2.6
B Spot 3	61.6	17.9	0.8	0.7	1.4	15.5	2.1

Figure 1 - Backscattered electron images of TCM particles from carbonaceous ores. The EDX analyses in the tables correspond to the numbers in the images. All EDX data is in weight %

SEM/EDX analysis of cross sectioned gangue grains from feed ores, have also identified carbonaceous inclusions within grains or mineral composites. Examination of grain mounts (not cross sectioned) shows that carbonaceous material can occur as disseminated bands throughout the gangue grain and, when exposed on the surface the carbonaceous material will manifest as a patch of C on the surface of the grain (Figure 2). The appearance of the C on the surface will depend its' position within the grain and upon the nature of the grain or aggregate. It commonly occurs along lines of weakness within the grains, for example fracture or cleavage planes (Figure 2-B). More commonly however the carbonaceous material is found indiscriminately disseminated though out the grains and exposure may be related to natural lines of weakness along grain boundaries.



	C	O	Al	Si	S	Fe	Mg
Spot 1	82.5	17.6					
Spot 2	81.7	17.5		0.3	0.6		
Spot 3		62.1					38.9
Spot 4	29.8	41.4	1.6			3.8	0.8

Figure 2 - Backscattered electron images of DCM particles from carbonaceous ores. The EDX analyses in the tables correspond to the numbers in the images. All EDX data is in weight %. Note the C-matter along cleavage traces in B

Based on the measured proportion of TCM versus the assayed proportion of organic C, the DCM can account for a significant proportion of the total organic C within the sample. Furthermore, this material may be structurally different from the traditional TCM. In several instances structural analysis of the TCM and DCM identified significant differences; the TCM approached the structure of graphitic C whereas the DCM appeared to be more like amorphous C. While structural differences were identified in several instances, for the most part the compositional identity of both the TCM and DCM in most ores is very similar. A discussion on the structural evaluation of the carbonaceous material within ores is given in the Raman section of this paper.

CHARACTERIZATION OF THE STRUCTURE OF CARBONACEOUS MATTER BY LASER RAMAN SPECTROSCOPY

Raman spectroscopy is used to characterize the properties of the carbonaceous materials. The technique uses the shape and width of the detected Raman bands to provide information on the nature of the carbon bonds. The degree of symmetry (or asymmetry) of characteristic Raman bands combined with their shift in wavelength provides information on the structure (maturity or degree of amorphous character) of the carbonaceous material. The characteristic Raman bands for carbon used in this study are from the first order region, 1100-1800 cm^{-1}. The spectra of carbon in this region are characterized by two distinct lines around, 1350 cm^{-1}, (D band) and 1580 cm^{-1} (G band). The relationship between the G (~1600) and D (1350) bands provide the most valuable information on the microstructure of the carbonaceous material.

Given the degree of graphitization or carbon organization of carbonaceous material is one of the main factors controlling Au as cyanide adsorption [6,7], Raman analysis holds the potential as a diagnostic tool capable of differentiating the type of carbonaceous matter and predicting its preg-robbing properties. This new approach, based on the degree of maturity or amorphous character of the carbonaceous material as determined from the Raman spectra, has been discussed by Helm [8]. The variability in degree of maturity covers a large dynamic range: from almost pure graphitic carbon to pure activated carbon and has a large impact on the preg-robbing capacity of the carbonaceous material.

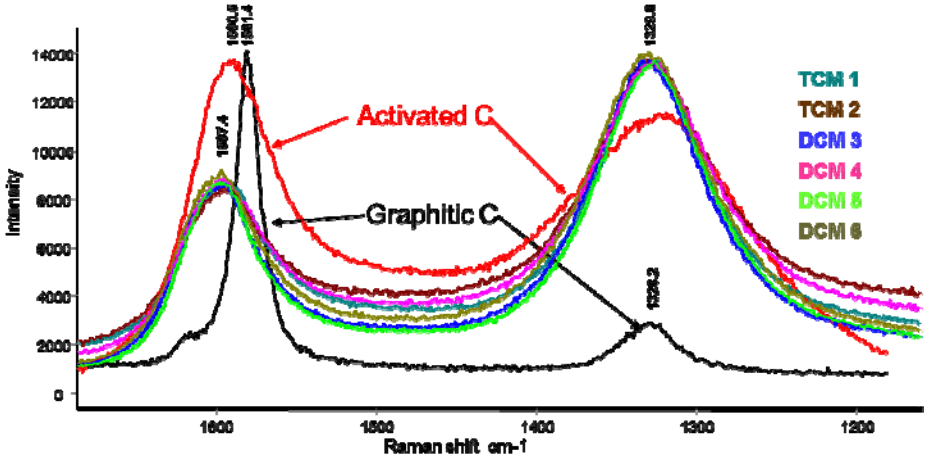


Figure 3 - Raman spectra of undifferentiated carbonaceous material from a single feed ore. Also shown are the spectra of activated carbon and graphitic carbon

Raman spectra of carbonaceous materials from a single feed ore along with the spectra of activated carbon made from coconut and graphitic carbon from a high grade metamorphic terrain are plotted in Figure 3. The most striking feature is that the spectra for most of the grains analysed is similar to that of activated carbon. Detailed examination of Raman spectra from a variety of carbonaceous materials from several different ore types have shown significant variability in the relationship between the D and G bands and which we believe can be used to potentially discriminate the different preg-robbing capacities for carbonaceous material. A similar relationship was presented by Helm [8] where the ability of carbonaceous material to adsorb $Au(CN)_2$ was related to the degree of maturity of the carbon. We have tested a similar technique with mixed results and believe that the classification of the various carbonaceous components needs refinement.

At present, research is being conducted toward developing appropriate deconvolution models which will identify and measure the degree of amorphous character of carbonaceous matter within various ore types. The fitting parameters for the deconvolution of the C spectra in the first order region are modified from the parameters used by Jawhari [9], by, which were based on the spectral variability in the degree of amorphous character in some commercially available carbonaceous materials. The spectral fit parameters are characterized by four distinct lines around, 1350 cm^{-1}, (D band) and 1580 cm^{-1} (G band) along with broad Gaussian bands at 1620 cm^{-1} and 1150 cm^{-1}, the latter are assigned to amorphous carbon Jawhari [9]. The fit constraints were defined by analyzing and fitting the spectra from 10 activated C grains. For accuracy in the determination of the spectroscopic parameters, curve fitting was performed for all spectra. The best curve fit parameters were identified as mixed Gaussian-Lorentzian. The results of these line fit parameters are given in Figure 4. As the variability in type of carbonaceous material is manifested in the characteristics of the D and G bands, the degree of amorphous character can be then calculated from the integrated peak intensity in relation to the peak height, Helm [8].

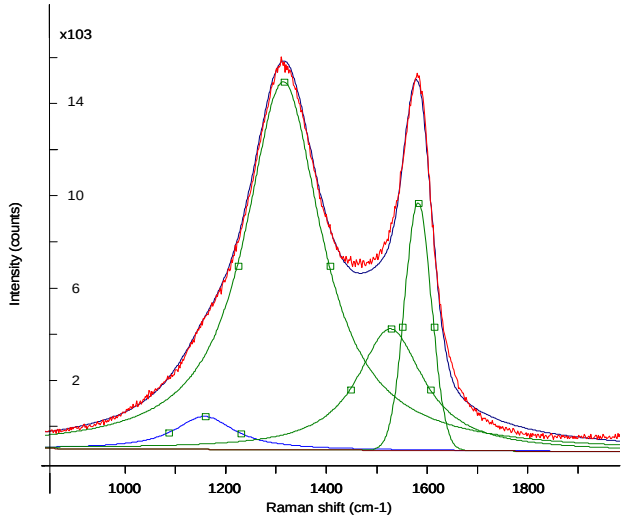


Figure 4 - Raman spectra from activated carbon illustrating the refined fit parameters used in the determination of the degree of maturity or amorphous character of carbonaceous materials present in ore samples

The objective of the ongoing research program are to, through refined peak fitting parameters: i) fingerprint the structure of the different types of carbonaceous materials present in various ore samples, ii) to rank them in terms of amorphous character carbon maturity (order of organized carbon), and iii) to establish the correct relationship between the preg-robbing capacity (as determined by preg-robbing doping tests or by Bottle Roll tests) and the nature of the carbonaceous material. The ultimate aim of the program is to relate the nature of the carbonaceous material in an ore to its potential to preg-rob.

CHARACTERIZATION OF THE PREG-ROBBING CAPACITY OF THE CARBONACEOUS MATTER PRESENT IN THE SAMPLE

Direct evaluation of the preg-robbed Au in ore samples is accomplished by TOF-SIMS analysis and doping tests. The TOF-SIMS technique is used to independently identify and quantify the total amount of surface gold preg-robbed on the C-matter Dimov [4]. In order to achieve an appropriate statistical representation, a large number of individual carbonaceous particles are analysed by TOF-SIMS with detection sensitivity for gold compounds in the low ppm range. A TOF-SIMS spectra on as received and doped with $Au(CN)_2$ carbonaceous particles are shown on Figure 5. The surface nature of the doped $Au(CN)_2$ is demonstrated on Figure 6 where images and spectra in the vicinity of mass 249 ($Au(CN)_2$) are shown before and after sputtering an area on the carbonaceous particle.

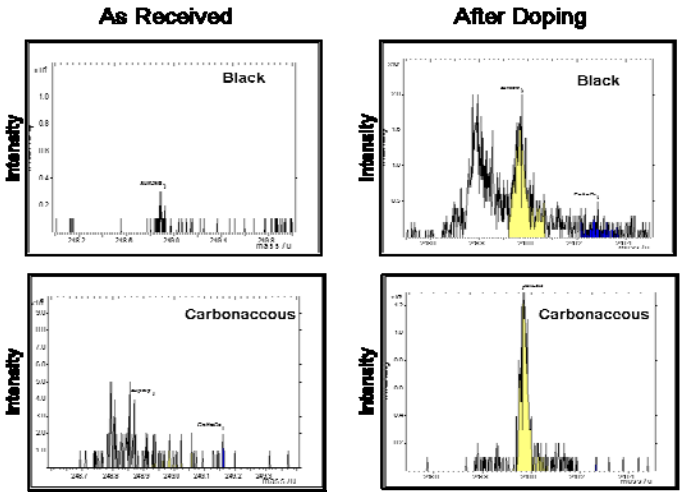


Figure 5 - TOF-SIMS Spectra in the mass region of $Au(CN)_2$ for as received (untreated) carbonaceous grains picked from the feed sample and after doping in 1000 ppm $Au(CN)_2$ solution. Black refers to dark grains with a patchy carbon surface coating (DCM) and carbonaceous refers to TCM material

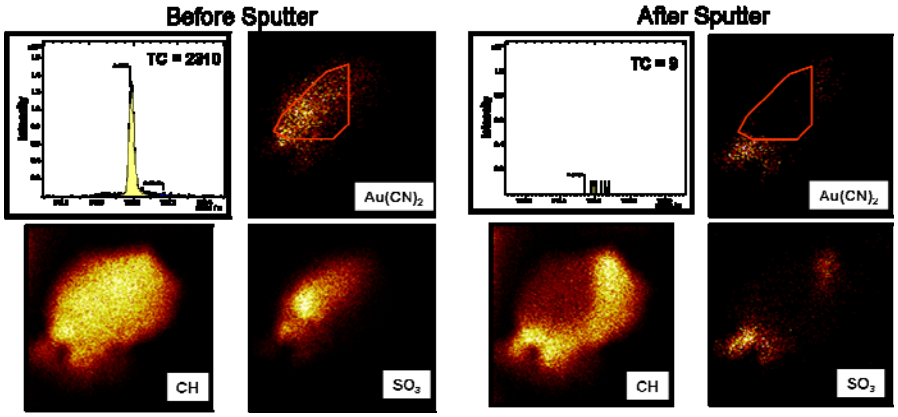


Figure 6 - TOF-SIMS spectra and reconstructed images for selected masses before and after a 20 second sputter with Cs+ ion beam. The spectra and total counts (TC) are data from the region of interest outlined in the polygon defined by the dark area (representing removed material during the sputter) in the CH image

A comparison between preg-robbed $Au(CN)_2$ measured by TOF-SIMS on disseminated carbonaceous particles (DCM) and on total carbonaceous matter particles (TCM) is shown on Figure 7. The data on the left site of the diagram shows the base line established by as received, un-doped carbonaceous matter and pure quartz grains. The data on the right site of the diagram shows the measured preg-robbed $Au(CN)_2$ on the surface of carbonaceous particles after doping with 500 ppm and 1000 ppm cyanide solutions.

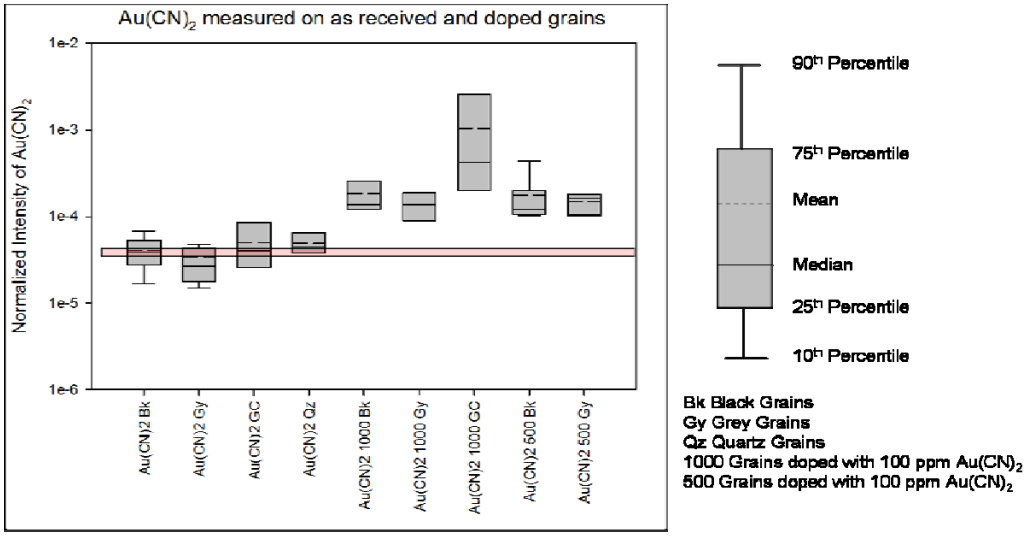


Figure 7 - Diagram showing the normalized intensity of $Au(CN)_2$ measured on the surface of as received carbonaceous particles, reference quartz and doped TCM and carbonaceous silicate (DCM) grains from a feed sample by TOF-SIMS. The data shows the variability in relative surface intensity for $Au(CN)_2$ in relation to the concentration of the doping solution

The TOF-SIMS data show a significant variability in the amount of preg-robbed surface gold on carbonaceous grains. This is largely due to the variable amount of disseminated carbon present or exposed on the surface of various grains. Figure 8 shows Pearson product moment correlation coefficients (r) for the TOF-SIMS data from 500 ppm doped feed sample carbonaceous grains. The diagram illustrates the statistical correlations between the preg-robbed surface gold on carbonaceous matter measured by TOF-SIMS with the presence of carbonaceous material in the feed sample. The correlation data clearly demonstrates the positive relationship between elevated levels of C (surface area of carbonaceous material) as indicated by species containing C (for example C, C_2, C_2H, C_4H…) and preg-robbed surface gold in the form of $Au(CN)_2$. The diagram also shows that $Au(CN)_2$ is negatively correlated with Si and Fe indicating a negative spatial relationship of Au components with non carbonaceous gangue mineral phases.

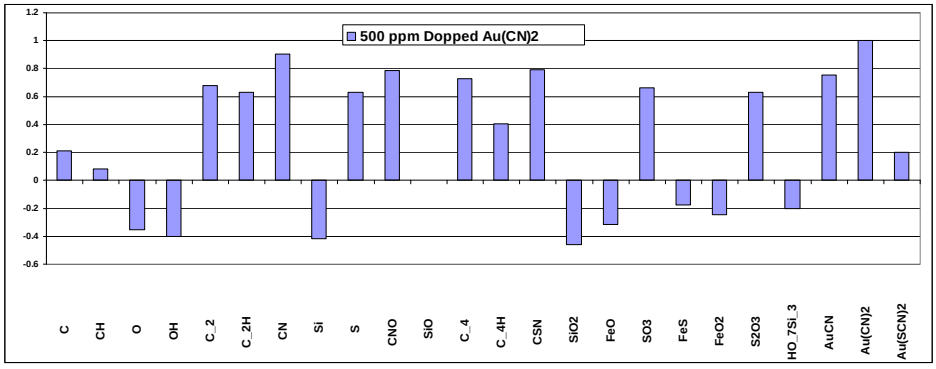


Figure 8 - Pearson product moment correlation coefficients (r, on the Y-axis) for the TOF-SIMS data for the 500 ppm doped carbonaceous grains in the feed sample. The correlation data clearly illustrate the positive relationship between elevated levels of surface area of carbonaceous material (as indicated by species containing C; for example C, C_2, C_2H, C_4H) and preg-robbed surface gold in the form of $Au(CN)_2$

An evaluation of the maximum preg-robbing capacity of the sample containing carbonaceous matter is done through doping tests using controlled amounts of $Au(CN)_2$ in solution. These standardized tests are performed on as received ore samples as well as on different size fractions in order to establish their specific contributions. When working with size fractions the samples are panned to remove the sulphides. The amount of preg-robbed surface gold in these doped samples is determined as a difference between the Au assayed values in the as received and doped samples for each corresponding fraction. Very similar Au assay values for preg-robbed gold in samples doped with 500 ppm and 1000 ppm $Au(CN)_2$ solutions indicate saturation levels of preg-robbing, hence a level of maximum preg-robbing capacity of the carbonaceous matter in this sample. The determined maximum preg-robbing capacity of the carbonaceous matter from doping tests provides an important insight on the expected behaviour of this ore during the process of gold recovery.

Table 1 - Estimated preg-robbing capacities from standardized doping tests and the corresponding normalized preg-robbing indices for different carbonaceous ore deposits

Sample I.D.	Origin	Size fraction	Estimated preg-robbing capacity g/t	TOC wt%	BET m^2/g	Preg-robbing indices	
						Normalized to TOC	Normalized to BET
Composite 1	Europe	Not sized	4.2	1.19		3.53	
		150-38	3.8	0.54	1,72	7.04	2.21
		38-20	4.63	0.18	2.84	25.72	1.63
Composite 2	Europe	Not sized	3.1	1.3		2.38	
		150-38	1.7	0.54	0.83	3.15	2.05
		38-20	4.53	0.05	1.84	90.60	2.46
Composite 3	Europe	Not sized	4.6	1.82		2.53	
		150-38	5.36	0.65	1.09	8.25	4.92
		38-20	9.41	1.70	2.15	5.54	4.38
Composite 4	Europe	Not sized	1.7	1.11	2.87	1.53	0.59
		150-38	0.5	0.49	0.9	1.02	0.56
		38-20	0.59	0.15	1.35	3.93	0.44
Composite 5	Europe	Not sized	1.3	1.04	2.18	1.25	0.60
		150-38	0.5	0.45	0.79	1.11	0.63
		38-20	0.3	0.13	1.28	2.31	0.23
Composite 6	Europe	Not sized	3.6	1.46	2.27	2.47	1.59
		150-38	1.6	0.61	0.88	2.62	1.82
		38-20	1	0.19	1.15	5.26	0.87
Composite 7	Europe	Not sized	4.3	1.57	3.49	2.74	1.23
		150-38	2.1	0.54	0.86	3.89	2.44
		38-20	1.5	0.18	1.5	8.33	1.00
Composite 8	Europe	Not sized	9.8	2.48	3.49	3.95	2.81
		150-38	2.79	0.72	1.13	3.88	2.47
		38-20	3.53	0.27	1.75	13.07	2.02
Composite 9	North America	Not sized					
		150-38	7.52		1.33		5.65
		38-20	11.15		2.35		4.74
Composite 10	North America	Not sized					
		150-38	20.64		1.55		13.32
		38-20	19.46		3.17		6.14
Composite 11	North America	Not sized					
		150-38	7.56		1.67		4.53
		38-20	6.62		1.76		3.76
Composite 12	North America	Not sized					
		150-38	99.13		3.12		31.77
		38-20	86.78		3.34		25.98

The degree of preg-robbing will be determined by several different parameters:

i) TOC: The total organic carbon content in the sample is assayed by a standard Leco analytical procedure
ii) Surface area: The "exposed" surface area of the carbonaceous matter on the DCM and TCM particles determined by BET surface area analysis
iii) Nature (maturity) of the carbonaceous material characterized by Raman spectroscopy.

In order to study the effect of the TOC, BET surface area and the size distribution on the preg-robbing capacity, a set of samples is subjected to doping tests, BET and TOC analysis. For comparative analysis of samples from different ore deposits or, different composites within one ore deposit, normalized preg-robbing indices using the total organic carbon (TOC) and BET surface area measurements are introduced.

The determined values for carbonaceous ore samples from several operating mines are summarized in Table 1. It includes the assayed values for TOC and BET surface data in as received and sized fractions, the maximum preg-robbing capacities estimated from doping tests in 1000 ppm $Au(CN)_2$ solution and the corresponding preg-robbing indices based on normalization to the TOC and BET values.

The data illustrate a number of important considerations:

- for the samples examined, the TOC is not necessarily higher in the finer fractions.
- for all the samples in the data set, BET is higher in the finer fractions.
- the determined maximum preg-robbing capacities for the set of 12 composite samples show up to 200 times difference: from 0.5 g/t (composites 4 and 5) to 99.13 g/t (composite 12), while the corresponding assayed values for TOC and BET surface data vary in much narrower range. This implies that the maturity of the carbonaceous material present in these samples may play a substantial role in the kinetics of the gold-cyanide complex sorption to the relatively fine grained carbonaceous matter naturally present in these carbonaceous ores.
- the estimated preg-robbing capacity when normalized to TOC is always over estimated relative to the sized samples and shows a large variations across the sized fractions
- the estimated preg-robbing capacity when normalized to BET is similar to the estimated capacity for the not sized or as received sample and shows the least variation across the sized fractions for each sample.

The data so far suggest that size fractioned preg-robbing estimates are most representative of the adsorption capacity of the sample when normalized to BET values as the these are more influenced by the adsorption capacity of the disseminated c-matter within the material as opposed to other minerals such as sulphide or silicates.

CASE STUDY ON APPLICATION OF THE STANDARDIZED PREG-ROBBING TEST

Five different sulphide concentrate composite samples from a carbonaceous ore deposit were chosen for this study. These samples are characterized by different contents of TOC and gold recovery by cyanidation (Table 2)

Table 2 - List of samples with their TOC and recovery characteristics

#	Sample I.D.	
1.	4526	Sulphide concentrate : Low TOC, Low Recovery
2.	4527	Sulphide concentrate : Low TOC, High Recovery
3.	4528	Sulphide concentrate : Average TOC, Low Recovery
4.	4529	Sulphide concentrate: Average TOC, High Recovery
5.	4530	Sulphide concentrate: High TOC, Low Recovery

The study was performed in order to examine the preg-robbing capacity of the samples. Given the variability in TOC and Au recovery as indicated in Table 2, the study was carried out on as received and sized fractions in order to address some questions related to the distribution of TOC with respect to different size classes and if this has some bearing on Au recovery in the cyanidation process.

Sample Preparation

Equal amounts of all five feed samples (500 g/sample) were wet sieved into 4 size fractions: +150 μm, -150+38 μm, -38+20 μm and -20 μm. Using gravity separation (carried out by super-panning), tail samples from two size fractions of the feed samples (-150+38 μm and -38+20 μm) containing mainly silica grains and carbonaceous particles were produced. Small portions of -150+38 μm and -38+20 μm panned feed tails size fractions along with as received and the -20 μm fractions were sent for BET surface area measurements and assayed for TOC. Following a routine standard procedure portions of the as received feed samples and from panned tails for size fractions -150+38 μm and -38+20 μm were doped with gold cyanide, $Au(CN)_2$ solutions at concentrations of 500 ppm and 1000 ppm. The as received samples and the doped samples were assayed for Au along with quality control reference samples.

For simplicity data for only three of the 5 samples analysed are shown in Figure 9. They are included for illustration and reflect for the most part the characteristics of all samples analysed. The relative mass distribution per size fraction is given in Figure 9-A. The feed samples have similar mass distribution with roughly 40%-50% of the material in the -20μm size fraction and 30-40% is within size fraction -150+38 μm. The relative distribution of the **TOC** content (Figure 9-B) in the corresponding size fractions closely resembles the mass distribution in these samples indicating relatively homogeneous distribution of the TOC within the mineral grains. One notable exception was observed in the -20 μm size fraction in sample 4530 which is substantially richer in carbonaceous matter.

A comparison between the assayed values for TOC and BET surface area for the corresponding fractions in the feed samples shows no systematic similarity (contrary to the observed similarities in the relative mass and TOC distribution), Figure 9-C and D. The difference is especially pronounced for the as received (not shown on Figure 9) and -20 μm fractions which show significantly higher BET values in all samples**.** While the TOC distribution seems to be relatively homogeneous within the mineral grains, the BET surface area is determined by the level of exposure of the carbonaceous material and this have different contributions for the sized fractions. Another possible reason for these differences is the fact that, in addition to carbonaceous matter, other species such as fines from clays and other minerals may be contributing to the assayed BET surface areas for the as received and -20 μm fraction**.**

All feed samples showed preg-robbing capacity. A comparative diagram of the estimated preg-robbing capacity for each feed sample (broken down to different fractions) is presented on Figure 10-A. The data show substantial differences in preg-robbing capacity among the different fractions within each feed sample and as well as between the five feed samples.

The -20 μm size fraction contributes strongly to the preg-robbing capacity in all samples due to the large proportion in the relative mass distribution (Figure 9-A), high TOC content and large surface area (5-10 times larger compared to other size fractions) (Figure 9-B). This is particularly evident for the feed sample 4530 where the mass proportion of this material is on the order of 50 %, and which contains a relatively high TOC content (~55%). Consequently this sample also showed the lowest rate of Au recovery (69.3%).

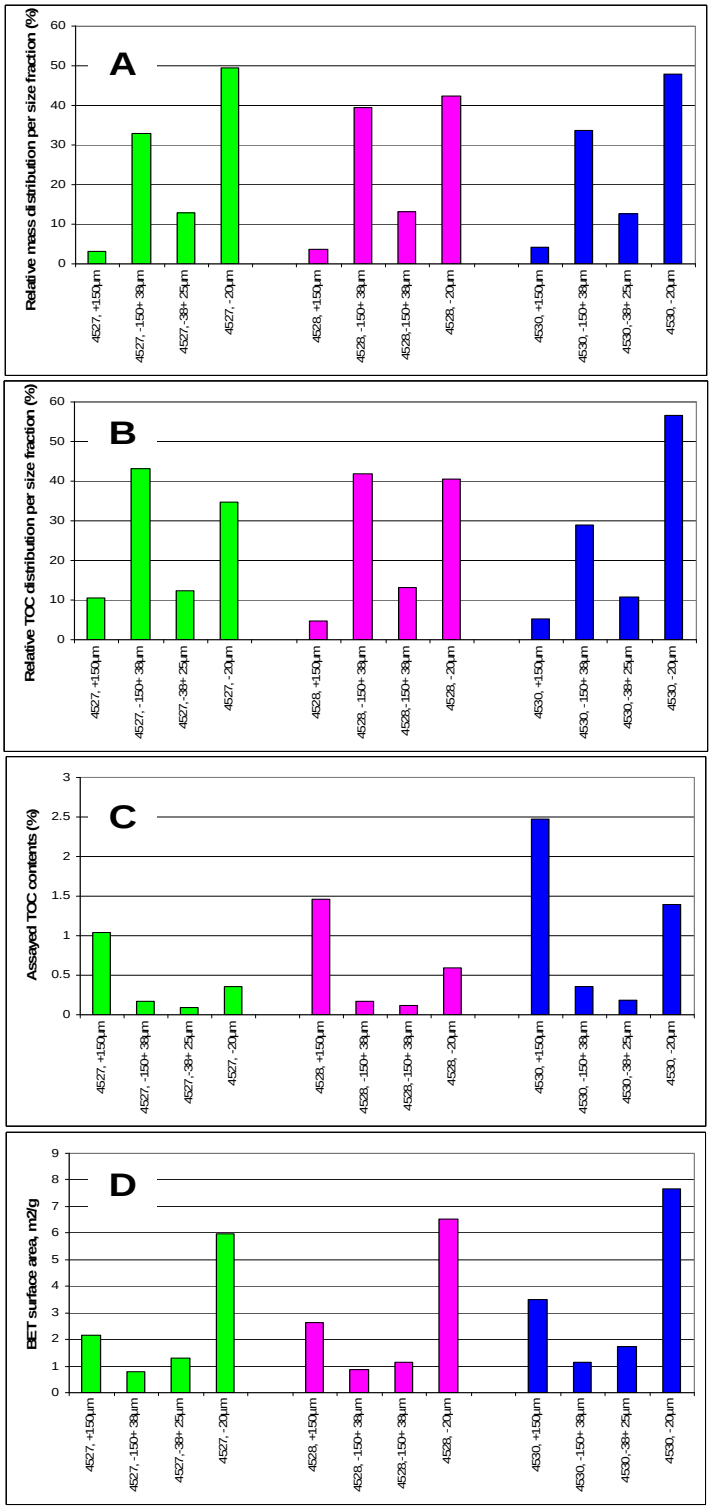


Figure 9 - A Comparative diagram for three of the five feed samples: A. the relative mass distributions per size fraction. B. the relative TOC distributions per size fraction, C: the assayed TOC content in selected fractions. D, measured BET surface area in selected fractions **Note:** The TOC data shown in B are for as received, not super-panned size fractions and reflect the assayed whole content of TOC in these fractions

In order to establish more objective preg-robbing index for the carbonaceous matter the raw data from the preg-robbing tests were normalized by the TOC content and by the BET surface area assayed for each of the studied samples. These new preg-robbing indices are shown on the comparative diagrams in Figures 10-B and C, respectively. The normalization results are very different. The estimated preg-robbing indices based on the TOC normalized data in some instances show large variations (> 5 times) among the different size fractions when compared to the values of the corresponding BET normalized preg-robbing indices. We believe that this discrepancy is largely related to the difference between the information provided by these two parameters. Assays for TOC evaluate the proportion of carbon within the sample regardless of the TOC surface properties/accessibilities which are associated to its capacity to preg-rob. The tests suggest that much of the assayed carbon may not be available for preg-robbing and likely resides within grains which are not accessible to leachate. The BET analysis on the other hand reflects the surface adsorption capacity of the material and, as such, provides a much better estimate of the effective surface area available for leachate interaction and potential preg-robbing. From the data shown it is evident that the normalized by the BET preg-robbing indices more accurately represent the preg-robbing characteristics of carbonaceous matter across the set of samples analyzed and provide more objective basis for comparison.

Cyanidation bottle roll tests on the five feed samples (after pressure oxidation) provided different gold recovery levels. The estimated values of Au losses are summarized in Table 3 and they vary within 10-30% range.

Table 3 - Cyanidation Bottle Roll test data

	Feed 4526	**Feed 4527**	**Feed 4528**	**Feed 4529**	**Feed 4530**
Bottle Roll (BR) Dissolution,%	78.93	89.19	78.85	89.50	69.27
Au losses , %	21.07	10.81	21.15	10.5	30.73

The established preg-robbing capacities/indices for the 5 feed samples are compared with the bottle roll test recovery data in Figure 12-A, B and C. With a notable exception of Feed 4529 there is a very good correlation between the trends of determined preg-robbing characteristics of these feed samples and the established gold recovery/losses data from BR tests. Although a direct comparison in absolute values between the estimated gold losses from BR tests and preg-robbing doping tests can not be done in this particular case (preg-robbing tests on the sulphide concentrate feed samples versus the bottle roll tests on the POX discharge samples) the similarity in the both trends suggests that a major reason for the variation in the BR recoveries is the impact of the carbonaceous matter present in these samples.

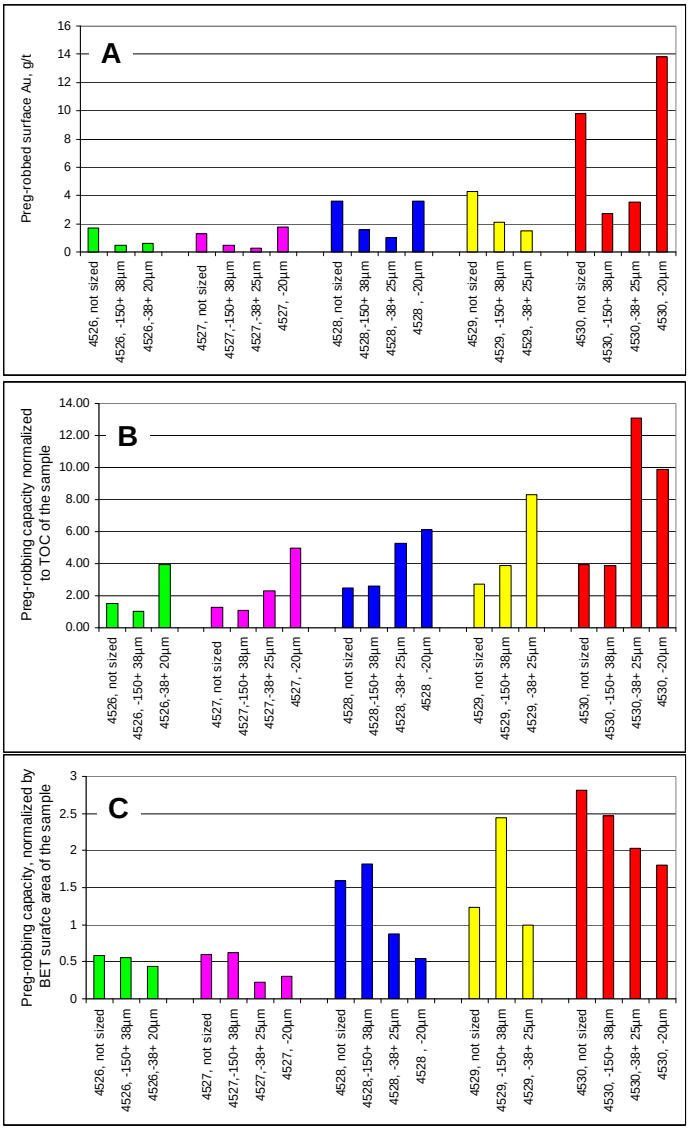


Figure 10 -. Comparison between A: the determined maximum preg-robbing capacity of carbonaceous matter from 4526, 4527, 4528, 4529 and 4530 feed samples doped with 1000 ppm solutions of $Au(CN)_2$ B: Estimated preg-robbing capacities values (preg-robbing indices) normalized to TOC for each sample. C: Estimated preg-robbing capacities values (preg-robbing indices) normalized to BET surface area for each sample

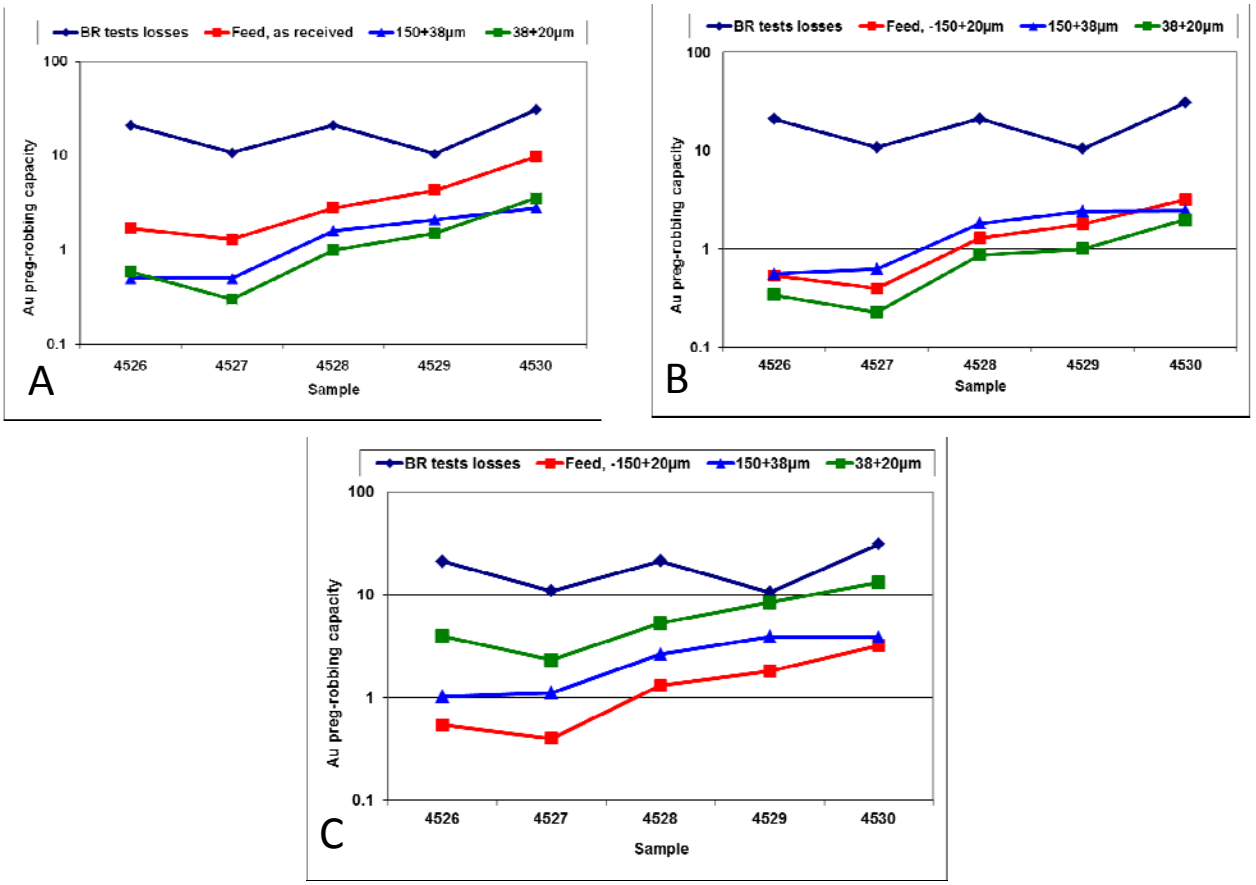


Figure 11 - Comparative diagrams between determined preg-robbing capacities and Au losses data from cyanidation Bottle Roll tests. Data for BR tests (gold losses in %) and for doping tests (maximum preg-robbing capacities and normalized preg-robbing indices) not scaled. A: As received, data from the doping tests has not been adjusted, B: Normalized to the BET, data from the doping tests are normalized by BET, C: Normalized to the TOC, data from the doping tests are normalized by TOC surface area

CONCLUSIONS

This paper describes technology and procedures for diagnostics of carbonaceous matter with regard to its preg-robbing characteristics and the effect it may have on the process of gold recovery by cyanidation. Two different aspects of the problems related to preg-robbing of carbonaceous matter were addressed; i) developing of proper techniques and procedures for predictive analysis and ii) accurate evaluation of the preg-robbed surface gold using a quantitative surface analysis by TOF-SIMS. The reported standardized procedure for characterization of carbonaceous matter in relation to its preg-robbing capabilities aims to bring insight into all relevant parameters affecting the preg-robbing behavior of c-matter: its composition and distribution, degree of maturity/degeneracy and maximum preg-robbing capacity. The estimated preg-robbing capacities of carbonaceous matter for a set of 12 composite samples from commercial mines exhibited a large dynamic range and differences up to 200 times. Given the fact that the corresponding range of TOC and BET surface area values for this set of samples covers far narrower range, it is assumed that a crucial parameter defining the preg-robbing capacity is the maturity or the degree of degeneracy of the naturally occurring ore carbon.

The Raman technique allows us to fingerprint this carbon structure and it is expected that with the development of appropriate deconvolution models, this technique could identify effective markers for predictive analysis of the preg-robbing behaviour of the carbonaceous material.

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