DYE PENETRATION TECHNIQUES USED TO DETERMINE HEAP LEACH POTENTIAL OF A TELLURIDE BEARING CRIPPLE CREEK BRECCIA ORE

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ABSTRACT

The Cresson gold deposit is located in the Cripple Creek district of Colorado. The deposit is composed of volcanic intrusive rocks and volcanogenic sediments where gold mineralization is associated with veins and cavities within a diatremal breccia.

The purpose of the current study was to:

1. Determine the penetration potential of the Cripple Creek Breccia.
2. Assess the relationship between penetration and gold recovery within the Breccia.

Two methods were applied using a cyanide solution containing ultraviolet sensitive dye to elucidate pathways of penetration within the rock. The first involved stagnant soaking of two-inch square pieces within the solution. The second method involved column leaching of ~100kg of Breccia crushed to P_{80} 12.7 mm (0.5 inch). Samples were selected at specified intervals to capture the penetration progress of the solution. Photomicrographs and image analysis were utilized to illustrate and quantify the degree of penetration.

Results indicated that the maximum penetration for the Cripple Creek Breccia (85 to 97%) due to a porous and permeable groundmass, containing large non-porous lapilli fragments. In addition, ~90% of leachable gold was recovered with only ~50% rock penetration.

INTRODUCTION

Dye penetration studies were first developed at SGS for the purpose of determining the fluid penetration amenability of differing rock types. The method was to place a large rock or drill core in a pan with 1 to 2 inches of a pre-mixed, water based fluorescent dye. The sample was sequentially cut after prescribed time periods to reveal a fresh surface. The cut surface was photographed under long wave ultraviolet light, and the same piece returned to the dye and allowed to sit until the next prescribed cutting.

Subsequent applications revealed that the repeated use of the same rock sample added errors including variable volume difference of the sample over time and the potential for increased fracturing due to repeated cutting, both possibly biasing the penetration results. Moreover, the use of a pre-mixed dye with a differing chemistry and physical properties than a typical cyanide or sulphuric leach solution may not effectively represent processes occurring in a heap or column leach test program. Analytical correlation was also not possible due to the lack of an appropriate solution reagent.

It was determined that a new technique was needed to better study the patterns and quantify the penetration in a typical reagent. The pre-mixed dye was replaced with a fluorescent additive to the reagent. The procedure for preliminary studies was also adjusted to allow complete submergence of more than one rock piece allowing only one cut per piece as well as a larger statistical representation. Further procedural modifications were then made to adapt this technique for use in column leach studies. These techniques now integrate metallurgical evaluation of the ore with evaluation of the ore with concurrent petrologic and mineralogical studies. Correlation of this integrated data provides a better understanding of controls on heap leaching, as is demonstrated for this deposit.

The test work procedures and results described below utilize sodium cyanide solution containing an ultraviolet fluorescent dye.

CRIPPLE CREEK DEPOSIT GEOLOGY

The Cripple Creek district in Colorado is composed of an irregularly shaped basin of sub-volcanic intrusions and volcanogenic derived sediments. The intrusion lithologies include syenite, tephriphonolite, phonolite and lamprophyre (an ultramafic alkalic rock). The deposit is hosted in a diatremal breccia pipe containing clasts of most district rock types, as well as the granitic wall rocks. Small bodies of lamprophyre occur as local intrusions within the pipe.

Preliminary petrologic analysis of the Cripple Creek Breccia (CCB) ore tested has indicated two differing alteration types within the breccia. The first is a more sericitic (phyllic) alteration of the breccia matrix and the second being of more carbonaceous (propylitic) origin.

Historically, gold mineralization has been associated with cavities that range in size from a few millimeters to more than 10's of meters. In the early 1900's it was noted that more than 1800kgs of gold was produced from one very large cavity (Saunders, 1986). Within the sample tested gold appeared to report interstitially to breccia fragments near pore spaces within the groundmass. Gold-bearing minerals in the breccia include calaverite, krennerite, montbrayite, petzite, sylvanite, hessite, steutzite, electrum and native gold. Mineralogical examinations have determined that up to 90% of the gold occurs as calaverite and krennerite. All gold-bearing phases illustrate a strong association with porosity and permeability in the breccia matrix.

TEST DESCRIPTION

SUBMERGENCE SINGLE BLOCK TESTS

In submergence tests, various rock pieces are placed within a dye enhanced sodium cyanide solution. Samples are cut into 51 mm (~2 inch) cubes and allowed to soak in the cyanide solution for periods of 8, 16, 32, 62, 128, and 256 hours. Samples of the reagent solution are also removed for gold analysis. Upon removal from the solution, the sample is sectioned in half and the exposed interior is photographed under ultra-violet light. The images are then processed using an Automated Digital Imaging System (ADIS) in order to quantify the area penetrated of the sample face. Figures 1 through 4 illustrate the penetration patterns observed on the exposed interior of the blocks from the CCB sample. The white areas are the fluorescing dye under ultraviolet light (white star), whereas the darker areas are un-penetrated portions (white arrow). Concentric and diffuse penetration is observed in Figures 1 and 3, whereas a patchier, concentrated pattern closely associated with porosity (Figure 2) and veining (Figure 4) are observed along with a slight concentric pattern in the remaining photographs.

Preliminary work can give a cursory determination of the penetration on a limited scale. Analytical / metallurgical correlation is, however, poor due to the statistical representation of the ore. This can give some idea of structural trends and penetration patterns seen in a larger column or heap situation and a cursory penetration versus time curve can be generated for differing rock types.

COLUMN TESTS

ColumColumn leaching in conjunction with dye penetration study integrates metallurgical, analytical, and mineralogical evaluations to quantify metal recovery and penetration over time, as well as geological and structural controls on leaching. Sampling of rock fragments is carried out during the column test, with approximately 500 grams of material being extracted from the column each time the solution is sampled. A representative selection of the largest rock fragments are sectioned in half and photographed for image processing.

Figure 5: Photograph illustrating evidence of solution flow with dye added within hours of starting (Dashed line indicates solution horizon – solution on right / dry on left)

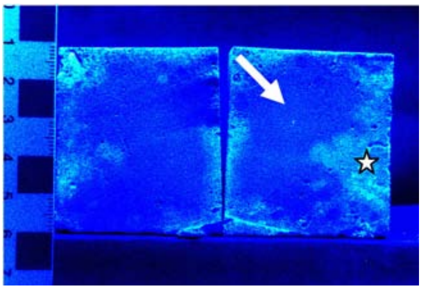

Figure 1: CCB 8 hours

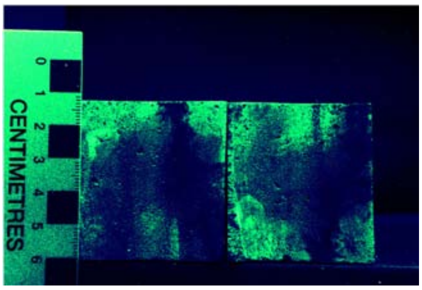

Figure 2: CCB 16 hours

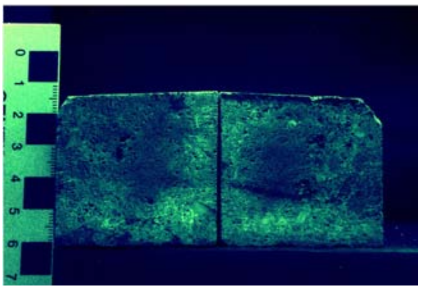

Figure 3: CCB 64 hours

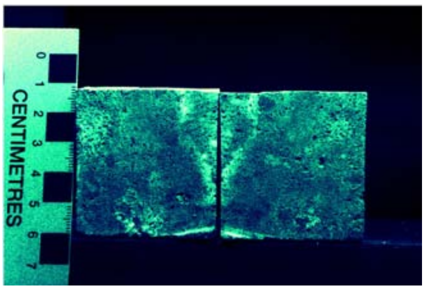

Figure 4: CCB 256 hours

Figure 6: Photograph of column window on Day 2 before sample removal.

The advantage of using the column leach test is the direct correlation between penetration and recovery. Due to the large volume and natural shape factor of the rock fragments, a better representation of fluid behavior into the particles is established. This sampling of the column material can also allow for a mineralogical characterization of the target mineral dissolution during the test. Figure 5 illustrates the initial flow of dyed solution during the initial introduction into the column (~ 2 hours). A dashed line indicates a break in the pathway of the solution where the upper portion has been initially wetted and the lower third is still dry. Figure 6 portrays the column window after 2 full days of solution introduction where the material viewed in the column window is completely wetted.

RESULTS

SUBMERGENCE DYE PENETRATION TESTS ON CRIPPLE CREEK BRECCIA

One large rock of CCB weighing approximately 10 kg was sectioned into 24, 51 mm square cubes. The sample was described as porous, loosely cemented, vuggy breccia, exhibiting partial oxidation to goethite and iron stained siliceous material. Lapilli fragments ranged in size to as large as 30 mm across. The vugs ranged in size from 4 to 20 mm across. Minor, random fracture patterns patterns connect the various vugs. Extensive fine pore spaces also occur within the breccia matrix. Sulphide mineralization occurs as fine disseminated sulphides (mainly pyrite).

Three, two inch cubes were suspended in separate containers of 2 g/tonne sodium cyanide solution mixed with the fluorescent dye in order to allow maximum penetration. Each container was marked for sample removal at specified times of 8, 16, 32, 64, 128, and 256 hours. At the end of the corresponding times, samples in that container were removed. Each cube was sectioned in half, photographed and described. Digital images were analyzed using ADIS software to determine the penetrated area.

Results indicated penetration into the breccia was diffuse, uniform and concentric. The nature of the lapilli fragments as well as veins of goethite and iron-stained material limited penetration. The uniform concentric penetration is a function of the overall matrix porosity. Gold extraction from these suspended samples was inconclusive since the penetrated solution was not displaced out of the particles in this non-agitated system. Therefore, to obtain a better correlation between solution penetration and gold extraction, the next step was to incorporate these findings into a column leach test.

COLUMN CYANIDATION TESTS UTILIZING FLUORESCENT DYE

A 195 kg bulk sample of CCB was submitted for dye penetration - column tests in order to determine the relationship between penetration and gold recovery. The test program included column cyanidation of 126 kg sample of P_{80} 12.7 mm ore with the active solution containing an established amount of fluorescent dye and a sodium cyanide concentration of 0.5 g/l. Samples of rock fragments and solution were sampled after 2, 4, and 7 days and once a week thereafter until maximum gold recovery was achieved.

Several fragments were selected from each sample period, each being sectioned and photographed. Each photograph was analyzed using ADIS in order to determine the surface area penetration of the exposed interior as previously described.

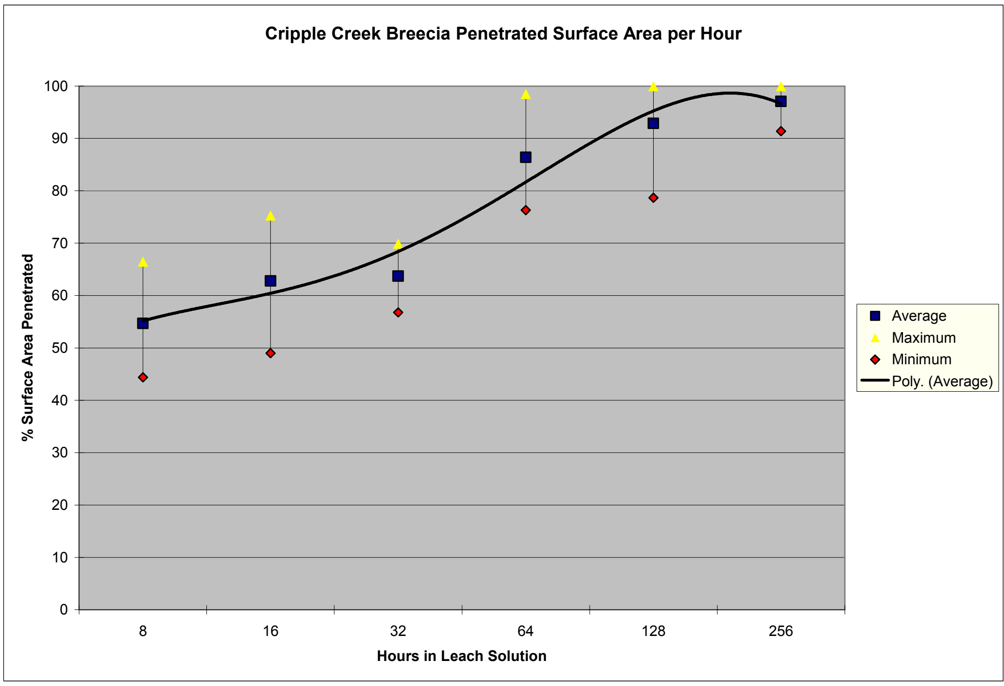

Figure 7: Penetration vs. Time for CCB

RESULTS FROM THE DYE-COLUMN TEST

The penetration results from the column test revealed four key characteristics of the breccia penetration:

- Two differing breccia types were observed; one porous and the other consolidated, recognized as differing alteration facies.
- Penetration is a function of porosity / permeability. Only minor amounts of fracturing or veining were observed in the samples.
- Depending on the sample orientation, there appears to be more intense penetration on the top sides of the sample than the bottom of the sample reflecting the downward movement of solution in the column.
- Maximum gold recovery can be correlated with a minimum penetration area at a specified time.

Macroscopic examination of the rock fragments identified rock types to be either porous or consolidated. Intermediate types were assigned according to the most prominent characteristics observed. This data was used to sort the penetration data for each rock type which allowed separate plotting of the data to identify the penetration characteristics. Figures 8 through 14 illustrate typical penetration patterns for selected days. Vugs and porosity are observable in Figures 9, 10, and 14 (white arrow) whereas large lapilli fragments are evident Figures 12, 13, and 14 (white stars). Diffuse and concentric penetration is characteristic of the primarily homogenous fragments (Figures 10 & 11) and is accentuated by structures such as densely concentrated pore spaces or vugs (Figure 9 and 13) and limited by consolidated non-porous lapilli fragments (Figures 12, 13, and 14)

Maximum penetration in the consolidated rock type occurs on Day 63 achieving a maximum of 80% area. In contrast, the porous rock type achieved 80% penetration 21 days earlier. Petrographic examinations reveal the difference between rock types is potassic vs. carbonaceous alteration of the rock matrix. This distinction is also observed on a larger scale within the deposit. The "porous" members were observed to be comprised of lapilli-sized fragments of microcline feldspar within a groundmass of adularia. These feldspar minerals were strongly altered to sericite and clay minerals, demonstrating partial to complete replacement of these fragments. "Consolidated" members of the data set were also composed of lapilli-sized fragments of microcline feldspar, altered to adularia within a fine groundmass of adularia; minor amounts of sericitic and clay alteration of the

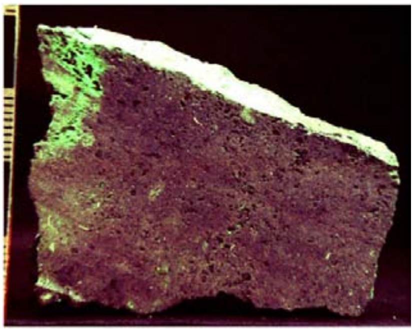

Figure 8: Day 4 Consolidated Breccia

Figure 9: Day 14 Vug in Porous Breccia

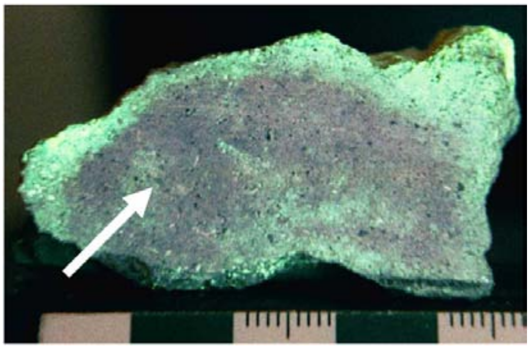

Figure 10: Day 21

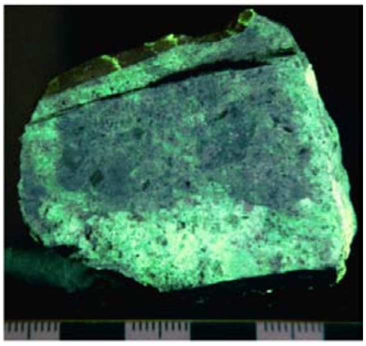

Figure 11: Day 35

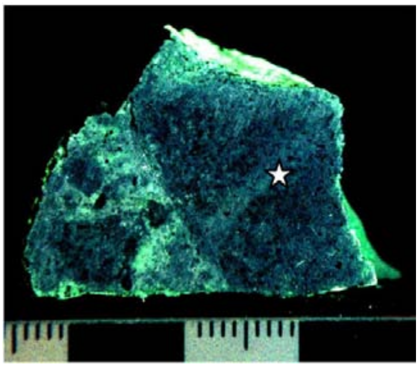

Figure 12: Day 56

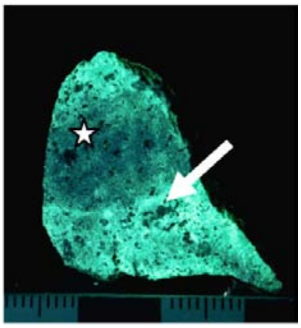

Figure 13: Day 77

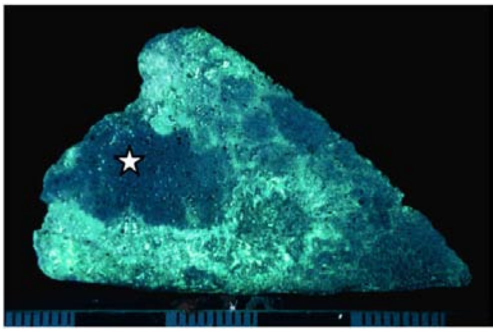

Figure 14: Day 92

feldspar fragments were observed. Ankerite was common lining pore spaces and was also observed in minor amounts within the groundmass and lapilli fragments.

As in the preliminary submergence data the penetration patterns were mainly uniform, diffuse and concentric patterns. Structures, such as veining and fracturing, were observed in only a minor amount of samples taken. Fine pore spaces and large vugs were more common and have a greater effect on penetration. Porosity measurements measured from polished thin section by ADIS indicate that the pore space can represent up to 5% of the fragment surface. When the data was sorted according to "porous" and "consolidated" fragments, porous particles ranged between 1 and 5% porosity, and the non-porous particles ranged from 0.4 to 0.5%

The correlation between penetration data and gold recovery allows for a quantitative evaluation of the mineralogical controls effecting penetration. Figure 15 illustrates the recovery / penetration vs. time curve which identifies a maximum gold recovery of 25% is achieved with a maximum penetration of 85% at Day 70. It can be interpreted from this curve that 23% gold recovery is attained at Day 49 with 60% penetration of the rock.

Overall gold recovery appears to be a function of mineral type as opposed to association and deportment. The association of gold with pore spaces allows for rapid access of dissolution fluids to the mineralization. The preponderance of calaverite and krennerite in this ore limits the amount of recoverable gold in a reasonable time frame. This particular ore was tested due to the refractory nature relative to other ores of differing gold host mineral proportions. The amenability of telluride minerals in a heap leach process to cyanidation requires more research, but these tests provide important insights.

Preliminary mineralogical data suggests the native gold and Au-Ag-telluride dissolution order as follows: native gold, electrum, and petzite, followed by hessite, stuetzite, sylvanite, and lastly krennerite and calaverite. While gold dissolution was the primary focus of the test work, the indication that silver, and gold-silver tellurides, leach preferentially to gold-tellurides in this particular sample was enlightening. Unfortunately, silver assays were not conducted on column leach test effluents rendering species – kinetics evaluation inconclusive. However, similar findings are documented by Henely et al. (2001) during a detailed investigation of the stability of native gold and Au-Ag-tellurides in a cyanide solution. Their observations support the order of dissolution as observed in this testwork where native gold is initially leached followed by high silver bearing Au-Ag-tellurides (petzite –hessite). Calaverite was found to be "very refractory" to cyanide solutions (Henely et al., 2001).

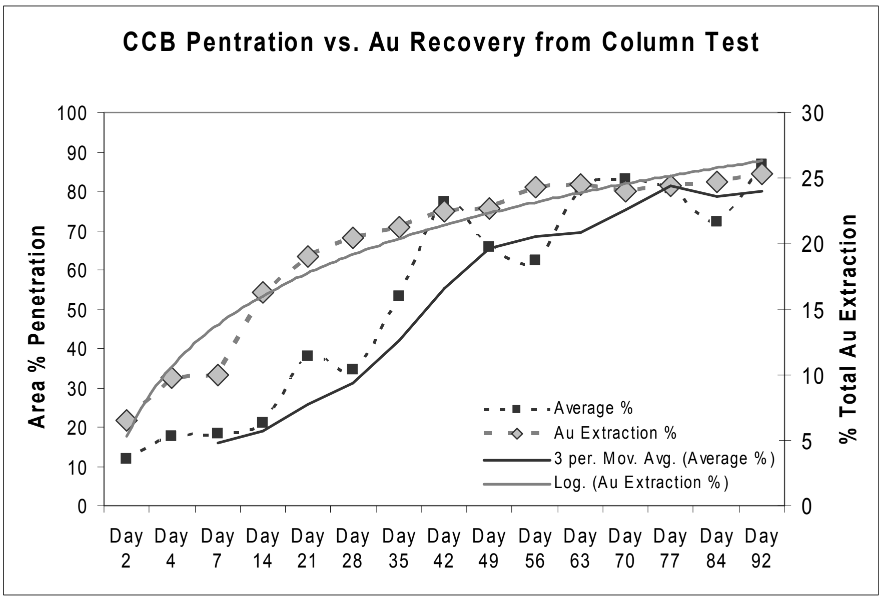

Figure 15: Correlation graph of Time vs. Penetration and Time vs. Au Extraction

DISCUSSION AND INTERPRETATION

This part of the paper is devoted to correlating dye penetration, mineralogical and metallurgical results. The description of the two methods employed for the CCB sample indicated:

- The penetration patterns are mainly concentric and uniform and related to the porosity and permeability of the groundmass. Penetration occurring from direct submergence of large (~2 inch square) blocks demonstrates a rapid and more complete penetration trend as compared to a slower and less complete penetration trend of the finer column material (Figure16). This is a function of the mechanics and limitation of contact between the solution and the particles in the column as well as the concentrated contact of the solution to the rock using the submergence method.
- The breccia rock types investigated using the submergence technique indicated that the overall trends of penetration are similar to the column testwork. As Figure 16 illustrates a similar slope between the two tests as well as a pattern of an initial plateau of the penetration in the first half of the time period followed by a sudden rise and gradual increase to maximum penetration (dashed lines).
- Maximum penetration in the column test was ~85% surface area after a total of 92 days whereas the submergence method indicated the CCB could achieve a maximum penetration of 97%. The difference between these is likely due to the difference in methods employed (submergence vs. solution flow) and the statistical representation of the rocks examined as the submergence method examined only 3 blocks (~2 inch^3) whereas the large column offered a much larger sample volume.

- From the column testwork it was determined that a minimum penetration of 50% of the crushed particle would yield 23% of a maximum 25% overall gold recovery, the limited gold recovery apparently due to the presence of Au-Ag telluride minerals.
- The macroscopic observations of "porous" and "consolidated" rock types within the CCB bulk sample were further detailed as potassic (phyllic) and carbonaceous (propylitic) alteration types by petrographic investigation. Sorting of this dye penetration data based upon these observations revealed that the penetration varies with alteration type. The "consolidated" breccia exhibited greater carbonaceous alteration limiting the open porosity of the groundmass (~0.5%). This results in an 80% penetration area after 63 days within the column (Figure 17). The "porous" breccia (Figure 17) ranging from 1 to 5% of the particle. This resulted in an 80% penetration of the material after 42 days effectively shortening the residence time of the phyllic material within the column relative to the propylitic material.

Further information is needed to understand the dissolution of Au-Ag-tellurides and a method that would increase their dissolution rate in heap leaching. Limitation of Au recovery is not attributed to the penetration of the particles in as much as leachability of the telluride mineralogy. Some work has been carried out by Climo et al. (2000) on dissolution of telluride minerals using biooxidation technology as an alternative to roasting with some success. The Cripple Creek ore deposit has had a long history of Au production and with advances in technology and a better understanding of the mineralogy and geological characteristics an even longer history may result.

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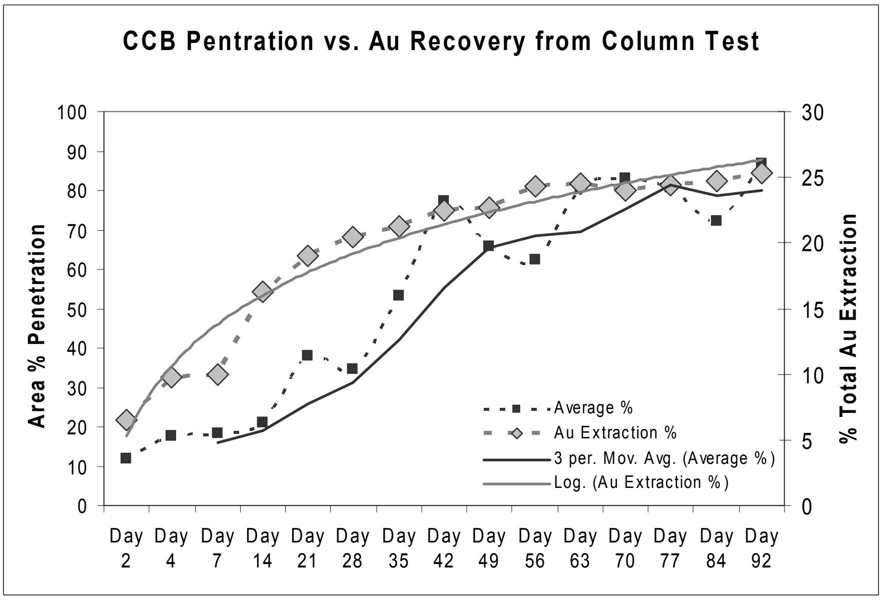

Figure 15: Correlation graph of Time vs. Penetration and Time vs. Au Extraction

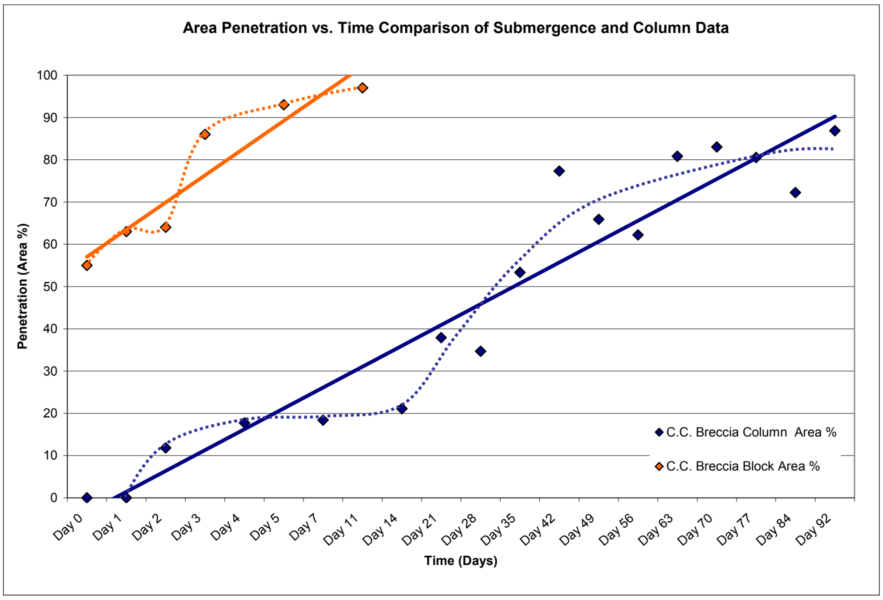

Figure 16: Comparison of Submergence vs. Column Penetration

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