Adding value with reverse circulation drilling at Pueblo Viejo

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ABSTRACT

The Pueblo Viejo project in the Dominican Republic installed an innovative sample system on its reverse circulation (RC) drilling rig during commissioning and subsequent commencement of operations. As knowledge of the orebody increased with mining and plant production, cost pressures became apparent that raised questions concerning the continued use of RC drilling versus blasthole sampling for ore control.

To justify the continued use of RC drilling for grade control, an in-depth study was undertaken to determine the quality of the sample and prove its value-add to the operation.

To investigate the differences in sample quality, a complete bench trial was initiated across both ore pits to compare RC drill results with blasthole assays on a side-by-side basis. The results indicated that based on ore block comparison between RC and blasthole sampling, RC identified an additional 20 per cent of high-grade (+ 4.5 g/t Au) ounces.

Previous work indicated that Au, Ag and Cu were all elevated in the drill fines at Pueblo Viejo (Goers and Almond, 2012). This previous test work did not consider the quantity of fines in an RC sample therefore new test work was undertaken to include particle size distribution analyses. This study would determine if the inclusion of fines in the sample was occurring and compare the quantity of fines in the sample against other sample systems and blasthole samples.

Comparisons between RC samples and blasthole samples indicate that for the RC samples a range of 30–35 per cent of the sample passed 300 mesh as compared to blastholes where the range of the sample passing 300 mesh was 15–30 per cent.

This paper includes a case study on the importance of accurate samples and how they have impacted throughput through the pressure oxidation process plant at Pueblo Viejo. The accurate samples provided by RC allow for improved stockpile and blending strategies, showing the importance of accurate samples to manage risk and create value, against the perception that savings can be made at the risk of poor sampling performance.

INTRODUCTION

The Pueblo Viejo gold mine (joint venture Barrick 60 per cent and Goldcorp 40 per cent) is located within the central portion of the Dominican Republic on the Caribbean Island of Hispanola in the province of Sanchez Ramirez (Figure 1). The project is 15 km west of the provincial capital of Cotui and approximately 100 km north-west of the capital Santo Domingo.

The earliest records of Spanish mine workings at Pueblo Viejo date from 1505. In 1969 Rosario Resources Corporation commenced exploration targeting outcropping sulfide veins in the stream valleys. Exploration activities progressed out of the valleys and the oxide portion (up to 80 m thick) of the deposit was discovered. In 1975, Rosario Dominicana commenced mining on the Moore Deposit. Mining, processing and exploration continued until July 1999 when with the oxide portions of the orebodies exhausted, poor sulfide recoveries of the metals resulted in the operation being shutdown.

During the 24 years of production the operation produced a total of 5.5 Moz of Au and 25.2 Moz of Ag. In 2001 Placer Dome Inc won a bid to evaluate the property. Placer Dome Inc completed a Feasibility Study in 2005 and the project was approved. Barrick Gold Corporation acquired Placer in 2006 and commenced a project review in March 2006. Pueblo Viejo commenced construction in February 2008. Pueblo Viejo commenced production at the end of 2012 using pressure oxidation with carbon-in-leach Au recovery to process 24 Kt of ore per day. By the end of 2016 PV had produced 4.2 Moz of Au and 12.3 million Ag ounces, with 2016 production of 1.167 Moz Au.

The Pueblo Viejo precious and base metal deposit is classified as a Cretaceous high sulfidation epithermal Au, Ag, Cu and Zn deposit. It was formed in subvertical funnel shaped alteration envelopes where hydrothermal fluids migrated upwards and laterally, along permeable horizons, depositing precious and base metals. The deposit is hosted in andesitic volcanic, andesitic volcaniclastics, and carbonaceous sediments. The hydrothermal alteration associated with the mineralisation consists of a core of silica, pyrophyllite, pyrite, koalinite and alunite. The 13.48 silica enriched alteration

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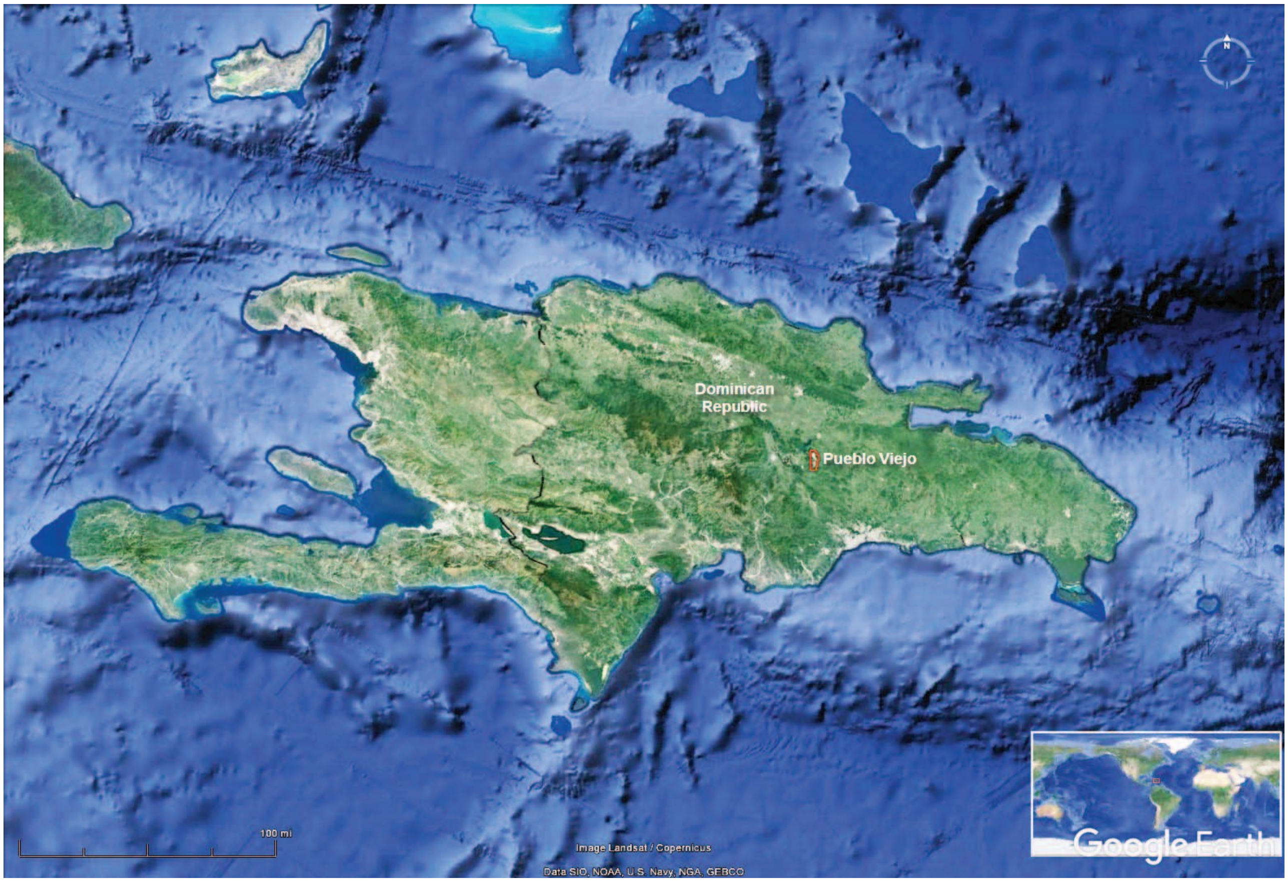

FIG 1 – Location map of the Pueblo Viejo Project in the Dominican Republic.

zones are surrounded by a halo of quartz-pyrophyllite and pyrophyllite alteration. Mineralisation is predominantly hosted in pyrite and to a limited degree in sphalerite and enargite. The pyrite mineralisation occurs as disseminations, layers, replacements and veins. The sphalerite and enargite mineralisation is primarily in veins. Au occurs as native Au, sylvanite ($AuAgTe_4$) and aurostibite ($AuSb_2$). The principal carrier of Au is pyrite where the submicroscopic Au occurs in colloidal size micro-inclusions (less than 0.5 microns). (Pueblo Viejo Project, Feasibility Study Update Volume 1, Geology, December 2007).

The end of year 2016 Reserves for the Pueblo Viejo deposit are 143.03 Mt at 2.93 g/t Au 13.48 Moz of Au, 79.68 Moz of Ag at 17.33 g/t Ag and 300.205 million pounds of Cu at 0.095 per cent Cu The final pit is constrained by the current tailings dam capacity.

The End of year 2016 Resources for the Pueblo Viejo deposit are 176.07 Mt at 2.33 g/t Au 13.18 Moz of Au, 65.35 Moz of Ag at 11.54 g/t Ag and 333.17 million pounds of Cu at 0.085 per cent Cu.

Mining is undertaken from two ore pits utilising 34 Cat 789 haul trucks, one Hitachi 3400 set-up in a face shovel configuration, one Hitachi 3400 set-up as an excavator and 3 Cat 994 loaders. Mill feed consists of ore from short-term stockpiles, used for sulfur control, blended with longer term stocks. The focus is on feeding highest grade material first to maximise project value, with the remainder of low-grade ore sent to stockpiles, which are estimated to grow to a maximum of 100 Mt during the life-of-mine.

The mine and processing plants rely heavily on sample data to accurately model and forecast, while samples are also imperative for process blending and control of sulfur on a daily basis.

The sample system used at Pueblo Viejo is the Progradex PGX1350R. The sample system allows for the capture and inclusion of both the coarse material and all the fines in the sample. This sampling system also utilises a Progradex TD1200 dust collector and an exhaust fan. The function of the exhaust fan is to create negative pressure within the sampling system to provide expansion space for the positive pressure drilling air as well as control internal system flow balancing. Coarse material is collected by the sampling system's internal cyclone and layered by a distribution nozzle below as it discharges through the bottom. The fines are captured by special filters mounted around the outside of the cyclone and these filters are pulsed with high pressure air to clean them and allow the fines to re-join the coarser material for inclusion into the sample below. The sampling system used at Pueblo Viejo has been proven over five years of operation.

Early test work indicated that the fine material at Pueblo Viejo contained a higher proportion of precious and base metals than the general sample and thus the inclusion of fines was critical (Goers and, Almond 2012). This test work compared the assay results from the fines of a sample against the assay of the coarser material for 1104 drill hole sample composites. In total 75 per cent of the fines assayed greater in value then the coarser material. However, due to the methodology of collecting the sample from the cyclone and from the dust collector in this study the proportion of fines in each sample was not determined. Therefore, the impact of fines and the potential error was not understood.

Results of particle distribution tests are shown in Figures 2–4. The variability of the blastholes in collecting the fines is

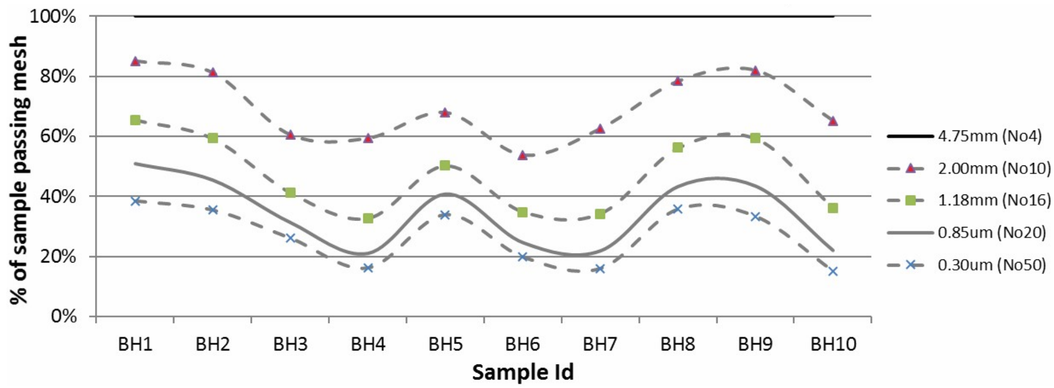

FIG 2 – Particle size distribution of blasthole samples.

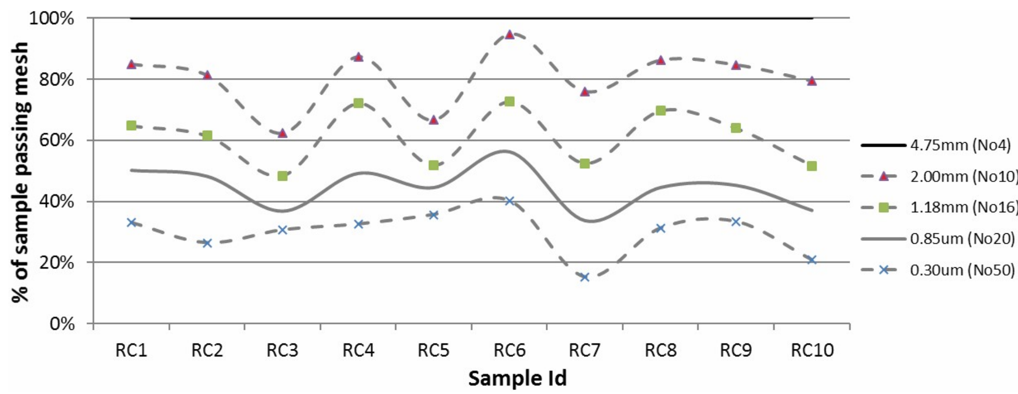

FIG 3 – Particle size distribution of RC samples without fines collection.

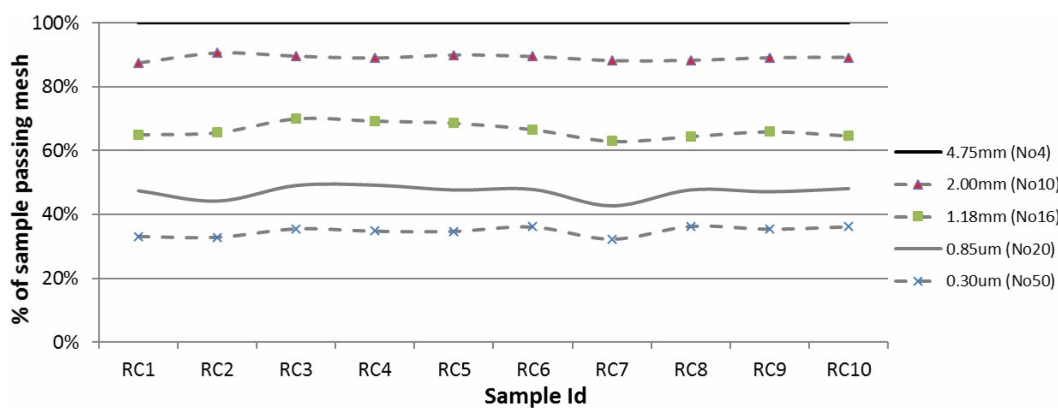

FIG 4 – Particle size distribution of RC samples with fines collection.

demonstrated as is the vast discrepancy of fines versus larger particles for blastholes versus RC. The data clearly shows the impact of the collection of fines based on the three sampling methods of blasthole sample, reverse circulation without fines and reverse circulation with fines included.

This data coupled with the particle size distribution data seen above led to the conclusion that the collection of fines was critical. This data also indicated that the sample system selected was collecting fines as designed. Given initial results, a case study was undertaken to determine if the added cost of the RC sample being produced by Pueblo Viejo was justified and this comparison consisted of a straight bench-by-bench comparison of blastholes samples versus the RC sample being taken at Pueblo Viejo.

BENCH BY BENCH CASE STUDY

During 2016 a study was undertaken to gather samples of both blasthole and reverse circulation across two benches in two ore pits (four benches in total) to compare and evaluate both sample methods.

Three cases were tested:

1. Case A, an interpretation and model was generated using the RC samples only.
2. Case B, the RC interpretation was modelled using the blasthole samples.
3. Case C, an interpretation and model was generated using the blastholes only.

Case A is the current grade control methodology of which the estimation is undertaken using the RC sampling with conditional simulation. Case B utilised blasthole data

TABLE 1

Comparison of 1104 drill hole fines assays against the corresponding drill hole cuttings assays. In total 75 per cent of the fines assays are greater in value to the drill hole cuttings value (823 from 1104 total samples); Goers and Almond, 2012.

	Fines	Drill hole	% fines/drill hole
Au g/t	3.95	2.92	135%
Ag ppm	30.5	25.7	119%
Cu ppm	726	498	146%
Zn ppm	8,750	7743	113%
% S	6.05	6.77	89%

interpolated separately using conditional simulation with modelling parameters adjusted to account for drill spacing and compositing differences, with ore block t and grades calculated using the Case A polygons. Case C used the blasthole model and ore polygons based on blasthole model and assays. Mapping and other available information such as resource/geology model, exploration drill hole logging was used across all cases; for example, pit mapping was used in both cases whilst RC data below the bench was used in the RC interpolated and not for the blasthole data as this would be available for the RC case and not for the blasthole scenario in normal operations.

The average grade across the benches were similar:

- RC 1276 Million ore tonnes at 3.92 g/t Au; 160 825 Oz Au.
- blasthole RC interpretation 1298 Million ore tonnes at 3.73 g/t Au; 155 825 Oz Au.
- blasthole 1276 Million ore tonnes at 3.81 g/t Au; 156 226 Oz Au.

The tonnage differences between the RC versus Blasthole/RC is caused by sulfur variation across the cases. The sulfur grade is a key component affecting the density equation used for tonnage calculations.

Complete results from the trials are shown in Tables 2 and 3.

The largest difference identified was in the high-grade ore category; ore material categories are critical in terms of maximising value by allowing the preferential treatment of the highest value material. Au grade typically drives value, silver and copper are also revenue generators and the sulfur grade is critical for plant feed. High-grade, which is processed immediately equated to 463 324 t at 5.35 Au g/t from RC versus 361 121 at 5.41 Au g/t from blastholes. Tables 2 and 3 show that the materials that would have been classified as low or medium-grade were reclassified as high-grade in the case of RC application. This comparison above represents approximately 1/20th of ore mined during 2016.

The ore feed at Pueblo Viejo comes from short-term layered stockpiles. These short-term stocks are created using a mix of ex-pit material and long-term stockpiled material blended together to smooth the sulfur feed and hit the optimal feed grade for sulfur. These stocks are rehandled to the crusher. This process makes it difficult to perform a direct comparison between the mining benches from the case study and the reconciled ounces from the process plant, as not all ore mined in a period is fed and often high-grade material may be delayed to another period I to meet plant sulfur requirements. A complex ore tracking system is in place at Pueblo Viejo involving the use of drones and stockpile block models for tracking of long-term stockpiles to account for the ore feed movement. During the three month period that the benches included in the case study were mined, the ore mined accounted for approximately 1/3 of the mill feed during this same three month period. The variance between geology predicted grades, and final bullion grades from the process plant were within ±2 per cent for Au and ±5 per cent for Ag. The rolling three month variances for the same period is 0 per cent for Au and ±3 per cent for Ag. This indicates that the samples from RC are matching closely with process plant production.

KEY ADVANTAGES OF RC DRILLING

While the clear advantage of having the Au upfront is demonstrated, several other benefits can be attributed to the RC. The following benefits are outlined in detail in subsequent sections:

- increased throughput at the process plant due to sulfur control
- mine planning advantages/ no assay delays
- decreased infill drilling requirements
- dry sample
- angled holes to intersect mineralisation
- split bench mining.

Throughput through the process plant

There are four autoclaves used for pressure oxidation of the sulfidic orebody at Pueblo Viejo process facility. As the mine out produces the process plant significantly, an elevated cut-off grade is used to maximise revenue. In addition, sulfidic ore requires blending to allow for smooth operation of the plant and improved throughput.

TABLE 2

Results from bench analyses.

Reverse circulation (RC)				BH with RC interpretation			Blasthole (BH)		
Blast ID	**Tonnes**	**Au**	**Ounces**	**Tonnes**	**Au**	**Ounces**	**Tonnes**	**Au**	**Ounces**
MO240B001	139 398	4.78	21 413	137 920	4.65	20 603	137 396	4.68	20 654
MO240B003	300 880	4.12	39 848	326 501	3.54	37 207	321 775	3.59	37 133
MO240B005	333 939	3.78	40 625	334 651	3.51	37 804	325 532	3.63	38 041
MO240B006	299 248	4.06	39 030	296 922	4.15	39 601	296 874	4.14	39 469
MO240B010	71 812	2.30	5317	71 352	2.15	4923	61 835	2.40	4766
MO240B202	48 178	2.29	3544	47 991	2.43	3751	48 013	2.44	3761
MO240B203	22 811	3.08	2256	22 587	2.70	1962	24 980	2.96	2376
MO240B204	60 462	4.52	8792	60 116	5.16	9974	60 077	5.19	10 027
Total	**1 276 728**	**3.92**	**160 826**	**1 298 040**	**3.73**	**155 826**	**1 276 482**	**3.81**	**156 227**

TABLE 3
Complete bench trial results.

		Grade control with reverse circulation			Grade control with blast holes			Difference Au ounces
	Blast ID	Au	Tonnes	Ounces	Au	Tonnes	Ounces	
High-grade Au> = 4.5 g/t	M0240B001	5.36	108 009	18 602	5.67	77 868	14 184	4418
	M0240B003	5.46	123 698	21 720	4.98	63 321	10 131	11 589
	M0240B005	5.03	118 020	19 078	5.02	76 921	12 406	6672
	M0240B006	5.49	88 709	15 661	5.50	108 917	19 245	(3584)
	M0240B204	5.84	24 888	4673	6.24	34 094	6840	(2167)
	Total high-grade	**5.35**	**463 324**	**79 734**	**5.41**	**361 121**	**62 806**	**16 928**
Medium-grade Au> = 3.0 and <4.5 g/t	M0240B001	3.67	4137	488	3.81	39 045	4782	(4294)
	M0240B003	3.66	103 440	12 162	3.66	153 802	18 113	(5951)
	M0240B005	3.58	130 239	14 979	3.60	152 487	17 663	(2684)
	M0240B006	3.66	166 737	19 609	3.67	126 023	14 867	4742
	M0240B202	3.28	7492	790	3.58	13 833	1593	(803)
	M0240B203	3.66	10 084	1187	3.54	10 729	1221	(34)
	M0240B204	3.79	28 758	3501	3.82	25 983	3187	314
	Total middle-grade	**3.64**	**450 887**	**52 716**	**3.66**	**521 902**	**61 426**	**(8710)**
Low-grade <3.0 Au g/t	M0240B001	2.65	27 252	2322	2.56	20 483	1688	634
	M0240B003	2.52	73 742	5965	2.64	104 652	8889	(2924)
	M0240B005	2.38	85 680	6568	2.58	96 124	7971	(1403)
	M0240B006	2.67	43 802	3760	2.69	61 934	5357	(1597)
	M0240B010	2.20	63 737	4510	2.22	48 557	3469	1041
	M0240B202	2.11	40 686	2754	1.97	34 180	2168	586
	M0240B203	2.61	12 727	1069	2.52	14 251	1155	(86)
	Total low-grade	**2.41**	**347 626**	**26 948**	**2.51**	**380 181**	**30 697**	**(3749)**

TABLE 4
Results of pit design change due to reverse circulation.

	Contained ounces	Contained high-grade ounces	Total tonnes	Ore tonnes
Previous phase design	398 077	245 766	4 205 041	3 223 009
Updated phase design	432 292	264 820	4 568 097	3 512 125
Difference	**34 215**	**19 054**	**363 056**	**289 116**

Through plant operation it was determined that smooth sulfur feed grades were critical to the throughput of the process plant. Additionally, the autoclaves have an upper limit for sulfur whereby the temperature within the autoclave becomes unstable, requiring additional cooling water at the expense of ore slurry.

Considerable work was undertaken during 2014 to stabilise the sulfur being fed to the process plant. The consistent sulfur has allowed for an increase in autoclave throughput from 216 t per operating hour to 238 t per operating hour, an increase of 10 per cent. The throughput at the autoclaves has improved further and whilst some of this is likely attributed to smooth sulfur feed grades, a number of mechanical modifications performed during this time frame also contributed.

At the heart of this consistent sulfur feed is accurate samples supplied by the RC grade control system, which allow for blending and the minimised variability. If inaccurate information is used then the blended stockpiles can result in sulfur spikes requiring throughput through the autoclaves to be reduced.

This increase in throughput over the year has enabled additional processing of approximately 650 000 t with plant feed grades averaging 5 g/t Au; for an addition of 95 854 Oz. By processing these ounces earlier in the life-of-mine, revenues upfront are increased.

Mine planning benefits

The ability to drill ahead four benches (made possible with an RC rig but not with a blasthole rig) provides timely data to geologists and engineering. This data allows for mine planning changes, forecast improvements and has been critical to meet production targets and to optimise ore feed to stockpiles and the process plant.

During 2016 the Moore Phase 2 pit was planned to conclude at the 150 bench, however, advanced drilling identified that high-grade mineralisation extended another 10 m. A subsequent redesign improved economics. Further design modifications were required in the ramp design due to geotechnical failures and again RC added value by identifying high-grade mineralisation to focus on resulting in an addition of 19 054 ounces of high-grade, which were sent to the process plant and increased revenue during 2016.

RC information collected ahead of time also enables haulage cycle and dig unit allocation to be optimised. The sulfur grade of material at PV is critical to the process plant and RC allows low sulfur areas to be identified and targeted, creating blending options. Earlier identification of sulfur grade allows for timely communication regarding potential shortfall associated with higher sulfide ore affecting the blending plan.

The RC drilling and assay returned prior to blasting results in improved blast design minimising dilution of ore blocks and inventory for mining is release immediately.

Decreased infill resource drilling requirements

The grade control drilling can be extended up to 100 m therefore this drilling can be utilised for infill resource drilling in areas where there is uncertainty in a cutback. This negates the need to mobilise a more expensive diamond rig for infill resource drilling. Current costs for an exploration rig are approximately three times that of an rc rig per metre and the mobilisation cost is significant due to limited rig availability and geographic location.

Dry samples

Dry samples are a key advantage of RC grade control and the fact that PV is located in a high rainfall environment averaging 1970 mm/a (data collected from 1983–2014) means that the samples obtained from blastholes can be severely affected by water.

The two main types of water affecting the sample at PV are:

1. groundwater
2. surface water.

The groundwater at PV is dynamic and is close to surface resulting in the majority of 48 metre RC holes intercepting water. The correct use of the RC system allows for the sample to be taken dry. The drillers use a blow down system which enables the air to force the water up and away from the drill head during rod changes, this system ensures that the water does not enter the rod string or sample system instead it is forced up the outside of the rod and away from the drill head and drilling continues dry.

The surface water at PV can be difficult to deal with and frequent afternoon storms present challenging mine

TABLE 5
Split Bench analysis 2016.

	10 metres			5 metres			Ounces difference
Blast ID	Tonnes	Au g/t	Ounces	Tonnes	Au g/t	Ounces	
MN350B008	2024	4.81	313	10 349	5.75	1912	1599
MO140B006	76 415	5.66	13 908	75 792	5.85	14 247	339
MO150B001	19 219	5.07	3131	26 945	5.15	4458	1327
MO150B003	14 837	5.87	2801	24 703	5.91	4697	1896
MO160B008	89 303	5.65	16 233	75 474	8.21	19 913	3680
MO160B009	11 693	5.08	1909	24 563	7.16	5654	3745
MO160B010	14 331	5.30	2440	14 671	7.32	3452	1012
MO160B011	33 257	5.26	5626	26 375	9.58	8122	2496
MO170B011	11 773	5.30	2005	23 767	5.97	4559	2554
MO170B012	63 698	5.99	12 257	63 494	7.51	15 340	3083
MO190B002	29 748	4.49	4296	31 661	6.53	6645	2349
MO190B003	12 397	5.10	2032	49 583	5.25	8374	6342
MO190B004	34 534	5.22	5797	44 755	5.77	8308	2511
MO190B005	6494	4.66	972	10 571	6.34	2155	1183
MO190B007	5702	4.95	908	8626	6.95	1927	1019
MO190B008	3026	5.11	497	22 200	4.89	3487	2990
MO190B009	6954	4.80	1074	8930	6.46	1855	781
MO190B010	16 138	6.22	3227	22 531	6.78	4911	1684
MO190B012	2484	5.02	401	8789	6.25	1765	1364
MO200B003	15 999	4.98	2562	43 268	4.57	6355	3793
MO200B008	26 098	4.60	3859	22 829	6.76	4958	1099
MO210B010	34 589	4.49	4994	34 504	6.39	7089	2095
MO210B020	4126	4.63	614	11 344	5.66	2064	1450
MO250C004	83 466	5.76	15 464	80 845	6.02	15 645	181
MO260C007	88 057	5.97	16 896	88 409	6.29	17 892	996
Total	**706 362**	**5.47**	**124 216**	**854 978**	**6.39**	**175 784**	**51 568**

conditions, with rainfall events of 80 mm inside a 24-hour period not uncommon. These conditions result in difficulties maintaining ideal bench conditions. Advanced drilling of four benches means that ore control personnel can supply mine operations staff an accurate picture of the ore zones ahead of time enabling decisions to be made to minimise dilution and identify suitable locations for sumps, road ways and drainage zones based on ore contacts.

Surface water presents difficulties when gathering blasthole samples. The blasthole cones can be significantly altered by surface water and fines being washed away. On-bench contamination also occurs with mining equipment operating in wet, muddy bench conditions.

Angled holes to intersect mineralisation

With the vertical flow of mineralisation permeating into horizontal zones, the inclined RC drilling allows for optimal intersection of the ore compared to the vertically drilled blasthole samples allowing for more accurate estimations of ore width and contacts.

Split bench mining

The two metre accurate sample obtained from RC holes allows for split bench mining (flitch mining) of ore zones. Studies undertaken during 2016 indicated that moving to a 5 m bench would have a negative effect on mine economics due to the slow mining rates and increased costs. However, this study showed that in certain areas of the ore zones there was a positive effect. The 2 m sample ahead of time allows for split benching to occur and with data available ahead of time, split benching plans can be undertaken in a manner to minimise additional costs and slower mining rates. During 2016 the use of split benching was undertaken in specific areas of mill feed to increase grade delivery to the process plant. In total, 25 blasts were split benched to reduce ore dilution. This reduction in dilution represented an increase of 51 568 delivered ounces to the process plant; data is shown by Table 5.

CONCLUSIONS

In conclusion, it has been determined that the benefits of RC drilling at Pueblo Viejo far outweigh the additional costs. The true value of accurate and improved sample quality can be difficult to determine and the argument between blasthole sampling and RC can often become a matter of personal opinions, past experience and company mandates. These examples clearly show to Pueblo Viejo management the added revenue generated by the improved sample provided by RC grade control. The 100 per cent recovery (fines collection) for sampling has led to continued long-term commitment by site management to the use of RC and the sample system installed.

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