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QOTHO CERTIFIED REFERENCE MATERIAL (QCRM)

QCRM-5-068

MILL FEED COPPER ORE

(MOLYBDENUM SULPHIDE CONCENTRATE)

CERTIFICATE OF ANALYSIS

CERTIFIED VALUES			
ANALYTES	**UNITS**	**CONCENTRATIONS**	**EXPANDED UNCERTAINTY**
Ag	g/t	8.4	±2.6
Ca	%	0.83	±0.04
Cu	%	0.40	±0.02
Fe	%	0.74	±0.07
Mg	%	1.51	±0.08
Mn	%	0.010	±0.002
Mo	%	52.15	±0.60
Pb	%	0.021	±0.004
S	%	35.1	±3.1
Si	%	2.78	±0.36
Zn	%	0.028	±0.008
ASSIGNED VALUES (FOR INFORMATION ONLY)			
ANALYTES	**UNITS**	**CONCENTRATIONS**	**EXPANDED UNCERTAINTY**
Al	%	0.10	±0.04
As	ppm	143	±65
Au	g/t	6.38	±0.26
Co	%	0.005	±0.004
Cu (Soluble)	%	0.024	±0.009
Ni	%	0.007	±0.004
Se	ppm	0.030	0.015

1. **Use:**
QCRM-5-68 is a certified reference material which is suitable for use as random control samples in routine analytical laboratory quality control, when inserted within a batch of samples and measured in parallel to the unknown. The QCRM can also be used as a control sample in the analysis of samples of a similar type, verification of analytical methods for Low grade Copper Ore or Molybdenum Concentrate and as a calibration standard for the calibration of equipment used for analysing similar materials.

This document was updated, as more data became available, for Arsenic, Selenium and Molybdenum. Only these three analytes were considered, during the re-evaluation.

2. **Origin of Material:**
This composite mill feed copper ore sample was sponsored by Rio Tinto, Kennecott, in the USA.

3. **Mineral and Chemical Composition:**
The typical mill feed is dominated by meta-sediments with minor amounts of intermediate to felsic intrusive rocks of the Bingham Stock. The metasedimentary rocks comprise roughly equal proportions of pyrite-poor and -rich clean, orthoquartzite and hornfels with accessory amounts of skarn. Intrusive rocks (and this material in particular) are dominated by molybdenum-enriched monzonite and lesser quartz monzonite. The mineralogy of this ore is compositionally in agreement with the above ore-based assessment. Relative to historic data, 2006 through 2019, the ore exhibits higher concentrations of quartz, pyrite and magnesium-rich clay minerals. Lower than historic percentages of the economic minerals, i.e. Cu sulfides and molybdenite, as well as typical rock forming minerals, such as: feldspars, biotite and amphibole / pyroxenes are observed.

4. **Date of Initial Issue:**
2 June 2020.

5. **Packaging & Handling instructions:**
The material was packaged as 100g unit sizes, placed in geo-envelopes, within a vacuum sealed aluminum foil bag. Open the seal of the foil with care and shake or otherwise agitate prior to use. Normal safety precautions for handling fine particulate matter are recommended, such as the use of safety glasses, breathing protection, gloves, and a laboratory coat. Once opened, material must be stored in a cool, dry environment. Results on page 1 is presented on dry basis. Analysis should therefore be done on dry basis, after drying to constant mass, at 105 degrees Celsius.

6. **Method of Preparation:**
The material was sieved through a 75-micron screen and the oversize was re-milled to ensure 100% passing through the screen. It was then blended, systematically divided, and packaged into 100-gram zip-lock bags. Randomly selected samples, from the bags, were tested in-house via XRF, to confirm homogeneity. Once confirmed and certification completed, the items were placed in geo-envelopes and vacuum sealed in aluminium foil bags.

7. **Methods of Analysis used:**
- Multi-acid digestions with ICP-OES finish
- Multi-acid digestion with AAS finish
- Sodium peroxide fusion with ICP-OES finish
- Copper by 3-acid digestion with Potentiometric Titration
- Copper by multi-acid digestion and electro-gravimetric finish
- Soluble copper by dilute sulphuric acid leach and AAS finish
- Silica by 4-acid digestion and gravimetric finish
- Pressed powder with XRF finish
- Fused beads with XRF finish
- Au & Ag by lead collection Fire Assay and ICP-OES or AAS finish
- Sulphur by Thermal Combustion analysis.

8. Analysis required:

An instruction letter was sent to all participants. The analysis required was noted in the instruction letter and reporting template, including but not limited to Ag, Al, Au, Ca, Co, Cu, Cu (Soluble), Fe, Mg, Mn, Ni, Pb, S, Si and Zn.

9. Participating Laboratories:

No	LABORATORY	COUNTRY
1.	AHK DRC South	Democratic Republic of Congo
2.	AHK Kitwe	Zambia
3.	AHK Lumwana	Zambia
4.	ALS Geochemistry Kempton Park	South Africa
5.	ALS Inspection UK	United Kingdom
6.	Intertek LSI	Netherlands
7.	Intertek Tschudi	Namibia
8.	Kamoto Copper Company	Democratic Republic of Congo
9.	Lubambe Copper Mine	Zambia
10.	Mintek	South Africa
11.	Mopani Mufulira	Zambia
12.	Mopani Nkana Analytical Services	Zambia
13.	OCC Kolwezi	Democratic Republic of Congo
14.	OCC Likasi	Democratic Republic of Congo
15.	Palabora Mining Company	South Africa
16.	Rio Tinto Kennecott	United States of America
17.	Robinson International	Democratic Republic of Congo
18.	SGS Lakefield	Canada
19.	SGS Netherlands BV	Netherlands
20.	UIS Analytical Services	South Africa
21.	Zambia Revenue Authority	Zambia

10. Assay Data:

Data used for Assigning Values and Certification.

LAB	Ag	Al	As	Au	Bi	Ca	Co	Cu	Cu (Soluble)	Fe	Mg	Mn	Mo	Ni	Pb	S	Se	Si	U	Zn
UNIT	g/t	%	ppm	g/t	ppm	%	%	%	%	%	%	%	%	%	%	%	ppm	%	ppm	%
LAB001			150		< 1000.00								51.5				300			
LAB002			200		< 1000.00								50				400			
LAB003			< 500.00																	
LAB004			< 500.00																	
LAB005			< 25.00		< 30.00												424.5			
LAB006			< 24.00		< 29.00												232			
LAB007			< 40.00		843												459			
LAB008			85		846.5												412			
LAB009			205																	
LAB010			200																	
LAB011			12.7		3.1												29.85			
LAB012			12.5		3.3												25.3			
LAB013													51.6							
LAB014													52.05							
LAB015													52.8							
LAB016													52.45							
LAB017													52.7							
LAB018													51.9							
LAB019													53							
LAB020													52.25							
LAB021													52.4							
LAB022													52.05							
LAB023	7.699	0.093	74			0.771	< 0.000	0.389		0.788	1.405	0.009		0.074		39.75		3.057		0.024
LAB024								0.378												
LAB025		0.081								0.553	1.547					36.463		2.426		

LAB	Ag	Al	As	Au	Bi	Ca	Co	Cu	Cu (Soluble)	Fe	Mg	Mn	Mo	Ni	Pb	S	Se	Si	U	Zn
UNIT	g/t	%	ppm	g/t	ppm	%	%	%	%	%	%	%	%	%	%	%	ppm	%	ppm	%
LAB026								0.367												
LAB027		0.104				0.579		0.287		0.542	1.595	0.007				31.094		2.481		0.029
LAB028								0.447		0.774		0.237		0.013						
LAB029								0.457												
LAB030							0.003		0.019							40.7				
LAB031		0.361				0.804	0.058	0.384	0.013	0.793	1.43	< 0.010		< 0.010				3.31		< 0.010
LAB032								0.42	0.012							38.588				
LAB033		1.472				0.946	0.056	0.579	0.02	0.766	0.269	0.016		0.027	0.178			5.192		0.056
LAB034						0.939			0.084	0.621	0.302	< 0.010								
LAB035	7.45	0.077	65.5	6.15		0.975	0.001	0.39		0.83	1.92	0.008		0.001	0.018	35.58		3.08	< 10.00	0.03
LAB036	4	0.85	< 1.000			0.775	0.001	0.341	0.021	0.94	1.42	0.02		0	0.02			2.455	< 5.00	0.045
LAB037								0.76												
LAB038		0.067	315			0.804		0.429	0.04	0.961	1.643			0.113		33.483		2.075		
LAB039	16.5	0.195	150	6.6		0.805	< 0.010	0.4		0.87	1.6	0.01		< 0.010	0.02	36.18		3.305		0.03
LAB040	10.3	0.135	187	6.515		0.775	< 0.020	0.4	0.015	0.66	1.35	0.095		0.007	0.02	26.5			10	0.02
LAB041								0.385												
LAB042									0.052											
LAB043								0.425												
LAB044		0.06				0.868	0.01	0.35		0.832	1.447	0.015								
LAB045	8.73	0.087				0.8	0.004			0.54	1.44	0.01		0.005	0.029			2.535		0.021
LAB046								0.395												
LAB047										0.7										
LAB048								0.377												
LAB049	8.615	0.091				0.805	0.002			0.645	1.465	0.01		0.005	0.028			2.52		0.021
LAB050								0.39												
LAB051								0.45	0.013							38.726				
LAB052	9.9	0.135	182	6.22		0.79	< 0.020	0.4	0.014	1.465	1.365	0.088		< 0.010	0.02	26.4			< 10.00	0.02

LAB	Ag	Al	As	Au	Bi	Ca	Co	Cu	Cu (Soluble)	Fe	Mg	Mn	Mo	Ni	Pb	S	Se	Si	U	Zn
UNIT	g/t	%	ppm	g/t	ppm	%	%	%	%	%	%	%	%	%	%	%	ppm	%	ppm	%
LAB053								0.405												
LAB054	4	0.89	< 1.000			0.77	0.001	0.605	0.025	0.9	1.405	0.01		0.004	0.02			2.445	< 5.00	0.04
LAB055	8	0.074	61.5	6.3		0.935	0.001	0.39		0.83	1.92	0.008		0.001	0.018	35.615		3.045	< 10.00	0.03
LAB056		0.043				0.916	0.01	0.342		0.715	1.442	0.01								
LAB057						0.907			0.08	0.61	0.268	0.006								
LAB058									0.056											
LAB059								0.441												
LAB060		0.064	285			0.816		0.427	0.05	0.923	1.663					33.475		2.075		
LAB061		0.364				0.807	0.049	0.383		0.817	1.424	< 0.010		< 0.010				3.26		< 0.010
LAB062								0.419		0.766		0.243		0.012						
LAB063								0.447												
LAB064							0.014			0.657										
LAB065								0.372												
LAB066		0.081				0.351				0.494	1.505					35.141		2.085		
LAB067								0.369												
LAB068	5.322	0.1	76			0.765	< 0.000	0.387		0.78	1.393	0.009		0.074		38.55		2.82		0.025
LAB069								0.372												
LAB070		1.04				0.811	0.158	0.583	0.014	0.7	0.218	0.014		0.026	0.225			4.263		0.058
LAB071	17	0.2	200	6.5		0.825	< 0.010	0.4		0.855	1.62	0.01		< 0.010	0.02	36.32		3.245		0.03
LAB072		0.101				0.583		0.293		0.536	1.605	0.008				30.906		2.482		0.03

Note: "less than" values were de-selected from the dataset, for all calculation purposes. They were however added back to the dataset, for information purposes only.

11. Method of Certification:

QM is a SANAS Accredited Proficiency Testing Scheme Provider, No. PTS0012

This material was distributed as test items, in the Qotho Copper PT Round 1 of 2020. The participating laboratories were each given 1 randomly selected sample from the batch, to analyse and report on in duplicate. Some laboratories reported results via more than one analytical method. Additional commercial analyses were later contracted to commercial laboratories. Obvious blunders were resolved with the laboratories (if any), after which the data was processed using Robust Statistics, through PROLab Plus.

Not all the participating laboratories were accredited. Historical performance in Qotho PT Schemes, as well as an evaluation of the CRM QA/QC data generated by the laboratories, during the analysis of this QRM, were considered, to evaluate the competence of laboratories. Where competence could not be confirmed, the affected data was deselected from the dataset. Certification of analytes was then done, provided that a minimum of 10 qualifying datapoints remained available.

Where analytes could not be certified, estimate concentrations were assigned, using all the data in the dataset.

12. Measurement of Uncertainty:

Standard uncertainty, uCRM, was calculated according to ISO 13528:2015 (equation 6), and it includes the effects of uncertainty due to inhomogeneity, transport, potential instability, and laboratory uncertainty. Because of all the uncertainties under consideration, QM further applies an expanded uncertainty, for certification purposes. The measurement uncertainty of the certified value is therefore calculated as follows: UCRM = kuCRM, where k is a coverage factor, which is determined from the Student's t-distribution, based on the degrees of freedom, per analyte.
This presents a certified value, as follows: xCRM ± UCRM.

Measurement uncertainty for Assigned values, are calculated in the same manner.

Laboratories which prefer to use the 95% measurement uncertainty, rather than the expanded uncertainty, all available information relating to measurement uncertainty of the certified/assigned values, are given below:

Analyte	Unit of measure	*s* (Standard Deviation of Dataset)	*v* (Degrees of Freedom)	*k* (Coverage Factor)	*u* (Standard Uncertainty)	95% Measurement Uncertainty	Expanded Uncertainty
Ag	g/t	3.399	11	2.201	1.169	± 2.3	± 2.6
Al	%	0.061	23	2.069	0.016	± 0.03	± 0.04
As	ppm	92.882	16	2.120	30.813	± 62	± 65
Au	g/t	0.285	5	2.571	0.101	± 0.20	± 0.26
Ca	%	0.063	24	2.064	0.016	± 0.03	± 0.04
Co	%	0.008	19	2.093	0.002	± 0.004	± 0.004
Cu	%	0.045	38	2.024	0.009	± 0.02	± 0.02
Cu (Soluble)	%	0.013	15	2.131	0.004	± 0.008	± 0.009
Fe	%	0.158	29	2.045	0.035	± 0.07	± 0.07
Mg	%	0.158	25	2.060	0.036	± 0.07	± 0.08
Mn	%	0.006	23	2.069	0.001	± 0.002	± 0.002
Mo	%	0.715	11	2.201	0.27	± 0.54	± 0.60
Ni	%	0.007	18	2.101	0.002	± 0.004	± 0.004
Pb	%	0.004	11	2.201	0.002	± 0.004	± 0.004
S	%	4.632	16	2.120	1.437	± 2.9	± 3.1
Se	ppm	0.014	7	2.365	0.006	± 0.012	± 0.015
Si	%	0.633	19	2.093	0.171	± 0.34	± 0.36
Zn	%	0.013	17	2.110	0.004	± 0.008	± 0.008

13. Metrological Traceability:

The values quoted herein are based on the consensus values derived from statistical analysis of the data from an inter laboratory measurement program. Traceability to SI units is via the accredited laboratories, as ISO 17025 requires laboratories to use CRM's traceable to the SI units, during the calibration of their equipment. Not all laboratories were accredited.

Fortunately, most laboratories reported on the QA/QC CRMs used during the analysis of this QRM and reported the values obtained during the sample run. Evaluation of their QA/QC performance serves as further evidence of metrological traceability.

Equivalence tests were performed on all analytes to determine whether the metrologically traceable data and those for which traceability evidence was not available, could be treated as equal (at a level of significance of $\alpha = 0.05$). Where equivalent, all the data was used. Where not equivalent, only the metrologically traceable data was considered.

14. Minimum sample size:

The recommended minimum sample size for the use of this material is as per the participants method validation criteria.

15. Period of validity:

The certified values are valid for this product, while still sealed in its original packaging, for a minimum period of 5 years from date of Initial Certification. Stability monitoring of inventory will be done at regular intervals. Any concerns regarding potential instability of the material, will immediately be communicated to all consumers.

16. Legal:

This certificate and the reference material described in it were prepared with due care and attention. The requirements of ISO Guide 31, ISO 17043 and ISO 17034 were followed in the preparation of this reference material and certificate of analysis.

Qotho Minerals, however, accepts no liability for any decisions or actions taken following the use of the reference material. The company has a complaints procedure, which will be made available upon request, should there be any dissatisfaction with either the product or the COA.

Certifying & Technical Signatory	
	
Qotho Managing Director	***4 April 2022***

This Certificate of Analysis (CoA) has been electronically signed using an Advanced Electronic Signature (AES) in terms of the Electronic Communications and Transactions Act No. 15, 2002 (ECT Act). Any amendments to the CoA can be detected by reference to the Signature Panel displayed in the electronic pdf version of the CoA.

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