Do you really know what's going into your mill?

Dr Toni Kojovic – November 2021

Presentation Topics

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- **Background**
- **HIT**
- **Users & Applications**
- **Case Study – Meadowbank (SAG Feed)**
  - ***Karl Leetmaa, Yanick Bergeron***
- **Case Study – Gibraltar (Blast Rejects)**
  - ***Adam Jordens***

Why Is Ore Variability Important?

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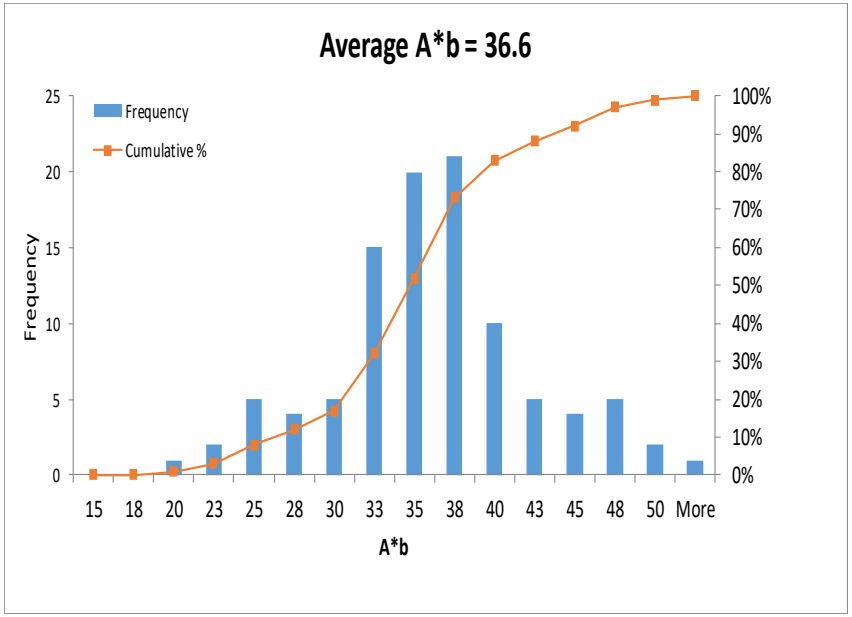
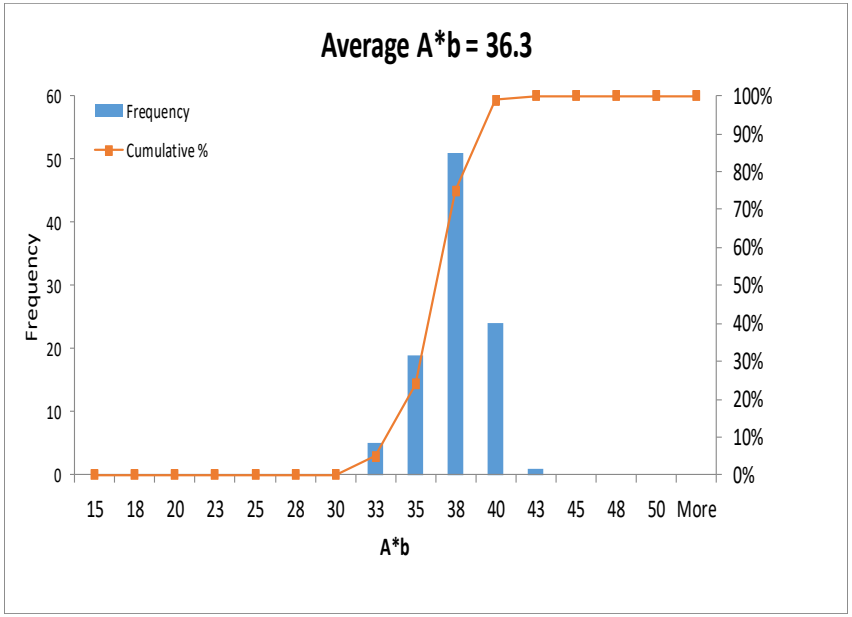
Same Axb, but very different implications in practice!





Current Status

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Need	Challenge
• Adequately measure the variability in a deposit	• Budget and time constraints on doing sufficient testing.
• Reach and sustain target production rates	• Mill circuit design is typically derived from averages on large core composites
• Successfully manage and improve the milling performance	• Often insufficient data on ore hardness variability on actual feed (must rely on geo model or mine plan estimates from comps)

A Solution

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- **Hardness Index Tester or HIT**
  - **designed to provide low cost, reliable, high volume ore hardness testing at site or in the lab.**
- **Impossible to achieve under typical budgets allocated for ore hardness testing.**
- **HIT exploits a unique feature of single particle breakage testing.**
- **HIT has NOT been designed to replace the bankable SMC/DWT or Bond tests**
  - **greatly extend the knowledge on the ore body hardness variability and actual feed to the mill.**

What is the HIT?

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- **Portable, easy and safe to use device for rapid rock hardness determination using small samples (<500g)**
- **HIT generates quantitative estimates of Axb (direct) and BWi (via calibration) in less than 10 minutes per sample (post preparation).**
- **Allows operational determination of rock hardness variability**
  - **Immediate results via Online data processing**
  - **Quality control protocols included**
  - **Allows real time decision making**
- **Enables routine testing of mill feed samples**
  - **Monitor performance /adjust mill settings for optimum performance.**

HIT Axb Test - Example

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1. Place rock in cup (approx. in centre)
2. Place cup in recess
3. Release drop mass to break rock by pulling gently on both levers
4. Remove broken fragments from cup (brush out if necessary, including scraping of impact head)
5. Repeat steps 1 to 4 until all rocks in sample are broken

- Complete product sizing (1 screen, 3 mins)
- Enter raw data into Excel sheets
- Upload raw data to Online Software
- Download Axb (or BWi) estimates

10 x 22.4x19mm fragments

Comparison HIT vs. JKDWT

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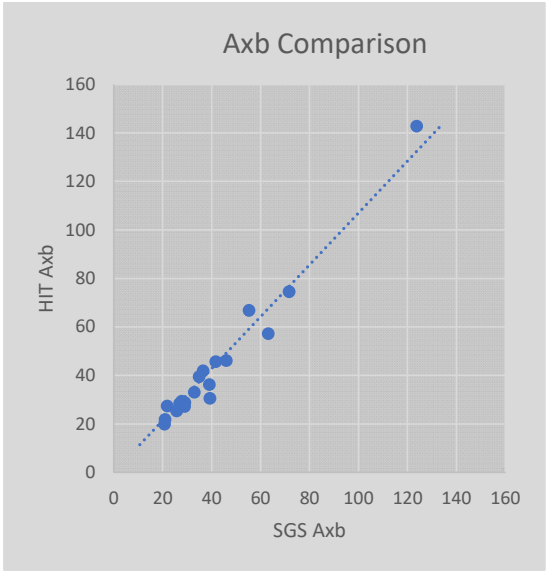
- **JKTech standard material tested in duplicate using HIT Axb test on 22.4x19mm**
- **HIT used on concrete, product 5 min sizing**
- **Detailed Full DWT results on 6 samples of standard material (Basalt) analyzed and compared with HIT results**

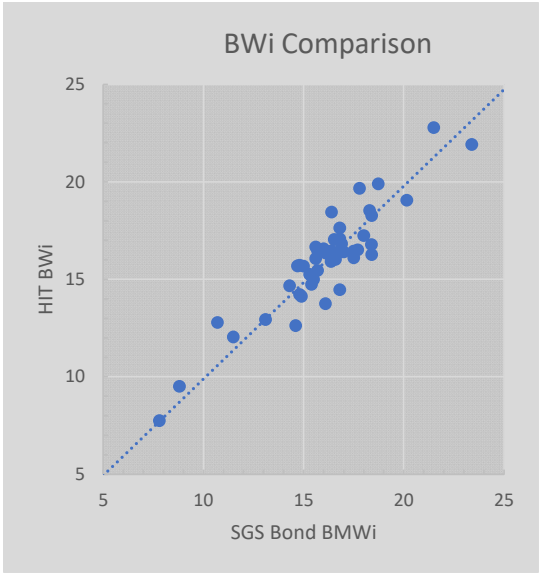
Test Site	Sample ID	Test	Type	Stat.	No. Samples	No. Part/ Sample	Av. Mass (g)	A x b
JKTech	Mt Marrow Basalt	DWT	**FULL**	**AVE**	**6**	**30**	**15.80**	**30.0**
				SD			1.40	1.4
SimSAGe	Mt Marrow Basalt	HIT	**-22.4/+19.0mm**	**AVE**	**2**	**12**	**16.50**	**30.0**
				SD			0.02	0.9

Shows clearly that HIT can match DWT A*b results well within the normal uncertainty of each test (providing material and sizing method are the same)

Comparison HIT vs. SMC and Bond

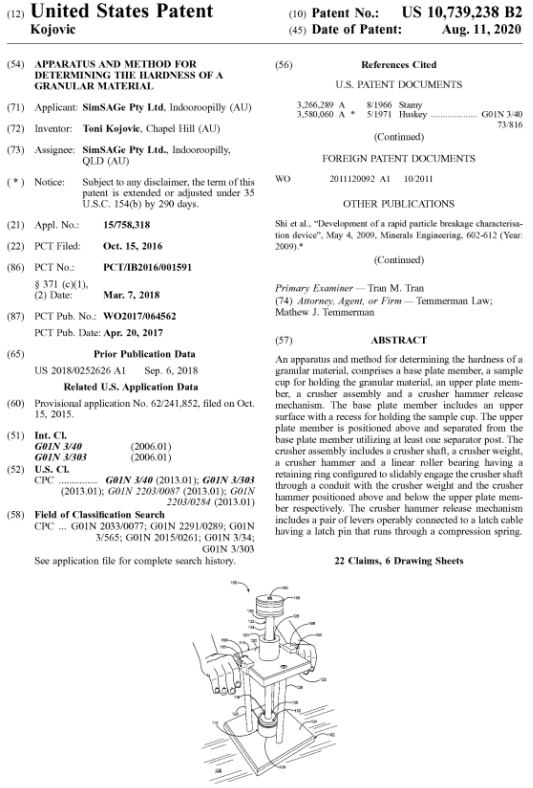
- **62 Drill core samples; SMC Axb and Full Bond BMWi**
- **HIT Axb and HIT Bond BMWi (via calibration model)**





HIT Status

- **Prototype built in Brisbane, Oct 2013**
- **Redesigned and fabricated in California, incorporating several novel features.**
- **U.S. Patent No. 10.739,238 B2 (Aug 2020)**
- **15 units in use; 3 orders pending.**
  - **AEML, Antapaccay, Batu Hijau (2), Chapada, Consulmet (Luaxe), Gibraltar, Newmont (3), Lihir, ME Elecmetal, Pinto Valley, Teck**
  - **ALS/Base Metal Labs/Bne Met Lab**
- **Usage statistics, Aug 2017 to Sep 2021**
  - **30,600 tests (19700 HIT-Axb, 10,900 HIT-BWi) ≈ 452,000 rocks**
- **Mechanical integrity very good, requiring only replacement of impact plates and bearing (at service).**
- **QA/QC important to sustain integrity of results**



(12) **United States Patent**
Kojovic

(10) **Patent No.: US 10,739,238 B2**
(45) **Date of Patent: Aug. 11, 2020**

(54) **APPARATUS AND METHOD FOR DETERMINING THE HARDNESS OF A GRANULAR MATERIAL**

(71) Applicant: **SimSAGe Pty Ltd**, Indooroopilly (AU)

(72) Inventor: **Toni Kojovic**, Chapel Hill (AU)

(73) Assignee: **SimSAGe Pty Ltd.**, Indooroopilly, QLD (AU)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 290 days.

(21) Appl. No.: **15/758,318**

(22) PCT Filed: **Oct. 15, 2016**

(86) PCT No.: **PCT/IB2016/001591**
§ 371 (c)(1),
(2) Date: **Mar. 7, 2018**

(87) PCT Pub. No.: **WO2017/064562**
PCT Pub. Date: **Apr. 20, 2017**

(65) **Prior Publication Data**
US 2018/0252626 A1 Sep. 6, 2018

Related U.S. Application Data
(60) Provisional application No. 62/241,852, filed on Oct. 15, 2015.

(51) **Int. Cl.**
G01N 3/40 (2006.01)
G01N 3/303 (2006.01)

(52) **U.S. Cl.**
CPC ***G01N 3/40*** (2013.01); ***G01N 3/303*** (2013.01); *G01N 2203/0087* (2013.01); *G01N 2203/0284* (2013.01)

(58) **Field of Classification Search**
CPC ... G01N 2033/0077; G01N 2291/0289; G01N 3/565; G01N 2015/0261; G01N 3/34; G01N 3/303
See application file for complete search history.

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Primary Examiner — Tran M. Tran
(74) *Attorney, Agent, or Firm* — Temmerman Law; Mathew J. Temmerman

(57) **ABSTRACT**

An apparatus and method for determining the hardness of a granular material, comprises a base plate member, a sample cup for holding the granular material, an upper plate member, a crusher assembly and a crusher hammer release mechanism. The base plate member includes an upper surface with a recess for holding the sample cup. The upper plate member is positioned above and separated from the base plate member utilizing at least one separator post. The crusher assembly includes a crusher shaft, a crusher weight, a crusher hammer and a linear roller bearing having a retaining ring configured to slidably engage the crusher shaft through a conduit with the crusher weight and the crusher hammer positioned above and below the upper plate member respectively. The crusher hammer release mechanism includes a pair of levers operably connected to a latch cable having a latch pin that runs through a compression spring.

22 Claims, 6 Drawing Sheets

HIT Potential Applications

- **Exploration Drill Core**
  - …rapid feedback to help develop metallurgical test programs, early inputs to geological modelling and mine planning, and quantify variability that impacts mill throughput.
- **Blast Hole Drill Rejects**
  - … verify what will actually be coming from the pit to manage blending of ore from stockpile to mill feed, and potentially optimize powder factors.
- **Mill Feed Samples**
  - compare actual hardness of ore from feed stockpile with predictions from mine plan and optimise the mill settings.

HIT Users x Application

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Company	Site	Application
Newmont	MTF Lab, Merian, Peñasquito	DDH, SAG feed samples
Agnico Eagle Mines Limited	CSD Lab / Meadowbank	DDH, SAG feed samples
Lundin	Chapada	DDH, SAG feed samples
PT Amman Mineral Nusa Tenggara	Batu Hijau	DDH, SAG feed samples
Glencore	Antapaccay	DDH, SAG feed samples
Teck	Highland Valley Copper	DDH, Blast reject samples
Newcrest Mining Limited	Lihir	Blast reject samples
Capstone Mining Corp	Pinto Valley	Blast reject samples
Taseko Mines Limited	Gibraltar	Blast reject samples

AGNICO EAGLE

Extract from SAG2019 Conference

"The value of daily HIT ore hardness testing at Meadowbank gold mine"

Yanick BERGERON, Senior Project Metallurgist
Karl LEETMAA, General Supervisor Process Plant Operations

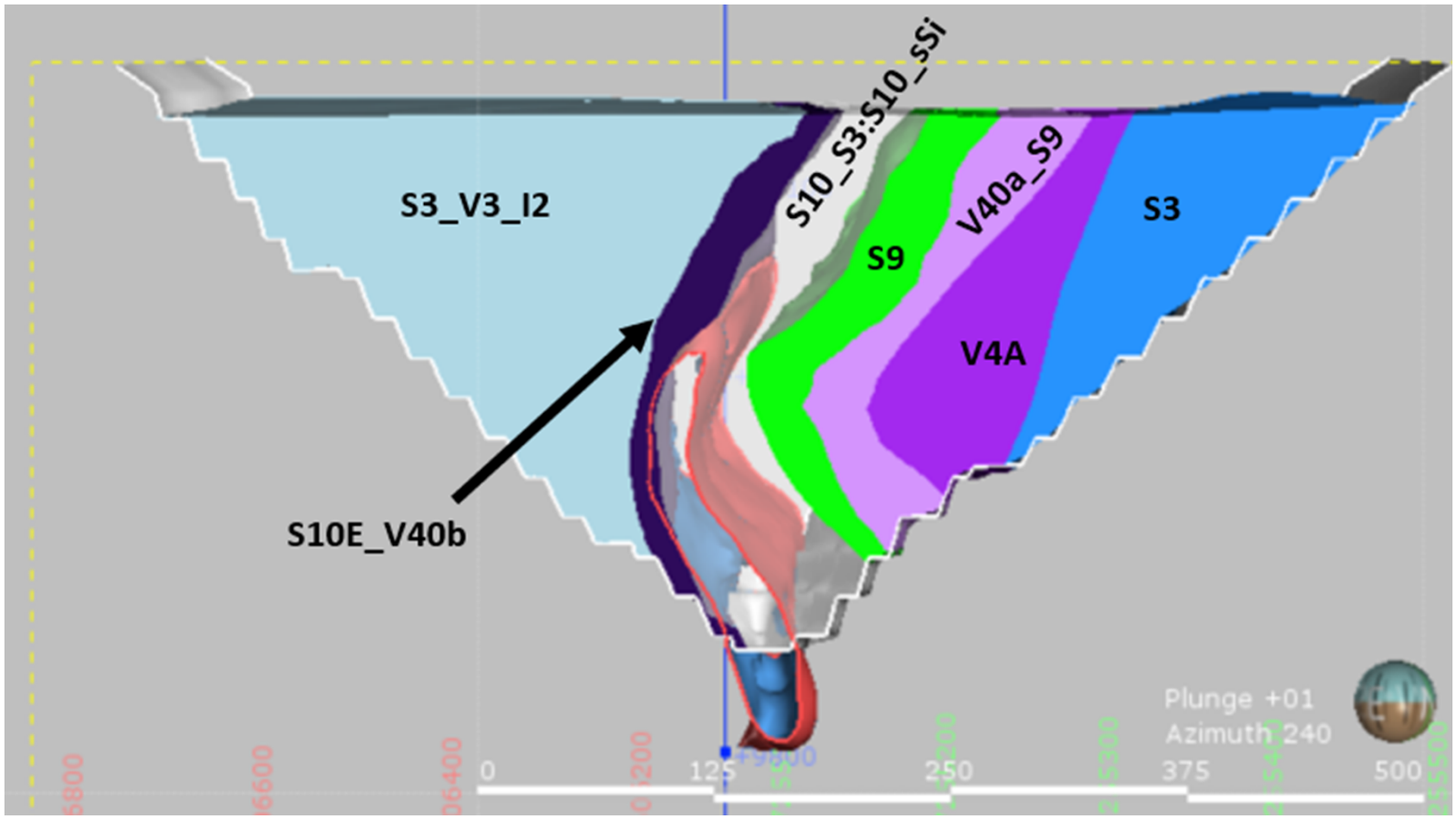
HIT Evaluation at Meadowbank

- Program initiated by AEML Meadowbank in late 2017
  - Significant ore variability; expected to affect both SAG and Ball Mill performance

SG (t/m^3)	Axb	Bond BMWi (kWh/mt)
2.72 - 3.15	25 - 52	13.7-16.2

- Can routine ore hardness testing, using daily SAG feed samples, assist in forecasting the SAB grinding circuit performance?
  - 10kg samples were collected over a 2-month period (53 operating days)
  - Submitted for HIT testing at CSD laboratory to provide estimates of both the competency (Axb) and grindability (Bond BWi) hardness.
  - Triplicate HIT Axb and duplicate HIT Bond Wi results (for each apron feeder sample collected)
  - Program extended until end of March 2018, with a further 107 days of sampling
- **Meadowbank deposit is now depleted and AEML has begun processing of Amaruq ore in their Meadowbank plant.**
- **Amaruq's geometallurgical program, including hardness characterization using the HIT, has been completed (August 2019).**

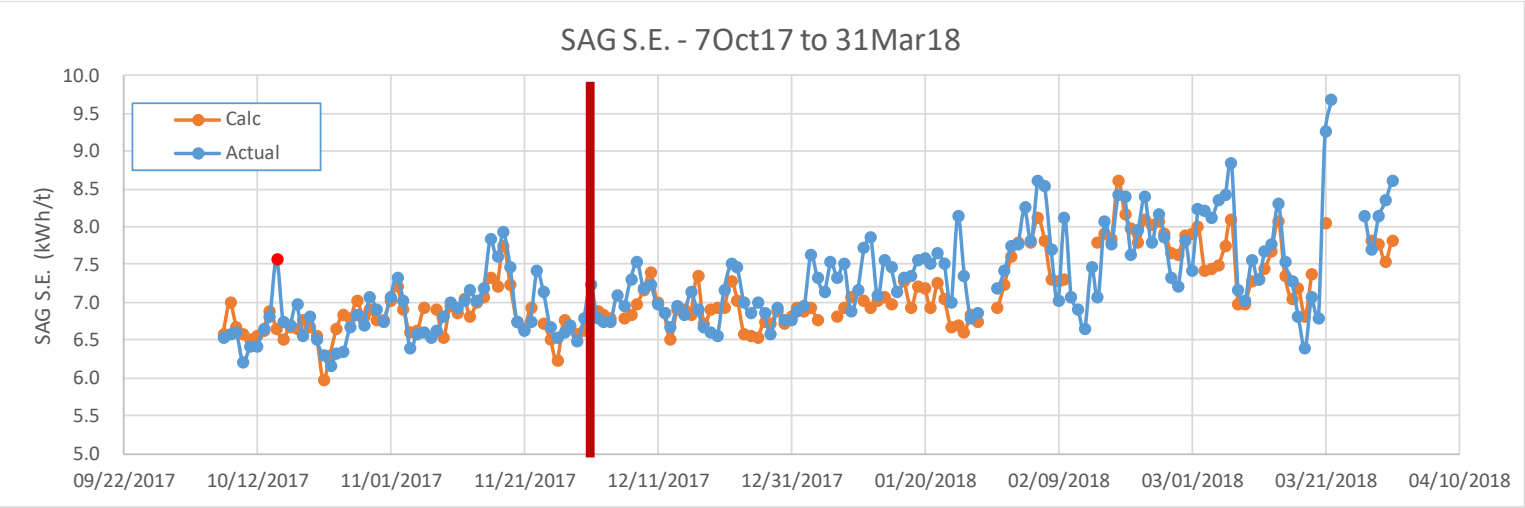
Amaruq Open Pit Geology Axb Hardness Model



Hardness domains interpreted from the standard and HIT results.

Validation Results

- Model developed from initial 53 days of monitoring used to forecast performance (SAG SE and Ball Mill P80) for remaining 107 days not used in model calibration.
- Clearly not as accurate as the calibration, but still within 5% relative error.
- Results very encouraging, correctly forecasting a major change in SAG Specific Power and BM P80 in mid-February 2018



Key Findings

- The Meadowbank HIT evaluation was the first of its kind
- Highlighted the key issues in attempting to use the HIT as a routine SAG feed hardness tester BUT results were still very encouraging!
  - Inconsistent sample taking due to operator changes.
  - Daily average operating performance vs one spot feed sample collected for HIT testing.
  - Manual sampling of coarse material challenging, despite finer SAG feed.
- As expected, variation in the grinding circuit performance was strongly correlated to the HIT ore hardness parameters.
- Better sampling strategy expected to improve model accuracy
- Data from the HIT test able to explain the throughput issues in Q1 2018.

- Given the success of the initial trial, Meadowbank continued with the HIT monitoring on their feed from the new Amaruq deposit.

Gibraltar HIT Experience

Presented at ME Global SUMMIT40 Conference

Adam Jordens,
Senior Metallurgist

Gibraltar HIT Experience

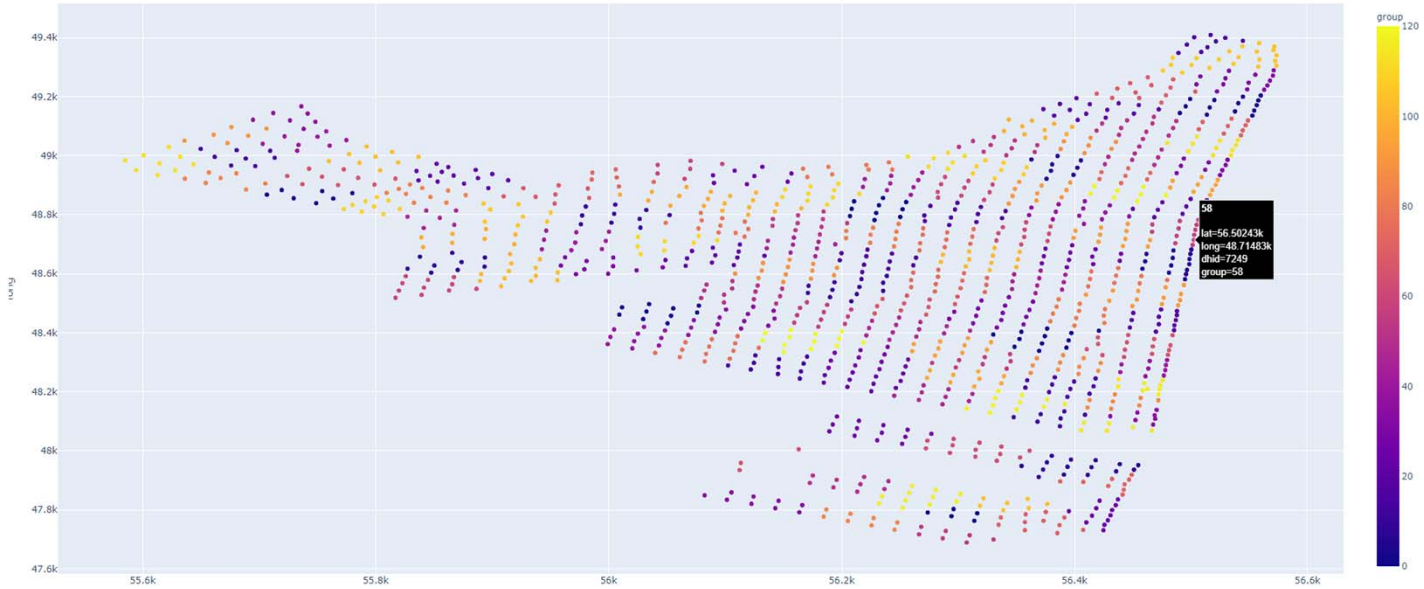
Blasthole sampling

- Gibraltar already processes drill rejects for chemical assay (mine planning)
- Drilling rejects samples submitted for assay have coarse fraction (-16/+13.2 mm) removed for HIT testing
- Samples are cross-referenced against drilling and blast database for lat/long
- Samples are grouped to provide adequate numbers of coarse rocks for triplicate testing

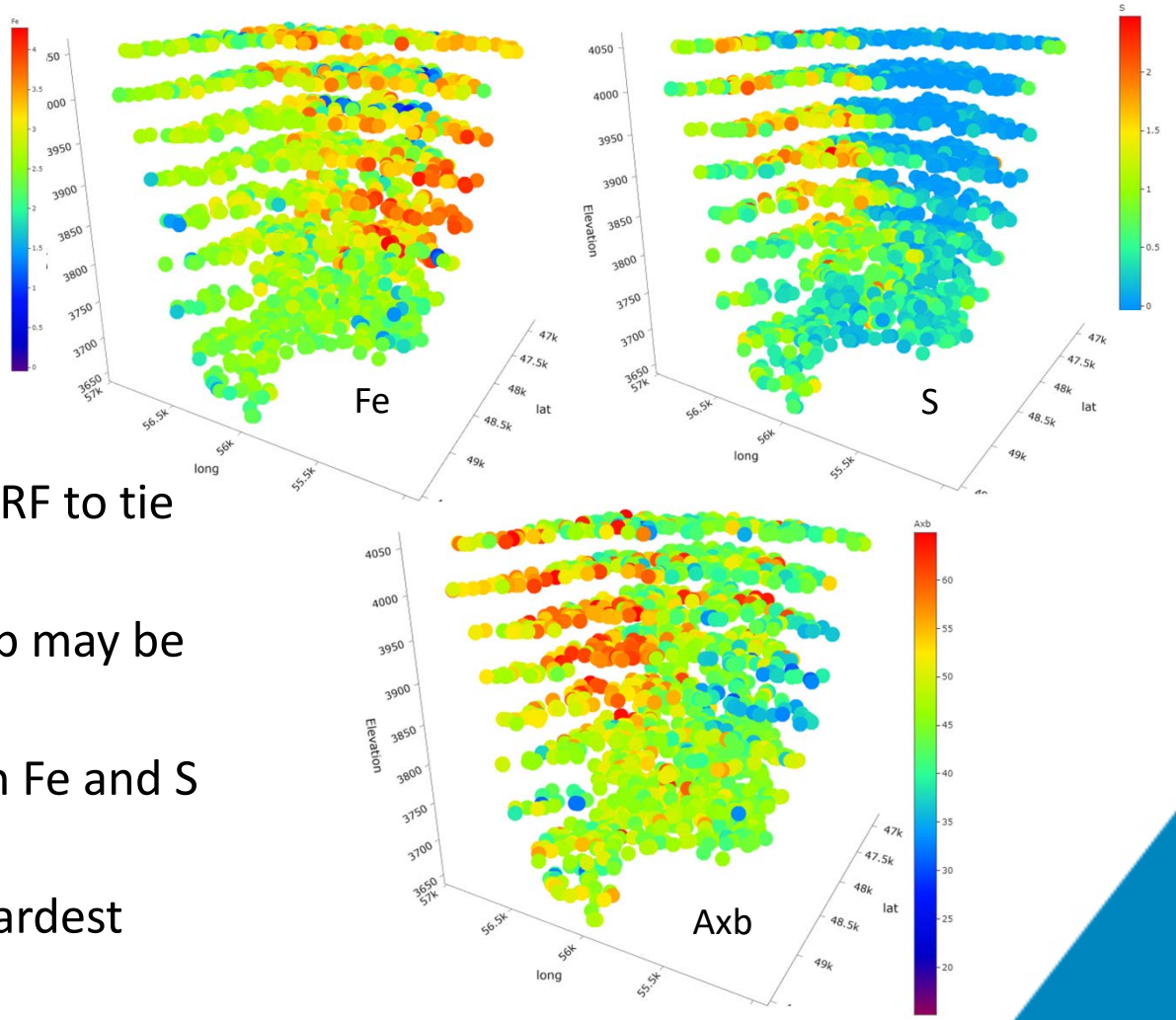
Gibraltar HIT Experience

Grouping

- Custom Python script to group nearest neighbours (lat/long)
- Available physical samples cross-checked against drill plot
- Groups selected for testing based on:
  - Testing resources
  - Maximizing spatial coverage for blast zone



Gibraltar HIT Experience



- All HIT samples are analyzed by XRF to tie hardness to geochemistry
- With full pit-sample XRF data, Axb may be estimated across each pit
- Axb shows strong dependence on Fe and S in this pit
- Regions of low S correspond to hardest samples (lowest Axb)

Long-Term Integration into Operations

Taseko Gibraltar

QA/QC

- Heavy use of HIT tester by multiple users requires diligent QA/QC program
- Importance of results for operating site lies in relative differences rather than absolute value accuracy
    - SAG mills have already been designed and installed

Value to Operations

- Value lies in identifying root cause of throughput variations:
    - Ore-driven (hardness, size)
    - Process deficiency (operator/control logic/process upset)
    - Equipment limitations
- Mitigation strategies have been employed for different ore zones
    - Powder factor
    - Crusher operation

Summary

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- **HIT provides an inexpensive and rapid solution for measuring ore hardness at site, in the lab or in the field.**
- **Industrial applications have confirmed integrity of device, mechanical and technical, and its potential for the generation of high volume Axb and Bond proxy information.**
- **HIT testing can easily show the difference in ore hardness, AND the extent of the inherent variability within the ore samples.**
- **Application of HIT testing to SAG feed and Blast Hole samples is now viable as a routine process, akin to assaying samples, providing valuable knowledge on the ore hardness variability and its impact on SAG throughput.**
- **Opportunities to automate HIT are being considered**

Gracias