International Journal of Mining Science and Technology 27 (2017) 71–76

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

# Void fill and support techniques to stabilize drift excavated through a transition zone mined by a TBM at the Stillwater mine

Johnson Josh [a,*], Jacobs Curt [a], Ferster Mark [a], Tadolini Stephen [b]

[a] Stillwater Mining Company, Nye, MT 59061, USA
[b] Minova, Georgetown, KY, USA

ARTICLE INFO

*Article history:*
Received 21 June 2016
Received in revised form 29 August 2016
Accepted 19 October 2016
Available online 21 December 2016

*Keywords:*
TBM
Ground
Dike
Cutterhead

ABSTRACT

Stillwater Mining Company is the only U.S. producer of platinum group metals (PGMs) and the largest producer outside of South Africa and Russia. The company controls a considerable portion of the J-M reef and is currently developing the "Blitz Project," which will provide a main haulage level, ore pass systems, backfill plants, and flow-through ventilation to increase production and ensure sustainable extraction of this critical strategic mineral. While driving two sub-parallel footwall laterals 8125 m in length, one of the development drifts experienced a massive fall in a geologically disturbed area created by a mafic dike intrusion. Combinations of a void fill material (Tekseal), polyurethane injection, fore poling coupled with steel arches, and supplemental bolting allow safe and efficient advance through this geologically disturbed zone. This paper presents the details of this project.



## 1. Introduction

Stillwater Mining Company is the only U.S. producer of platinum group metals (PGMs) and the largest producer outside of South Africa and Russia. The Company controls a considerable portion of the J-M reef and is currently developing the "Blitz Project," which will provide a main haulage level, ore pass systems, backfill plants, and flow-through ventilation to increase production and ensure sustainable extraction of this critical strategic mineral.

Tunnel boring machines (TBMs), shown in Fig. 1, have been used extensively at both the Stillwater Mine and the East Boulder Mine to develop access to the J-M Reef. The J-M Reef is a PGM-bearing reef deposit located in the Stillwater Complex near Nye Montana. The mining properties and location are shown in Fig. 2.

The Blitz Project is named after the Blitz mining claim and is designed to develop the Eastern extent of the J-M Reef. Project consists of a 5.5 m diameter TBM drive on the 50E (1562 m above sea level) and a 4.7 m × 4.7 m drill and blast heading on the 56E (1750 m above sea level). The Benbow Decline will be completed running perpendicular to the TBM by drilling and blasting methods. The TBM drift will be used for exploration drilling, ventilation, and will serve as the main haulage level. The 56E will be used for ventilation and exploration drilling. The Benbow decline will serve as the exhaust drift.

### 1.1. Geology

The Stillwater Complex is a 27-million-year-old, layered, ultramafic, intrusive rock exposed to the surface for 47 km along the Beartooth Range of South-Central Montana. The deposit, originally emplaced sub-horizontal, now sits dipping anywhere from 42° to the North, to overturned 80° to the South. The complex can be broken down into three major units: the basal series, the ultramafic series, and the banded series. The basal series averages 160 m in thickness and is a bronzite-rich unit with pods of massive sulfide. The ultramafic series ranges in thickness from 840 to 2000 m and is primarily composed of alternating layers of bronzitite, harzburgite, and dunite, with bands of chromite. Finally, the banded series has over 4500 m of layered norites, gabbros, and anothosites. The J-M Reef, the primary host for the platinum group mineralization within the deposit, sits in the lower portion of the banded series, 200–400 m above the ultramafics. A visual graphic of the Stillwater Complex Formation is shown in Fig. 3.

The excavations for the Blitz project have been designed to mine near the top of a major norite unit (norite zone 1) and the base of a banded gabbro, norite, and anorthosite unit (gabbro zone 1) roughly halfway between the ultramafic contact and the J-M Reef. This massive norite unit provides the most dependable ground conditions for mining but can become compromised by regional crosscutting structures and crosscutting mafic dikes of varying thickness. The mafic-rich rocks of the complex are prone to serpentine and talc alteration along fractures and joints. The

* Corresponding author. Tel.: +1 303 579 9330.
*E-mail address:* jjohnson@stillwatermining.com (J. Johnson).

http://dx.doi.org/10.1016/j.ijmst.2016.11.007
2095-2686/

**Fig. 1.** Robbins Main Beam (TBM) during setup.

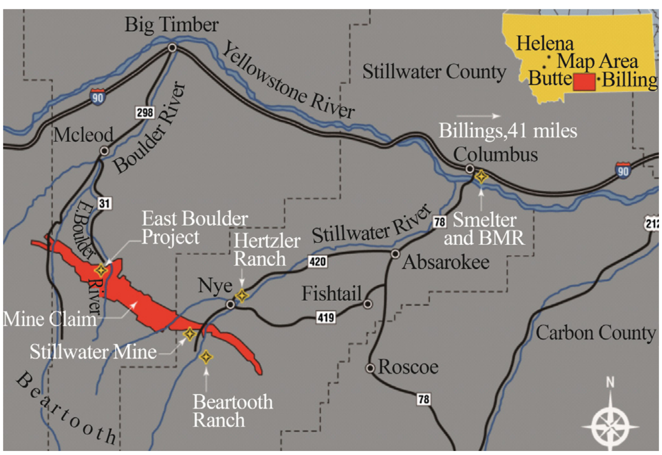


**Fig. 2.** JM Reef & Stillwater Mining properties.

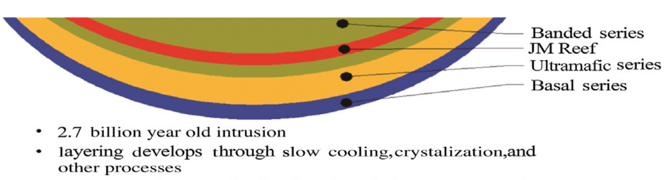


**Fig. 3.** Stillwater complex formation.

mafic dikes are typically associated with major structures, which can create difficult ground conditions with small block size and serpentinized contacts over distances of just a few meters to a few hundred meters.

### *1.2. Ground instability*

Geotechnical and exploration drilling is completed on regular intervals. Core drills are used to identify the J-M Reef to the North, the ultramafic series to the South, and expected ground conditions straight ahead of the TBM. Probes vary from 156 to 312 m, depending on conditions. In April 2014, the drilling revealed faulting and altered ground straight ahead of the TBM. That fault zone was intercepted in May by the TBM and drastically slowed advance rates. In July, more probes were completed and 94 m of highly fractured dike was identified straight ahead of the TBM. Limited maneuverability of the TBM required direct advance through the dike.

Until August 2014, only one crew operated the TBM four days a week due to the limited availability of experienced manpower. A second crew was added in August. Crews were scheduled Monday through Thursday for day and night shifts, which allowed for maintenance of the TBM over the weekend. By August, ground convergence in the fault zone, shown in Fig. 4, was so great that the steel ventilation ducting on the trailing decks had to be cut off and replaced with smaller oval ductwork to allow the machine to pass.

Poor ground conditions continued to slow the advance. In January 2014, one crew was able to mine 180 m of drift, but, in October 2014, two crews were only able to mine 28 m. By late October, the TBM was within 9.4 m of the dike contact. The dike was dipping away from the TBM creating a wedge consisting of low strength altered joint rock under high stress. The conditions in September 2015 are shown in Fig. 5. Note the folding of the roof; mesh and bolt installations stabilized the immediate roof. Fig. 6 shows the small block size and the geological alterations of the immediate roof.

Several times, the crew attempted to shotcrete the back with a high-strength accelerated-set polyfiber mix. Shotcrete was allowed to set up for 72 h before bolt installation and advance attempts were made. The shotcrete and ground failed due to the vibrations from drill hammers during bolting and cutterhead during advance. The failed shotcrete is shown in Fig. 7.

Ground failure continued until advance was no longer an option, and the void was filled. Fig. 8 shows the void. The wedge of poor rock continued to chimney up until the total height was over 18.7 m and was no longer measureable.

After the first void was filled and the TBM advanced through that zone, there were two smaller sections of fallout; one of which required filling before advance could continue. A schematic of the initial and subsequent failure zones is shown in Fig. 9. After investigating the situation, an error in the Program Logic Controller (PLC) was found that showed that all six drive motors were pulling full load amps, while, in reality, only half of the motors were working as designed. The lack of torque applied to the cutterhead required operators to back the head off of the active face to get the head to turn. This allowed ground to start failing. As the head was pulled back, muck would fail against the head and continually "chase" the head back. The lack of adequate torque to the cutterhead was the reason the second section required void fill.

**Fig. 4.** Drift convergence August 2014 (mesh was installed tight to rock surface).