Investigating Potential Subvertical Dewatering Wells at an Open Pit Mine

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Abstract

Groundwater poses a risk to mining at the Iron Ore Company of Canada (IOC). Ore bodies being mined are currently dewatered via borefields comprised of vertical wells. While vertical wells are a proven technology, and have enabled mining to progress below water table, they are not an optimal solution for every situation. Subvertical wells are an optimal alternative. Two subvertical pilot holes were recently drilled at IOC. Both intersected strongly weathered low RQD (<50%) aquifer and are therefore interpreted as viable well targets. This paper presents drilling results, in the context of well theory, and advocates for the construction of subvertical wells at IOC.

Keywords: Angled Well Drilling, Anisotropic Aquifers, Mine Dewatering, Iron Ore

Introduction

IOC is a leading North American producer of iron ore products and is jointly owned by Rio Tinto (project manager), Mitsubishi Corporation, and Labrador Iron Ore Royalty Corporation. Mining operations are located in the province of Newfoundland and Labrador, in eastern Canada (Fig 1). Five hydrogeologically complex ore bodies are being mined, near to or below water table, to meet current production targets.

At IOC mining below water table is achieved by dewatering ore bodies, in advance of mining, via borefields comprised of vertical wells. Sustained pumping has enabled mining to progress below the water table in active pits. While vertical wells are a proven technology, they are not a universal solution. Their main limitation is the required alignment between well collars, hydrogeologic features, and stable areas of the pit (i.e., areas not scheduled to be mined within five years).

Identifying long lived vertical wells has become problematic, but not impossible, in IOC's Luce Pit due to hydrogeologic features failing to align vertically with stable areas as the pit deepens. However, extensive hydrogeologic features do exist proximally to stable areas. As a result, subvertical wells represent a potential solution.

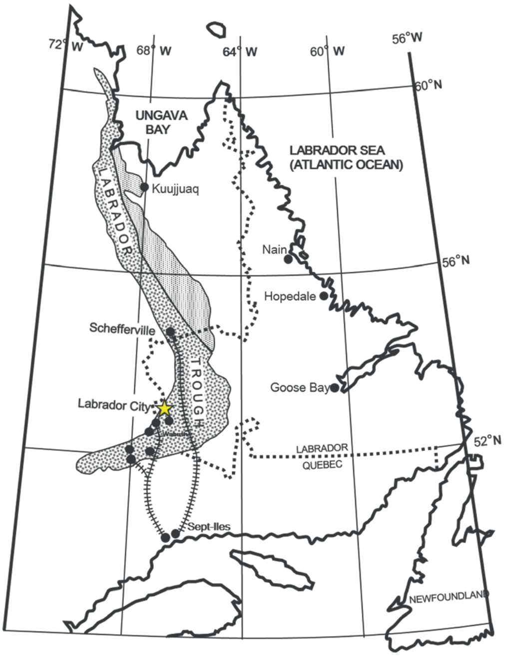

Figure 1 Geographic map of Labrador. Labrador Trough superimposed for context. Star indicates the location of the mine. Modified after Rivers et al. *(1978).*

Hydrogeologic Features

Rock comprising the deposit occurs within the 2.17–1.87 Ga aged Sokoman Iron Formation (Wardle *et al*. 2002), which is part of the larger Labrador Trough (Conliffe 2019) (Fig 1), and has been metamorphosed, folded, and faulted during two orogenies (van Gool *et al*. 2008). The age and tectonic evolution of the deposit gives rise to a variety of complex hydrogeologic features.

These features can be divided into two hydrogeologic domains (Moran 2019). Domain One, representing the majority of the deposit, is comprised of unaltered crystalline metamorphic non-porous and minimally transmissive rock (Brown *et al*. 2019). Domain Two is limited in extent and comprised of limonite alteration (Piteau 1981) associated with shear zones.

Hydraulic conductivity of the altered rock is several orders of magnitude greater than unaltered rock (Gnansounou *et al*. 2015) (Table 1). Domain Two features form distinct aquifers within Domain One. A well intersecting Domain Two features will be productive while a well only intersecting Domain One features will not (Moran *et al*. 2020).

Limonite alteration corresponds to low Rock Quality Designation (RQD) values at IOC (Moran *et al*. 2020). RQD values below 50% signify weathering while RQD values of 100% signify solid rock (Deere *et al*. 1988). Low RQD, limonitic rock, below water table and at depth, is a good indicator of potentially productive hydrogeologic features (Moran *et al*. 2020).

In Luce large low RQD, limonite altered, shear zones exist along the west wall of the pit (Owen *et al*. 2017). These features are proximal to an existing stable pit area, the Luce 470 elevation Dewatering Corridor (Fig 2a) and form the largest aquifer in this pit. The corridor, and the features, are therefore an ideal location for subvertical well placement.

Methodology

Work to identify subvertical well targets, along the Dewatering Corridor, began in 2019. Preliminary work involved reviewing the existing diamond drill core database for continuous intervals of strongly limonite altered low RQD rock. Continuity of the identified zones was confirmed through examination of the geologic, structural, and geotechnical models. Rates of groundwater decline, observed in surrounding piezometers, and the need to replace or augment existing wells were also considerations. Additionally, it was decided that target inclination should not exceed 20°, from vertical, in order to minimize potential complications during future well construction. Two potential targets, LU-20-594 and LU-20-595, met the selection criteria.

LU-20-594 and LU-20-595 were diamond drilled, in HQ diameter (63.5 mm) core size, during October 2020. Diamond drilling was utilized to maximize the amount of information retrieved. Falling head tests were conducted on both holes. Drill core was geologically and geomechanically logged, with particular attention paid to alteration and RQD patterns, and the core assayed at IOC's on site laboratory. Thin sections were made from select samples. 50 mm PVC pipe was installed to full depth and pressure transducers, programmed to collect hourly groundwater level readings deployed.

Results

LU-20-594 Pilot Hole

LU-20-594 is a potential subvertical replacement well for an existing, highly productive, vertical dewatering well (In-Pit 13). LU-20-594 was drilled at a 20° dip and a 183° azimuth to 203 meters. Drilling was stopped short, of a planned 250 meters, due to caving associated with extremely limonite altered low RQD rock. The hole intersected altered rock with RQD values ranging from 0% to <50%, from 110 meters to 203 meters (end of hole) (Fig 2b). Figure 2c shows the

***Table 1** Hydraulic conductivities for select Domain One and Two lithologies (Gnansounou* et al. *2015).*

Lithology	Hydraulic Conductivity (m/sec)	Geometric Mean(m/sec)
D1 Quartz-Carb (n=8)	5×10^{-11} to 9×10^{-7}	4×10^{-9}
D1 Quartzite (n=6)	2×10^{-10} to 2×10^{-7}	4×10^{-9}
D1 HMO (n=5)	4×10^{-11} to 3×10^{-4}	7×10^{-9}
D2 Limonite (n=4)	3×10^{-8} to 2×10^{-5}	6×10^{-7}

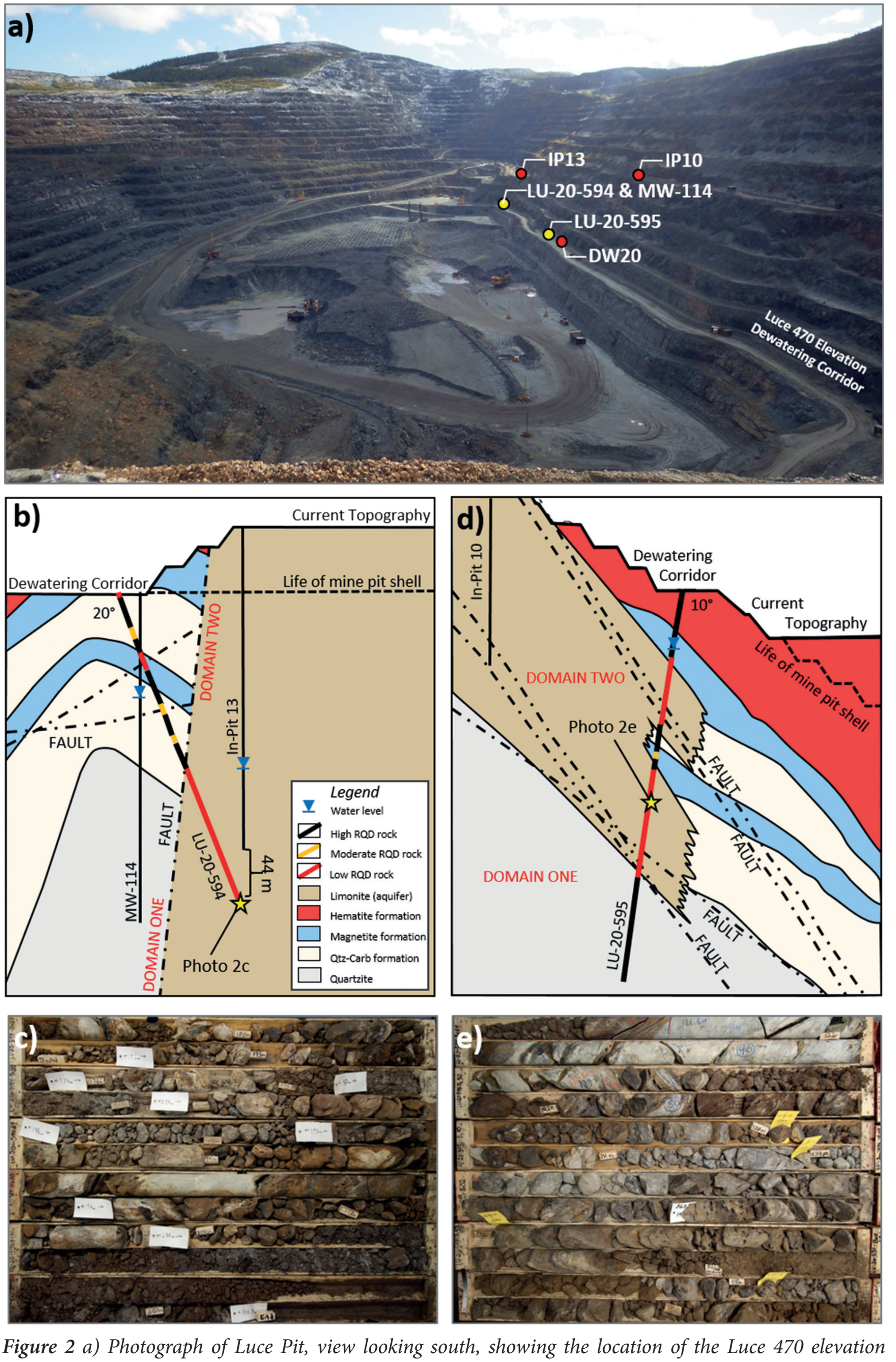

Figure 2 a) Photograph of Luce Pit, view looking south, showing the location of the Luce 470 elevation Dewatering Corridor, LU-20-594/595, IP13, and DW20 b) cross section showing LU-20-594 drill trace (shear zones modified after Owen et al. *2017), c) LU-20-594 drill core (169-203 m), d) cross section showing LU-20-595 drill trace (shear zones modified after Owen* et al. *2017), e) LU-20-595 drill core (121-144 m).*

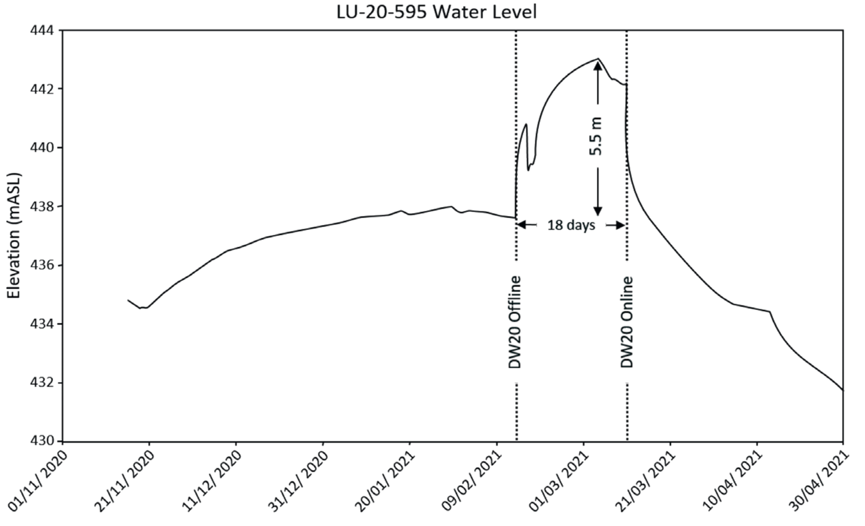

Figure 3 *LU-20-595 hydrograph annotated with DW20 downtime.*

drill core, from the very deepest portion of LU-20-594, altered to the consistency of sand (0% RQD). Thin sections show limonite alteration on the microscopic scale (Wingrove 2020).

The initial groundwater level was 73.2 meters (corrected for dip) below the collar. A falling head test was conducted upon conclusion of drilling. 1,052 litres of water were pumped downhole, over a 31 minute period, increasing the water level in the hole by 0.4 meters. Upon cessation of pumping the water level rapidly decreased.

Based on these results LU-20-594 is considered a viable subvertical well candidate. It is also 77 meters deeper than the bottom of, and in the same hydrogeologic feature as, In-Pit 13.

LU-20-595 Pilot Hole

LU-20-595 is a potential subvertical replacement well for an existing, moderately productive, vertical well (Dewatering Well 20 [DW20]). LU-20-595 was drilled at a 10° dip and a 303° azimuth to 251 meters. Drilling reached target depth. The hole intersected limonite altered low RQD rock, in two distinct intervals: from 44 to 83 meters and 104 meters to 182 meters (Fig 2d). RQD values range from 2% to <60%. Rock below 182 meters is unaltered and high RQD representing non-hydrogeologically productive material. Figure 2e shows the low RQD, limonite altered rock, intersected at depth in this hole.

The initial groundwater level was 35.9 meters (corrected for dip) below the collar. A falling head test was conducted upon conclusion of drilling. 1,770 litres of water were pumped downhole, over a 30-minute period, increasing the water level by 14.6 meters. The water level returned to a pre-test level four minutes after cessation of pumping.

Groundwater level increases during periods when DW20, located 60 meters north, is not pumping (Fig 3). This indicates LU-20-595 intersected features connected to the larger hydrogeologic features.

Based on these results LU-20-595 is considered a viable subvertical well candidate. Furthermore, it intersects the same hydrogeologic features at over twice the depth as DW20 (Fig 2d)

Discussion

Subvertical wells are simply vertical wells drilled at a steep angle. Both well types are straight casing completions and therefore share fundamental characteristics. Many vertical wells have been constructed at IOC making subvertical wells a logical progression. The crucial difference between the two well types is that subvertical wells can access a larger area, and more hydrogeologic features, from a single collar location (Short 1993). This concept is demonstrated in Figure

4. This makes subvertical wells especially advantageous in areas with limited space, like the 470 elevation Dewatering Corridor, to collar wells. In comparison, vertical wells are constrained to intersecting water bearing features directly below where the well is collared.

Figure 4 illustrates how a 200 meter long well drilled at progressively shallower angles increases the range of ground accessible from a single collar location. A 200 meter well drilled at 10°, from vertical, covers approximately 3,681 m^2 while the same length of well drilled at 20° covers approximately 14,698 m^2. Increasing the angle by 10° results in a 300% increase in the coverage area!

Increasing the area accessible from a single collar location also potentially increases the number of accessible hydrogeologic features. Hydrogeologic features can be large and continuous, like those intersected in LU-20-594 and LU-20-595, or small and discrete (e.g., faults, joints). The application, and benefit, of subvertical wells is different for different features. For large well-connected features (aquifers), like those proximal to the 470 elevation Dewatering Corridor, the main benefit is the flexibility from which the feature can be accessed (e.g., location of the wellhead). For discrete features, subvertical wells improve productivity because flow into a well is proportional to the amount of a well's surface area in contact with transmissive rock (Short 1993). By orienting a subvertical well, parallel to and down dip, the amount of well surface area in contact with transmissive rock is maximized.

Figure 5 is a hypothetical cross section, not representing any one pit or deposit, illustrating the concept of dewatering well placement. As mining deepens Luce Pit hydrogeologic features and stable areas of the pit are failing to optimally align (5a). Vertical wells can still be constructed but they intersect transmissive rock for only a portion of their length, and it is necessary to construct them in areas of the pit that will be relatively short lived (Fig 5b). Subvertical wells fully or partially resolve these problems. Well collar locations, water bearing features, and pit shells can be uncoupled by collaring at a suitable location and drilling at an angle into hydrogeologic features (Fig 5c). The length of transmissive rock intersected can be maximized by adjusting the subvertical well azimuth and dip (Fig 5d). Subvertical wells even have the potential to be collared outside, and angled under, pit limits (Fig 5e).

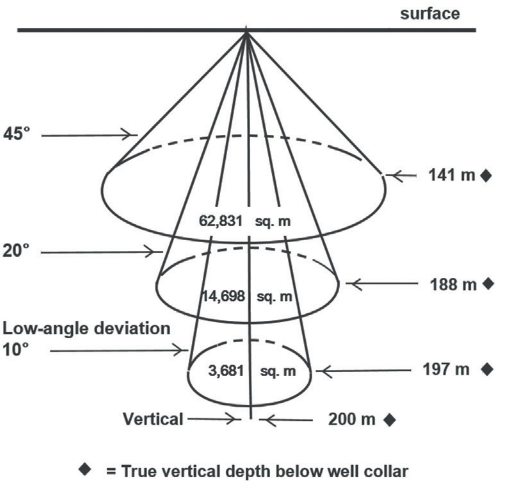

Figure 4 Subvertical wells increase accessible ground from a single collar location. Figure modified after short (1993).

Conclusions

Dewatering Luce Pit with subvertical wells is an enhanced alternative over vertical wells. Subvertical wells potentially increase mining flexibility, broaden the range of available targets, result in longer lived wells, and reduce the need for costly pit step outs. They can unlock further value by increasing the type, number, and productivity of water bearing features. Two viable subvertical well targets, LU-20-594 and LU-20-595, have been identified in Luce Pit. They are recommended to be re-drilled as subvertical dewatering wells. Successful implementation of subvertical wells has the potential to unlock substantial value, not only in Luce Pit, but across all pits at IOC.

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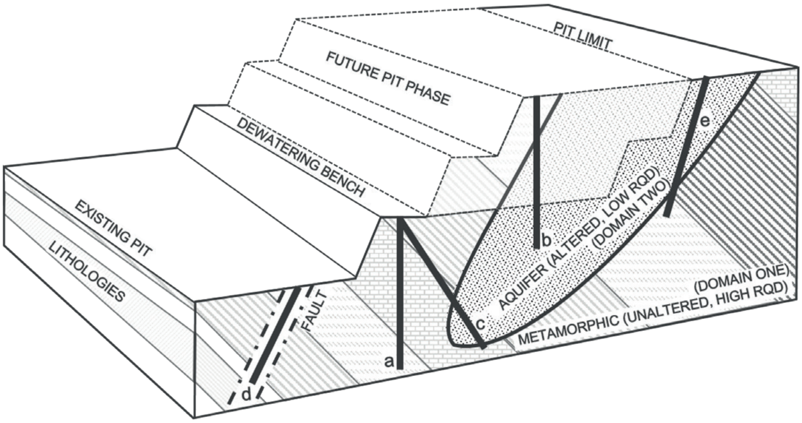

Figure 5 Hypothetical section demonstrating vertical and subvertical well placement relative to mine design and hydrogeologic features.

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