HYDROGEOLOGY OF THE HOMESTAKE MINE

Perry H. Rahn and William M. Roggenthen
Department of Geology and Geological Engineering
South Dakota School of Mines and Technology
Rapid City, SD 57701

ABSTRACT

Mining of gold ore at the Homestake Mine in Lead, South Dakota, ceased in December, 2001. Water normally pumped from as deep as 8,000 ft below the surface will begin to flood the mine if and when the pumps used to de-water it are turned off. We estimate the total volume of voids (drifts, shafts, and stopes) within the mine to be approximately 752 million ft³. At a constant rate of ground water infiltration estimated at 500 gpm, this void space would take approximately 21 years to fill. The dewatered zone of the Precambrian and Tertiary intrusive rocks may contain an additional void space of 35 million ft³, which would increase the time necessary for filling the mine to approximately 22 years.

INTRODUCTION

On December 14, 2001, the Homestake Mine ceased mining ore although pumping and closure activities continue to the present time. Since the discovery of the original lode in 1876, the mine produced about 10% of the nation’s gold. The mine includes an Open Cut, shown in Figure 1, but most of the mine is underground and contains a vast network of drifts, shafts, and volumes that were mined-out (Fig. 2). At 8,000 ft depth, it is one of the deepest mines in the world. The mine has about 63 levels and approximately 300 miles of horizontal drifts (Davis, 2001).

An experiment to capture solar neutrinos using a 100,000 gallon chlorine detector has been operating at the 4850 ft level since 1965. Data from this experiment provided critical information about the neutrino flux through the earth, and the cessation of mining has led to proposals to expand the neutrino experiment. The expansion of the physics experiments would increase the types of neutrinos that could be detected and the efficiency of the detection (Bahcall et al., 2001). The experiments might be located as deep as the 7400 ft level, and the large volume of rock that would overlie the experiments would greatly decrease the cosmic ray background radiation and thus allow a host of particle physics experiments to be conducted. One concern, however, is the amount of water in the mine. If completely abandoned, the pumps used to dewater the mine would be turned off, and ground water would begin to flood the drifts and shafts.

Construction of the proposed particle physics experiments will take considerable time and effort and will present some engineering challenges. The
Figure 1. Topographic map of Lead, South Dakota (from Deadwood South and Lead USGS 7.5' topographic maps), showing location of Homestake Mine. The contour interval is 40 ft. Cross section A-A' is shown in Figure 2.
handling of the water inflow during the interim period between abandonment and the construction of the experiments will be an important factor. It is useful, therefore, to consider the scenario of complete abandonment, which would entail the shutting down of the pumps used to dewater the mine.

Water presently entering the mine primarily comes from ground water sources resulting from natural precipitation and recharge from local streams. The average annual precipitation is approximately 28 in, of which approximately 8 in infiltrates and recharges the Madison Limestone (Driscoll and Carter, 2001); presumably recharge to the Precambrian rocks would be much less. Streams that could supply recharge include Whitewood Creek, Deadwood Creek, and Grizzly Creek (Fig. 1). The main portion of the mine directly underlies Whitewood Creek but some of the shallower drifts underlie Deadwood Creek. Whitewood Creek at Deadwood has an annual discharge of 27 cfs (Driscoll and Carter, 2001). Using data from similar Black Hills streams (Rahn and Davis, 1993), the average discharge for Deadwood Creek is approximately 2 cfs.

While the mine operated, water discharged from the mine included naturally infiltrating ground water (approximately 500 gpm) and water contained in the tailings used to backfill the mined-out volumes (approximately 1,000 gpm) (Davis, 2001). The specific locations where ground water enters the mine are not known, although a likely collection and inflow point is in the open pit, which connects to the underground through a series of older workings. The combined discharge of Whitewood and Deadwood Creeks (29 cfs) greatly exceeds the 500 gpm (equivalent to 1.1 cfs) now entering the mine. Therefore, a direct connection between these streams and the underground does not exist at the present time. In general, the Homestake Mine is considered a "dry" mine because, considering its vast size, relatively small amounts of ground water seep into the mine.

The purpose of this paper is to examine the hydrogeology of the Homestake Mine with particular emphasis on the rate of ground water that would fill
the mine upon abandonment. In order to determine the time required for water to fill the mine, it is necessary to determine the void space that is created by: (A) man-made openings created directly by the mining, and (B) the dewatered void space created by the cone of depression from the dewatering activities.

A. Volume of Voids Created by Mining

To determine the artificial void space in the mine, we assume that the void space is due to: (1) drifts, shafts, and (2) the mined volumes (stopes) that were back-filled with tailings:

(1) Drifts:
We assume there are 300 miles of drifts and shafts, with a typical 10 ft X 10 ft cross-section. Therefore the volume = (5280 ft/mile)(300 miles) (10 ft X 10 ft) = 158 X 10^6 ft^3.

(2) Mined volumes:
The total gold production of the mine was approximately 40 million (troy) ounces (http://pubs.usgs.gov/gip/prospect1/goldgip.html). We assume the ore contained an average concentration of 0.3 ounces of gold per ton. Therefore the tonnage mined = 40 X 10^6 oz/0.3 oz/ton = 133 X 10^6 ton.

In addition to the voids created by mining the ore (per se), "waste rock" was also removed. We assume the waste rock amounted to 25% of the volume of ore mined. Therefore, the total rock removed by mining activities in connection with ore removal = 125% (133 X 10^6 ton) = 167 X 10^6 ton.

To convert tonnage (mass) to volume, we assume the rock density = 2.7 gm/cm^3 = 168.5 lb/ft^3 = 0.08425 ton/ft^3. Therefore, the volume of mined out volumes (including the ore plus waste rock) = 167 X 10^6 ton/0.08425 ton/ft^3 = 1,980 X 10^6 ft^3.

The mined-out volumes were back-filled with tailings (largely sand). We assume the porosity of these back-filled zones = 30%. Therefore, the void space in these zones = 0.30 (1,980 X 10^6 ft^3) = 594 X 10^6 ft^3.

From the above, the total man-made void space at the Homestake Mine is:
(1) Drifts . . . . . . . . . . . . . 158 X 10^6 ft^3
(2) Mined volumes . . . . . . . 594 X 10^6 ft^3
Total . . . . . . . . . . . . . . . . . . 752 X 10^6 ft^3.

B. Volume of Voids Due to Dewatering

The extent of the cone of depression created by dewatering can be approximated. No observation well surrounding the Homestake Mine is known which could be used to construct a cone of depression around the mine. However, hydrologic information from nearby perennial streams and abandoned mines allow for a general interpretation of the cone of the depression. For example, Whitewood Creek and Deadwood Creek (Fig. 1) seem to maintain their flow all year long. The Cutting Mine (near Central City on Fig. 1) is the water...
supply for the town of Lead. Originally, water ran freely out of the portal of this abandoned mine, but now the water is just at the entrance (Fred Raubak, pers. comm.).

In 1994 an exploratory drift was completed which extended northward from the 6800 level approximately 13,000 ft (Lalonde, pers. comm.). The drift encountered ground water reportedly under very high pressure. Based on this observation, the cone of depression had not extended into this region at the time of the construction of the drift.

The cone of depression most likely is not symmetrical. The mine is developed in Precambrian metamorphic rocks with minor amounts of Tertiary intrusives (Bachman and Caddey, 1990; Rogers, 1990). Jointing, foliation, and lithologic changes in the Precambrian rocks should influence the shape of the cone of depression. For example, joints measured from aerial photographs in Precambrian rocks show N 30º W and N 75º E trends (Lisenbee, 2000). Rahn and Johnson (2002) found that a N 20º W foliation in Precambrian metamorphic rocks near Nemo strongly influenced the direction of flow of contaminated ground water. The N 20º W to N 30º W foliation extends throughout Precambrian rocks in the Black Hills. As such, it would be expected that a cone of depression would be more extensive from the mine in this direction. Yet the Cutting Mine, located northwest of the mine, still contains water. It appears, therefore, that a large cone of depression from the Homestake Mine does not exist. Rather, in this low permeability rock, dewatering probably is restricted to the workings and the rock in the immediate vicinity of the mine (Fig. 2).

Given the above discussion, a simplifying assumption is that only the mined area itself, the complex of shafts and drifts, has been dewatered during the 100+ years history of the Homestake Mine. To calculate this volume, we assume a geometry of a truncated cone having a 15,000 ft diameter at the 8000 ft. level and extending upwards at a 45º angle to the surface. Thus the dewatered volume is 3.5 x 10¹² ft³.

The porosity of this dewatered zone can be only estimated. The mine is mostly within Precambrian metamorphic rocks of the Homestake Formation, a grunerite schist. Some fractures exist, and in the dewatered zone the gravitational water can drain out, leaving a void space. Fracture porosity and permeability in metamorphic rock decreases exponentially with depth (Davis and DeWeist, 1966). We judge that the average porosity of all the dewatered rocks would be less than 0.01 %. Of this, we estimate that only 10% of the void space would contain gravitational water that actually drained out due to dewatering, and the remaining 90% of the water would be retained due to capillary forces. Therefore, the volume of water removed is approximately 35 X 10⁶ ft³. If the mine were to fill, water would resaturate these voids. It should be noted that if gravitational water occupied 50 % of the pore space, then the volume of water removed by dewatering would be increased by a factor of five.

From the above, the total voids created by the mine workings and the dewatering is:

Mine workings . . . . . . . . . . 752 X 10⁶ ft³
Cone of depression . . . . . 35 X 10⁶ ft³
Total . . . . . . . . . . . . . . . . 787 X 10⁶ ft³
Time Required to Fill the Mine

To determine the length of time required to fill the voids, we assume a constant natural ground water infiltration rate into the Homestake Mine of 500 gpm. Assuming a constant rate of fill, the length of time required to fill the Homestake Mine = 787 X 10^6 ft^3/66.84 ft^3/min = 11.7 X 10^6 min = 8176 days = 22.4 years.

The rate that ground water fills any mine would not be constant with time. An analogy can be made to a pumped well. When the pump is turned on, the water level in the well drops quickly at first, but then gradually slows down until a nearly constant water level is obtained. When the well is turned off, the water level in the well quickly rises, but slows down as it gradually obtained the water level before the pump was turned on. The recovery curve is a mirror image of the drawdown curve (Driscoll, 1986). The drawdown and recovery applies to the well being pumped and the area immediately surrounding the well. For the Homestake Mine, it is not feasible to apply well pumping analogy using aquifer constants (transmissivity and storativity) to create a theoretical cone of depression and the mirror image curve for recovery Precambrian rocks in the Black Hills. Transmissivity can be estimated from specific capacity measurements. Galloway and Strobel (2000) measured the specific capacity for 71 shallow Precambrian wells, and they found an average of 51 gpm/ft of drawdown. The Precambrian rocks generally have low permeability (Rahn and Gries, 1973), but transmissivity values representative of the 8000 ft section are not available. Nevertheless, from typical well drawdown and recovery behavior, one would expect a gradual slowing of the rate of filling. Therefore we believe the 22-year figure obtained above using a constant 500 gpm recharge rate is a minimum time to fill.

CONCLUSION

If pumping of water ceased at the Homestake Mine, we believe it will take more than 22 years to flood the abandoned workings. Our calculations are based on limited data concerning the porosity of the dewatered zone, as well as unconfirmed data concerning the size of the mine and the ground water recharge rate. Additional work would be useful to more fully delineate the variation of porosity and permeability of the metamorphic rocks as a function of depth.

As the water rises to its original (pre-mining) elevation, discharge from the workings would be expected to flow into Whitewood and Deadwood Creeks. The chemistry and the discharge rate from these workings in the future are not known. However, if any adverse environmental impacts from this water were to occur, they might be due to acidity and dissolved metals because the ore contains arsenopyrite and other sulfides, and it is known that the unregulated disposal of tailings in Whitewood Creek resulted in arsenic contamination of surface and ground water (Goddard, 1989; Rahn et al., 1996).
REFERENCES CITED


