Dissolution-Induced Mine Subsidence at the Retsof Salt Mine

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INTRODUCTION

On March 12, 1994, a roof fall occurred within Akzo Nobel's Retsof salt mine near Geneseo, New York. The roof fall was part of a process that led to an unstoppable inflow of fresh water into the mine. The inflow has since completely inundated the mine. Piping of sediments through fractured hard rocks (limestones and shales) over the mine caused sinkholes to form over the inflow area. Dissolution of salt from within the mine by the inflowing fresh water produced significant increases in both subsidence rates and eventual subsidence over a finite area along primary flow paths from the inflow to the higher elevations of the mine. This paper discusses the dissolution-induced subsidence during the 21 months of active inflow and the first several months after the mine was filled.

The roof fall on March 12, 1994, affected what is known as 2 Yard South, which consisted of an isolated yield-pillar panel. From descriptions by Akzo Nobel Salt employees and Dr. Hamish Miller and Mr. Gary Peterson, rock mechanics consultants who inspected the inflow area, a 30-foot-thick mass of shale roof rock fell into the panel, and water was flowing from the eastern access to the panel. This water was generally believed to have been flowing through broken or fractured shales from the overlying limestone rocks (Onondaga, Cobleskill, and Bertie Formations) and into the mine. The inflow rate was first measured at more than 5,000 gallons per minute (gpm). Later, based on the volume of the mine affected by the advancing shoreline as the mine filled, the inflow rate is estimated to have been more than 15,000 gpm but less than 20,000 gpm. The time required to fill the mine (approximately 21 months) substantiates this range.

Sometime during April 1994, water may have also begun to flow into the mine within another panel known as 11 Yard West. Panel 11 Yard West had been mined as a yield-pillar panel in a manner similar to 2 Yard South. Indications for inflow into this panel were an increased rate of water level rise in the mine and later, surface-subsidence patterns. On May 25, 1994, a sinkhole developed above 11 Yard West. A similar, although smaller, sinkhole had developed over the 2 Yard South panel a few days after the start of the inflow in that panel. By early June 1994, the sinkhole over 11 Yard West was about 600 feet in diameter and 70 feet deep. The calculated volume of the 11 Yard West sinkhole was 340,000 cubic yards (yd^3) and the volume of the 2 Yard South sinkhole was 140,000 yd^3, based on June 8, 1994, measurements. The size of these sinkholes has not visibly increased since that time.

Significant surface subsidence has been measured over the entire southeastern area of the mine. Even away from the sinkholes, the surface subsidence rate increased severalfold after the inflow when compared to the subsidence rates measured before the inflow. This accelerated subsidence has since abated, and the current subsidence rates over the areas of the mine where historical data were available are now at or less than preinflow rates.

To understand the recent subsidence over the Retsof Mine, one must consider the mine as three distinct areas. One area (inflow area) encompasses the surface immediately over 2 Yard South and 11 Yard West, which is the area of the sinkholes and the area immediately surrounding them. The size of this area is about 50 acres. The second area (significant dissolution area) is over that part of the mine within about 10,000 feet of the first area and covers about 1,000 acres. The third area includes the surface over the rest of the mine; about 5,500 acres. Dividing the mine into three distinct areas is required because what has happened is different for each area. The three areas are shown in Figure 1.

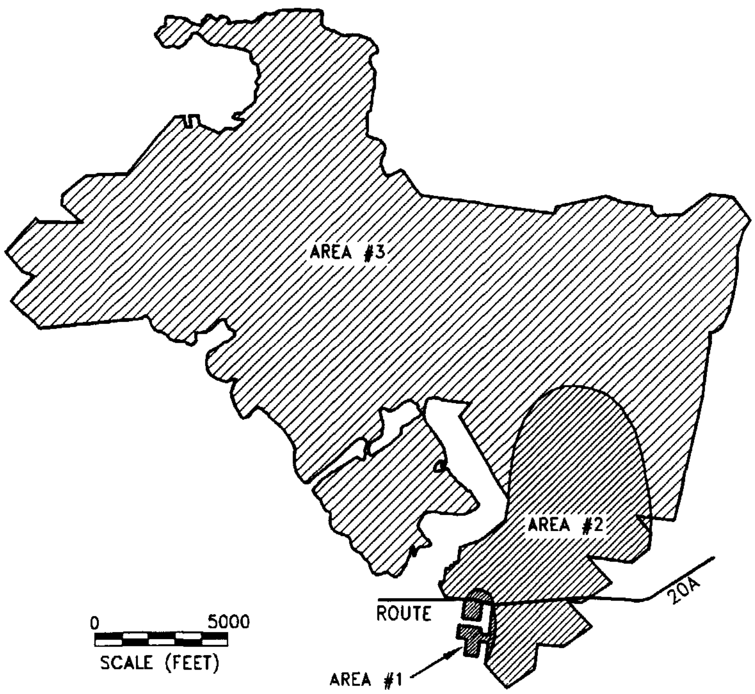

Figure 1. Division of the Retsof Mine Into Three Areas for Discussion Purposes.

In the immediate inflow area, surface damage manifested itself within the first few months to nearly its full extent. Two sinkholes developed over the area where water entered the mine. Apparently, the rock layers above the mine fractured because of unusual geologic conditions in combination with mining. These fractures allowed fresh water from the overlying water-bearing glacial valley till to flow downward and through limestone and shale formations. As the water passed through the shales and, later as it flowed through the mine, salt was dissolved. The removal of salt caused a loss of support for the shales and other rock above the mine. Eventually, where dissolution was severe, the shales and limestone layers above the shales broke and fell into the void created by dissolution. When the limestone layer broke, it allowed the glacial till from the top of the rock all the way to the surface to slump downward, which is what created depressions on the surface (sinkholes). The sinkholes and damage to the highway, the Route 20A bridge, and a nearby farm are localized consequences of where water entered the mine and are not the result of general subsidence over the mine.

The second area is defined as where the fresh water dissolved salt left to support the rock above the mine (overburden). This dissolution area is outside the immediate inflow area and extends northward for about 10,000 feet. Because support was taken away, the overburden moved downward faster than normal. For example, before the inflow, the surface over the southeastern area of the mine was subsiding at a rate of about 0.5 foot per year. In the same area approximately 5 months later, the surface subsided at measured rates of 3 to nearly 50 feet per year. It is obvious now that a large amount of salt was dissolved from this area. Therefore, the subsidence was larger and sooner than would have been expected for a dry mine situation. On the other hand, because a large amount of salt was dissolved in this area, less salt was dissolved in other, more distant, areas of the mine.

A significant portion of the mine (about 5,500 acres) has been filled with saturated brine. The presence of the brine has not produced deleterious effects. In fact, subsidence rates over the area should be (and apparently are) reduced by the beneficial confinement on salt pillars provided by the brine pressure. Future subsidence over the large area of the mine (Area 3) will approximate the magnitude expected for a dry mine scenario, but will occur at a slower rate. Consequently, centuries may pass before ultimate subsidence is achieved.

Figure 2 shows a contour plot of the measured subsidence over Areas 1 and 2, as described above. The maximum subsidence is about 18 feet (north of the inflow areas). Most of Area 2 experienced from 2 to 10 feet of subsidence during the 24-month period. The magnitude and pattern for the subsidence can be explained by the dissolution of salt within the mine as it filled. Van Sambeek [1996] presents a complete set of subsidence plots for the period from March 1994 to March 1996.