The Compass: Earth Science Journal of Sigma Gamma Epsilon

Volume 85 | Issue 4 Article 1

3-10-2014

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Recommended Citation
Neuhauser, Kenneth R. and Redetzke, Daniel J. (2013) "An Applied Geophysical Detection and Subsequent Mitigation of an Abandoned Well Casing Penetrating the Permian Hutchinson Salt at an Undisclosed Kansas Salt Mine," *The Compass: Earth Science Journal of Sigma Gamma Epsilon*: Vol. 85: Iss. 4, Article 1.
Available at: https://digitalcommons.csbsju.edu/compass/vol85/iss4/1

AN APPLIED GEOPHYSICAL DETECTION AND SUBSEQUENT MITIGATION OF AN ABANDONED WELL CASING PENETRATING THE PERMIAN HUTCHINSON SALT AT AN UNDISCLOSED KANSAS SALT MINE

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ABSTRACT

A surface field survey, using a cesium magnetometer, successfully targeted the spatial location of an abandoned buried well casing. Surface excavation exposed the top of the well casing, but attempts to drill out the casing from the surface failed due to the difficulty of keeping the drill bit on-line with the casing. The casing was successfully sealed off by grouting through the ceiling and floor from within the mine.

KEY WORDS: Environmental geology, geologic hazards.

INTRODUCTION

In early February, 2010, miners at an undisclosed Kansas Salt underground mine encountered an abandoned well of unknown type and origin. The well was not documented with the state geologic survey nor shown on any available maps. The well created a potential hazard to the mine as it was a conduit for groundwater to enter the mine which had the potential to cause damage by dissolution of salt and potential small-scale flooding. The well was not immediately visible to the miners as it was located about one meter into the solid working face at the end of a side-cut, just off to the side of the main drift +heading. Instead, it was discovered when trapped water which had developed head pressure burst out through three "boot holes" that pierced into the well bore cavity during normal salt blasting involved in the mining process. No one was present when this occurred, as the miners evacuate just prior to blasting at the end of each shift. The evidence of the sudden burst of water appeared sometime after the blast, as an unusual mark left behind on the wall or “rib”, as miners commonly call it, where the water had sprayed out and deposited bits of shale and debris from the old well (fig. 1). The excess water soaked through to the base of the freshly blasted pile of salt, although it was not immediately apparent until the salt was removed.

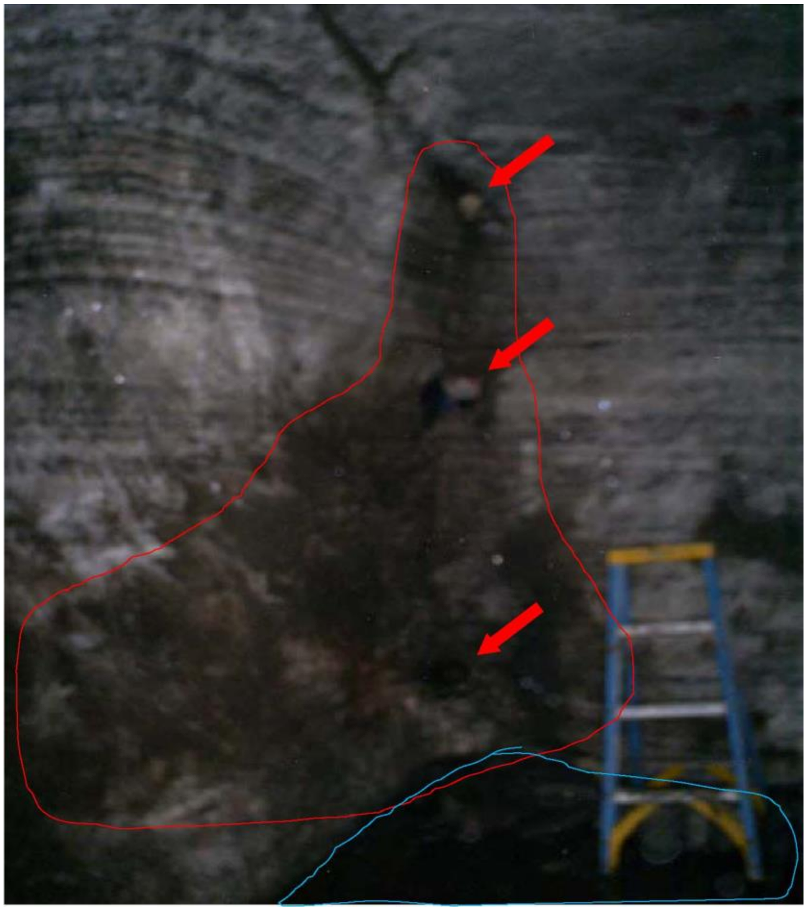

Figure 1. Red arrows indicate where the blast “boot holes” which intersected the abandoned well are located. The thin red line outlines the area along the “rib” affected by the water/mud spray following the blast that exposed the abandon well bore. The blue line outlines standing water left on the floor. The ladder is 1.5 meters’ high.

During the first few days after the incident, water began to trickle from these “boot holes” (fig. 2). After a few weeks, the underground mine manager was able to collect the water in buckets and was able to estimate water inflow rate at 7-10 GPH (Gallons Per Hour). Over the course of the next few months, that rate eventually increased to as much as 22 GPH. The leaking water was tested with a Salometer and the salt-saturation level was found to be near 100%.

Shortly after the encounter, several attempts were made to get a better view of the well bore with lights, bore scopes, mirrors, and other devices. There was much speculation at this time as to what the miners had actually encountered. At this point the actual cause of the water leak was not determined.

Figure 2. Water flowing from one of the three “boot holes”.

MITIGATION STATE 1: LOCATING THE SUSPECT WELL CASING

An integrated consulting and services firm was chosen as the primary consultant to determine what the hole was and eventually propose possible remediation and sealing of voids as needed. With their advice, it was decided to explore the possibility of an abandoned well casing as the source of the water leakage. To locate the possible well, a magnetometer survey was proposed. Magnetometers can detect localized changes in the Earth’s magnetic field created by buried iron-bearing objects such as a buried well casing. The consulting firm coordinated with a team from Fort Hays State University and local Kansas surveyors to locate the abandoned well (fig. 3).

Figure 3. Fort Hays State University geophysics crew from left to right Dr. Kenneth Neuhauser, Mr. Toby Eck, Mr. Jeff Lawler, Mr. Chris Schmidt (deceased). Mine Foreman and independent consultant on the right.

Magnetometer Methods Employed

An 80 meter by 80 meter grid with 10 meter N-S and E-W field spacing was established over a potential surface locality inferred or projected upward from the underground mine. Four separate surveys over the same grid were conducted to assure at least one quality run. All four provided the same usable data. A cesium vapor G-858 unit (Geometrics) was used for the survey. Techniques employed to locate the well head followed those proffered by Breiner (1973), Frischknecht, *et al.* (1983), Rivers (1995), and Jordan and Hare (2002). Data were downloaded using Geometrics MapMapper 2000 and contoured using Golden Software Surfer 8.0 2004 Golden, Colorado. The depth estimate was calculated using Golden Software Grapher 6.0 2011 Golden, Colorado, and the half-width rule (Peters, 1949).

Magnetometer Survey Results

The results of magnetometer survey were successful in targeting the spatial position of the buried metal object. Half-slope depth calculations (Peters, 1949) indicated a depth range to the top of the well casing of 0.2-1.5 meters below the surface of the ground (figures 4-7).

Figure 4. Goggle Earth image of survey area 80m x 80m in yellow. Red star targets location of well casing.

Figure 5. View east with study area Well casing target located approximately 5 meters due east of Mr. Jeff Lawler (right, carrying the magnetometer unit) who is walking northward and parallel to the field grid

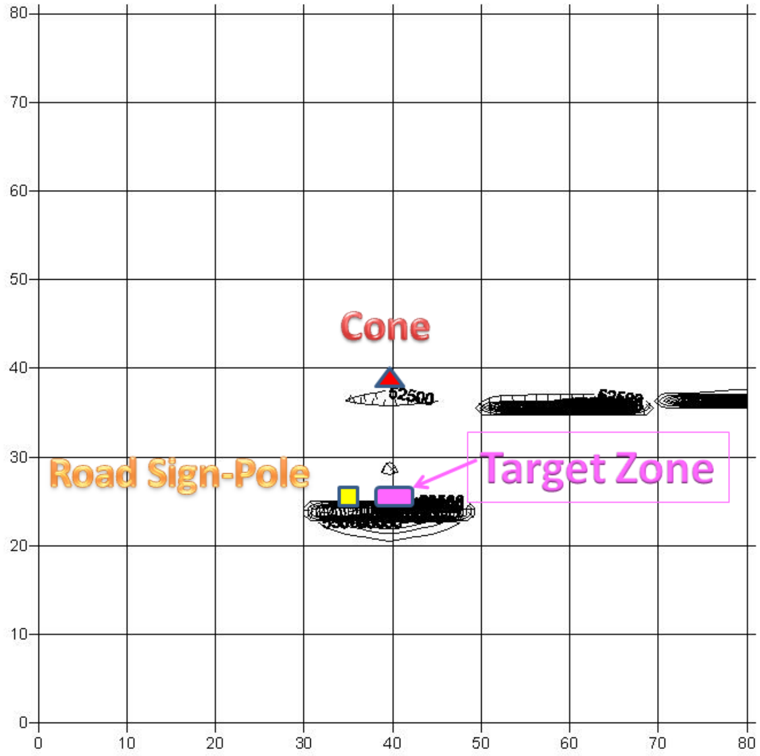

Figure 6. North to towards top of figure. Magnetic anomaly map and targeted suspect well casing. Grid in meters. Red line = North-South profile line through anomaly. Golden Software Surfer 8.0 2004 Golden, Colorado.

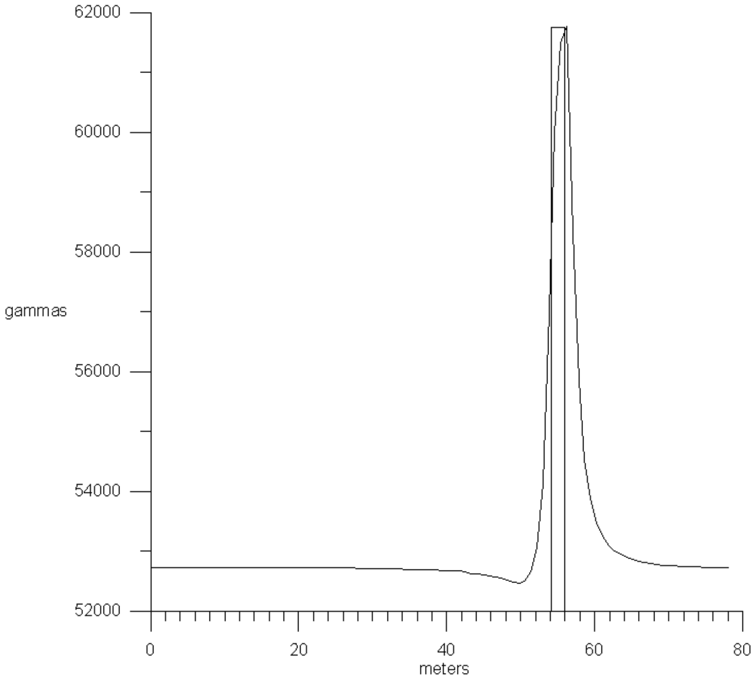

Figure 7 North (left) to South (Right) cross section through anomaly. Half-slope method (Peters, 1949) used to calculate depth to casing Golden Software Grapher 6.0 2011 Golden, Colorado

MITIGATION STAGE 2: DRILLING OUT THE WELL CASING

Once the abandon well casing was located and exposed with a backhoe and shovels (fig. 8), the consulting firm devised a plan to "overdrill" the old casing in an attempt to remove it from the hole. The proposed purpose of removing the original casing in this manner was to provide a clean surface which was intended to be sealed with grout down to the mine level. A local well-drilling company was chosen as the primary contractor to complete the drilling operations.

Figure 8 Exposed abandoned well casing located 0.6 meters below ground level. View Southwest

Unfortunately, attempts to "over drill" and completely remove the old rusted casing failed. The drillers managed to over drill and remove approximately 33 meters of the casing before slipping off to one side and drilling an additional 20 meters, unaware they had diverged from the original alignment. This was largely caused by the fact that the original well deviated more than 16 meters from vertical as confirmed by the surveyors. Once the drilling deviation was discovered, mine management decided that it was not desirable to continue drilling on the misaligned hole as it would not accomplish the original goal of removing the old casing and it was feared they would end up with two holes into the underground workings rather than one. Drilling operations were abandoned shortly thereafter.

A dialogue began to find other options of plugging the abandoned well from the mine level. At this time, there was little activity with regard to the remediation of the water leakage into the mine. The underground personnel were routinely hauling the excess water away from a “pond” which had accumulated near the well underground. Water inflow rates had increased to approximately 20 GPH and surface drilling operations had been completely abandoned by this point.

MITIGATION STATE 3: GROUTING OF THE WELL FROM THE MINE LEVEL

In 2010, a plan to plug the well from the mine level was underway. The plan involved pumping grout to increasing elevations in stages through a complex series of riser pipes installed up the well bore from the mine level. To prepare for grouting operations, a grout suitable for the environment had to be developed that could be transported to the remote underground site in dry sacks. It was ultimately decided that a mix which utilized brine water and had good sulfate resistance be used. However, this proved to be challenging because of the remote location of the job site in the underground mine. Cements with good sulfate resistance were not available in bags, only in bulk, thus mine officials designed a mix utilizing Portland Type I/II Cement which is the most common type in bags. The mix was comprised of a cement/fly-ash/brine mix in the following quantities: Two 42 kilogram sacks of Type I/II Portland Cement , one (1) 32 kilogram sack of Type F Fly Ash (for sulfate resistance), mixed with 60 liters of 100% saturated brine. This mix worked well, as it volumetrically fit into the hopper of the diesel powered grout mixer/pump (fig. 9).

Figure 9. Diesel powered grout pump.

The next step was to provide working access to the hole in the ceiling which was located 4.3 meters above the mine floor. Portable scaffolding was discussed but it would not easily accommodate the specific conditions. Instead, a wooden structure (fig. 10) was chosen as the work platform. It was custom built at the site to support a specially designed aluminum plate which held the five individual grout riser pipes in place. A multi-level work deck was installed approximately 2 meters below the mine roof for access to install and utilize the pipes and valves above for grouting operations.

Figure 10. Wooden structure with aluminum plate to hold riser pipes.

The riser pipe elevations (above the mine roof) were set at 0.6, 3.4, 9.1, 21, and 30.5 meters. These elevations were chosen using volumetric estimates derived from photos and videos taken from inside the well bore from the mine level. The elevations and stages were designed to accommodate the working time of the grout and to maximize the volume filled with each stage of pumping. Grout was pumped from each lowest open pipe to the next highest pipe during each stage of the process, progressively moving higher each time. A valve on each of the lowest pipes, used to pump each stage, was closed after that stage was completed. Since the lower pipe was then at the bottom of the fresh grout, it had to be closed off to prevent the grout from escaping back down. Once closed, it was effectively rendered unusable after that specific stage. Return of grout from each higher pipe confirmed the success of each pour. Upon, completion of that pour and stage, the higher pipe was flushed with brine to remove any grout from the walls of the pipe and left open to drain any excess water which accumulated on top of the fresh grout. Ultimately, the 30.5 meter elevation above the mine roof was reached using this method. After reaching this elevation, the grout was allowed to cure for several days.

The initial goal was to try and reach the top of the salt formation with the grout. However, because of the volumes needed, the remote underground location, and the size restrictions on available equipment, this was no longer a reasonably achievable goal. Based on photos and videos, we knew the hole was not uniform in shape or size but in fact varied widely in diameter through at least the zone we were able to see, as dissolution affected different layers depending on salt and shale content (fig. 11).

Photos from the borehole camera show the 15 cm diameter hole through several of many zones of less soluble material. At first glance, these narrow zones with the original diameter intact may appear to be the end of a pipe. However, after penetrating several of these zones with the camera, it became apparent why the diameter was changing so drastically. Zones of shale, gypsum, and sandstone, likely kept the original diameter intact as they were much less soluble than adjacent salt layers. Knowing the original diameter was 15 cm, it was relatively easy to estimate the diameter of the areas enlarged by dissolution as shown in the photo. This information was used to estimate volumes for grouting.

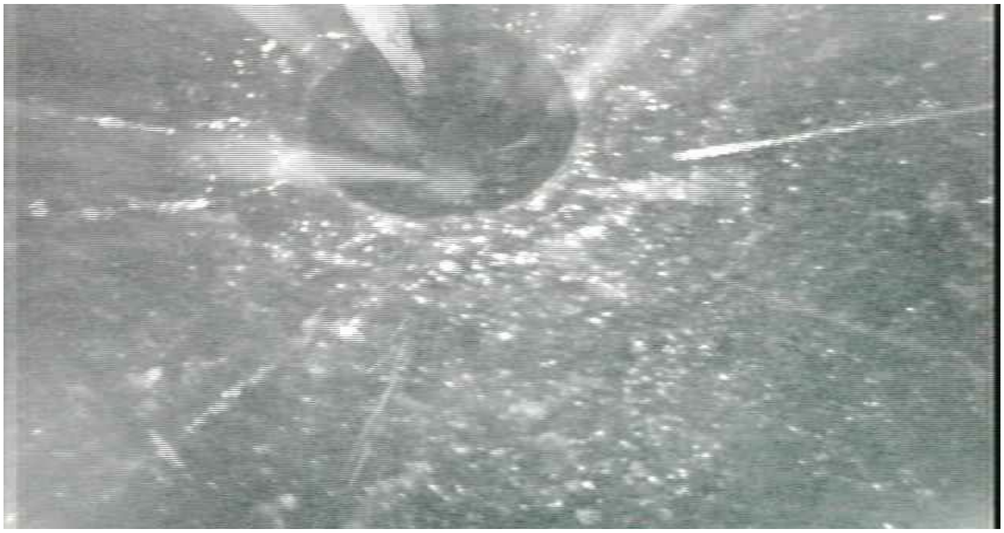

Figure 11. Borehole camera view up to base of shows the 15 cm diameter hole.

It was assumed the hole would continue to vary to the top of the formation. It was also speculated the hole would be very large at the top of the formation and take on a long narrow funnel shape the rest of the way down to the mine level. The reason for this shape is due to the rapid saturation of the relatively fresh water as it comes into contact with the salt formation from above. This shape would be controlled by the water's natural tendency to flow along the sides due to surface tension, rather than drip straight down. However, once the angle of flow is exceeded because of dissolution, the water will begin to drip because of gravity. Ultimately, this process shapes the hole into something that would resemble an inverted incandescent light bulb. Initial dissolution of salt rapidly saturates the relatively fresh water to about 97%. It takes much longer exposure to reach 100% saturation. Therefore, the remaining portion of the hole below the initial contact area suffered comparatively minor dissolution.

Mine officials decided that it would be beneficial to know the volume of the remaining void above the 30.5 meter elevation for future grouting operations if necessary. To determine this, a known quantity of pressurized air was released into the void using a special manifold attached to the 30.5 meter riser (fig. 12). The air pressure was allowed to equalize between the void and the attached air tank. A water gauge attached to the manifold was read and the resulting pressure was used to determine the volume utilizing Boyle's Law. The height of the remaining void was still unknown but was estimated to be approximately 23 meter based on average salt thicknesses in the area. Using this estimated height as a base, the average diameter for that portion of the hole was calculated. The air pressure test was conducted four times and the average volume of the void was determined to be 46 cubic meters. This is almost 7 times the volume of the lower portion of the well as it passes through the salt formation to the mine level.

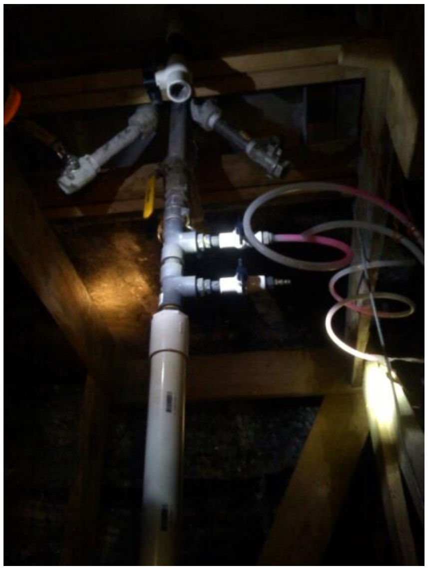

Figure 12. Air manifold for the pressure/volume test.

It is important to note the saturation level of the water collected at the mine level flowing from the abandon well bore above. The water was nearly 100% saturated with sodium chloride. Since there was a significant void near the top of the salt formation, as indicated by the air volume test, it was reasonably determined the incoming water was relatively fresh and must have come from somewhere well above the salt formation. There is a known water table at the top of the salt seam, however, had this been the source, it would have been saturated long before reaching the well bore and would not have had the ability to create a void through dissolution.

Our original volumetric estimates were based on the assumption the water was fresh prior to contact with salt inside the well bore. Having data from the mine foreman of the water flow rate from the onset, and knowing the saturation rate for salt, we could determine how much salt could have potentially been dissolved over a given time period. Comparing this estimate with the actual volume as determined by the compressed air test using Boyle's Law calculation, the numbers were nearly identical, which confirmed dissolution was caused by relatively fresh water.

The final stage of grouting in the upper portion of the well bore involved pumping grout to the 125-ft elevation. This was confirmed by head pressures measured at the pump compared to the density of the liquid grout. After the grout reached that elevation, bentonite slurry was made with fresh water and the volume of the 30.5 meter riser was displaced for 28.7 meters in order to provide future access for additional grouting if necessary. The remaining 9.5 meters up to the top of the fresh 38 meter pour will have to be drilled out to accomplish future grouting if necessary. It was determined that eliminating the lower 29 meters of drilling by filling that portion of the pipe with bentonite (bentonite does not set up like grout) was the best option for future grouting access. It allows access part way up through the grout column inside the original hole without compromising the seal created by the grout. It also provides an alignment for the drill steel to intersect the known remaining void (fig. 13). Alignment of any future drilling operations is critical because of the relatively small size of the drilling target, the void left above the very hard grout. Trying to hit that void from any other angle through solid salt would be extremely challenging due to the nature of drilling from underground. Trying to hit a 1.5 meter diameter target, 138 meters away into solid rock is not an easy task. Especially considering the target void was now underlain by grout, a much harder substance than the surrounding salt. This difference in material density and hardness could possibly divert a future drilling operation away from the void if it happened to hit the grout before intersecting the void above the grout. Drilling up through the center of the grout column was the best option for any future grouting access and only requires drilling a fraction of the distance through solid material. This is especially evident given the failed attempt of the over drilling operations from the surface earlier in the year. It would be extremely difficult to locate the upper end of the original casing and drill inside it down to the top of the grout plug from surface. However, this is still another possibility, although likely an extremely expensive option for future access if absolutely necessary.

Plugging of the lower portion of the hole in the mine floor

Upon the completion of the upper grout plug, focus was shifted to the remaining open hole in the mine floor. The depth of the hole was measured and known to be at least 6 meters below the mine floor. Attempts to open it deeper were made but largely unsuccessful. To plug the hole, a 6 meter section of 3.2 cm 316SS pipe was installed 6 meters down the hole and grouted in place to act as a packer. Once the grout had set around the pipe, the section of the hole below the lower end of the pipe was flushed through a miniature "Blow-Out-Preventer" (fig. 14). This was done to ensure that any trapped or dissolved gasses that might be present in the water could be contained and controlled.

Figure 14. Miniature "Blow Out Preventer" on lower hole.

The hole was successfully flushed to a 7.4 meter depth measured from the mine floor which was consistent with the bottom of the formation, a likely target elevation to stop drilling if one were prospecting for salt. Grout was placed in the hole using the flush line as a tremie pipe and was pressured to

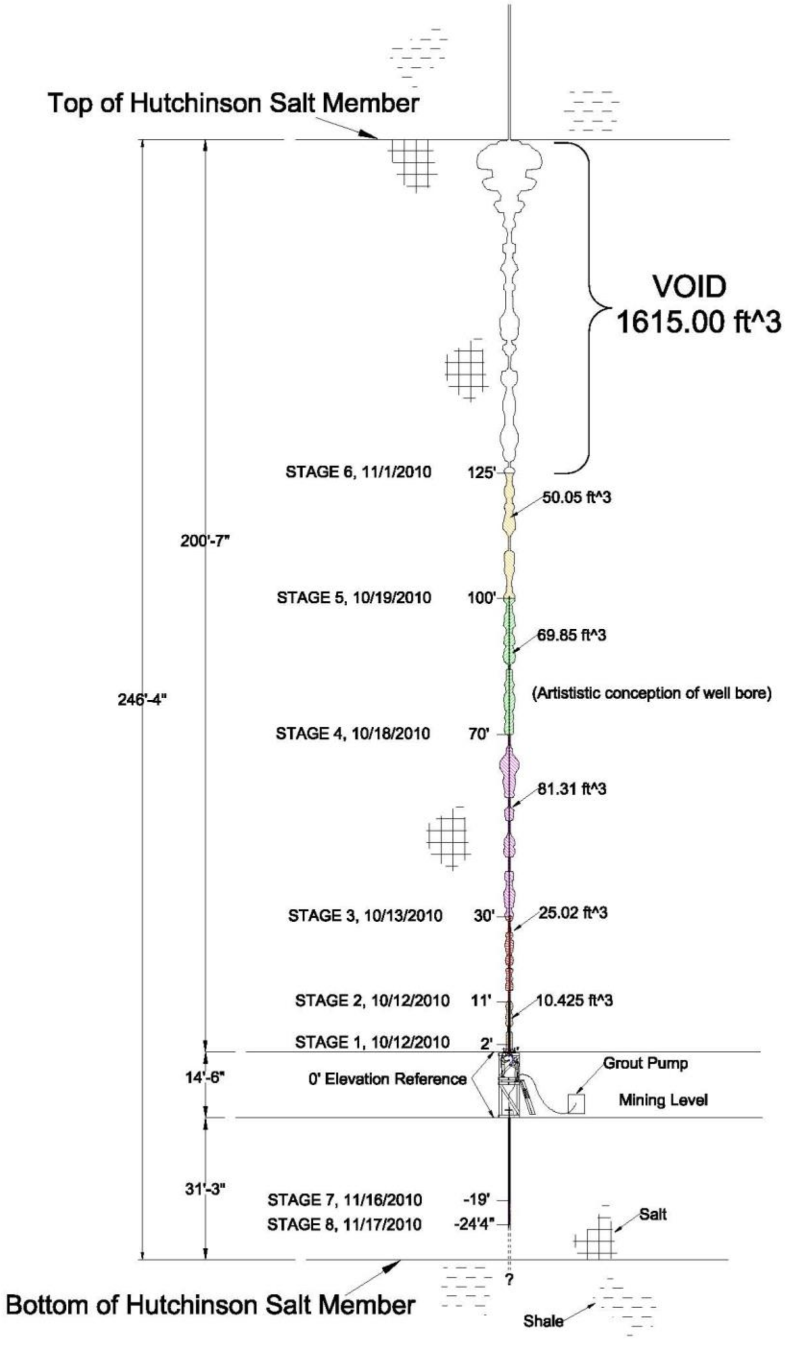

Figure 13. Cross sectional view of well bore based on video, photo, grout volume, and air volume data from the remaining void.

100 psi for 5 minutes. This was done to ensure that no leakage of grout was occurring around or below the initial encased "packer" pipe and to ensure there was no connection to any possible void below 7.4 meters from the mine floor.

CONCLUSION

The sealing of the abandoned well from the mine level appears to have been successful thus far. Time will be the ultimate test. However, the grout mix bonded very well with salt at the mine level during some of the design mix testing and actual pumping. Given the bonding capabilities of the grout with the surrounding rock salt, and being protected from further dissolution by at least 23 meter column of saturated brine water, the plug should remain intact and sealed for the life of the mine.

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