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Case History of the Collapse, Eruption, and Emergency
Backfilling and Grouting of the Abandoned Crystal Salt
Mine Shaft, Ellsworth County, Kansas

by

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Case History of the Collapse, Eruption, and Emergency Backfilling and Grouting of the Abandoned Crystal Salt Mine Shaft, Ellsworth County, Kansas

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ABSTRACT

An underground room and pillar salt mine beneath the town of Kanopolis, Kansas, was worked from the late 1890's to 1947. Salt was extracted from an eleven foot-thick bed 800 feet below surface. Access was through twin vertical shafts. The mine was abandoned in 1947 after fresh water leaking down behind the main hoist cribbing caused so much sloughing of shale and clay stone that the shaft compartment lost its vertical alignment, jamming the hoisting equipment. In 1949 the main shaft and adjacent auxiliary ventilation shaft were reportedly filled with trash, rotten hay, car bodies rock, debris, and earth fill to the surface. The exact locations of the shafts were graded over and lost. A brick factory was later constructed adjacent to the ventilation shaft. In October of 2000, the auxiliary shaft suddenly caved in, then erupted a column of water and debris 250 feet into the air, destroying part of the adjacent brick factory. The crater formed by sloughing of surficial deposits into the shaft threatened homes in the town of Kanopolis. Eventually, over 20,000 cubic yards of shot-rock boulders and 55,000 cubic yards of sand, bricks, and bentonite were required to backfill the resulting sinkhole. A complex series of bentonite aquifer seals, and a grouted subsurface structural plug were also included in the closure design.

PROJECT BACKGROUND

The Crystal Salt Mine lies beneath the town of Kanopolis, in Ellsworth County, Kansas (Figure 1). It operated from 1923 to 1947. Salt was extracted from room and pillar workings in an eleven foot-thick bed 800 feet below surface. Twin vertical shafts located on the east edge of town in the SW1/4, SW1/4, Section 30, T.15S, R.7W. provided access to the workings. The shafts were 19.5 feet by 11.5 feet in dimension, and tightly timbered from surface to mine level, to control fresh water leakage into the salt strata.



Figure 1.

The mine was abandoned in 1947 due to shaft problems. Fresh water leaking down behind the main hoist cribbing caused so much sloughing of shale and clay stone, that the shaft compartment lost its vertical alignment, jamming the hoisting equipment. In 1949 the main shaft and adjacent auxiliary ventilation shaft were reportedly filled with trash, rotten hay, car bodies, rock, debris, and earth fill to the surface. The exact locations of the shafts were graded over and lost. A brick factory was later constructed adjacent to the auxiliary/ ventilation shaft along the existing rail siding.

Twenty-three years later, in January 1972, the main shaft caved open, leaving an open hole over 700 feet deep. Within a matter of weeks, the collar of the shaft failed, and flowing groundwater at a depth of 30 feet in the unconsolidated surface aquifer rapidly created a crater 130 feet by 95 feet in dimension. Over twenty thousand cubic yards of sand and clay stone bedrock eventually caved and filled the main shaft to a depth of 35 feet below surface. The original excavated shaft volume was only 4,500 cubic yards, indicating an extensive void space had developed from salt dissolution and roof collapse (Walters, 1978).

Fifty-one years after abandonment, on October 26, 2000, at 10:02 am local time, the nearby auxiliary shaft adjacent to the brick factory suddenly caved in. Workers reported that a pile of waste brick in the yard adjacent to the railroad siding began to disappear into itself, "like sand down an hourglass". Moments later, accompanied by ground shaking and a tremendously loud roar, a geyser of air, water, sand and several thousand cubic yards of bricks erupted over 300 feet into the air. This debris fell on the adjacent plant building, destroying a large section of the factory. Several more separate eruptions as violent as the initial blast followed during the next few minutes, causing further damage to the factory, and destroying nearly every vehicle in the adjacent parking lot. Miraculously, no one was killed or seriously injured. As before, a large crater quickly formed in the unconsolidated sand aquifer, taking out the railroad siding and a boxcar, and threatening to totally destroy the plant foundations. An estimated 125 to 200 gallons-per-minute of fresh water poured into the open shaft from the base of the unconsolidated surface sand aquifer. The flowing water and soft, weak clay stone bedrock caused the crater to grow from an initial diameter of 45 feet to over 150 feet in diameter. Surface configuration as of November 4, 2000 is shown in Figure 2.

Acme Brick Company initiated an emergency project to stabilize the plant foundation, backfill the shaft, and save the factory. A plan to backfill the shaft, protect surface aquifers, and stop fresh water from entering the salt strata was developed. This plan also called for construction of a large subsurface grouted structural plug to support backfill and water sealing bentonite layers, preventing them from settling down into the mine workings.

As reclamation work proceeded, it soon became clear that the shaft volume would be several orders of magnitude larger than the original excavation. Fifty-one years of fresh water flowing into the salt and salty shale created a massive irregularly shaped subsurface void. Additionally, as backfilling proceeded, the soft, weak clay stone strata exposed in the shaft walls continued to slake, and cave outwards and upwards.

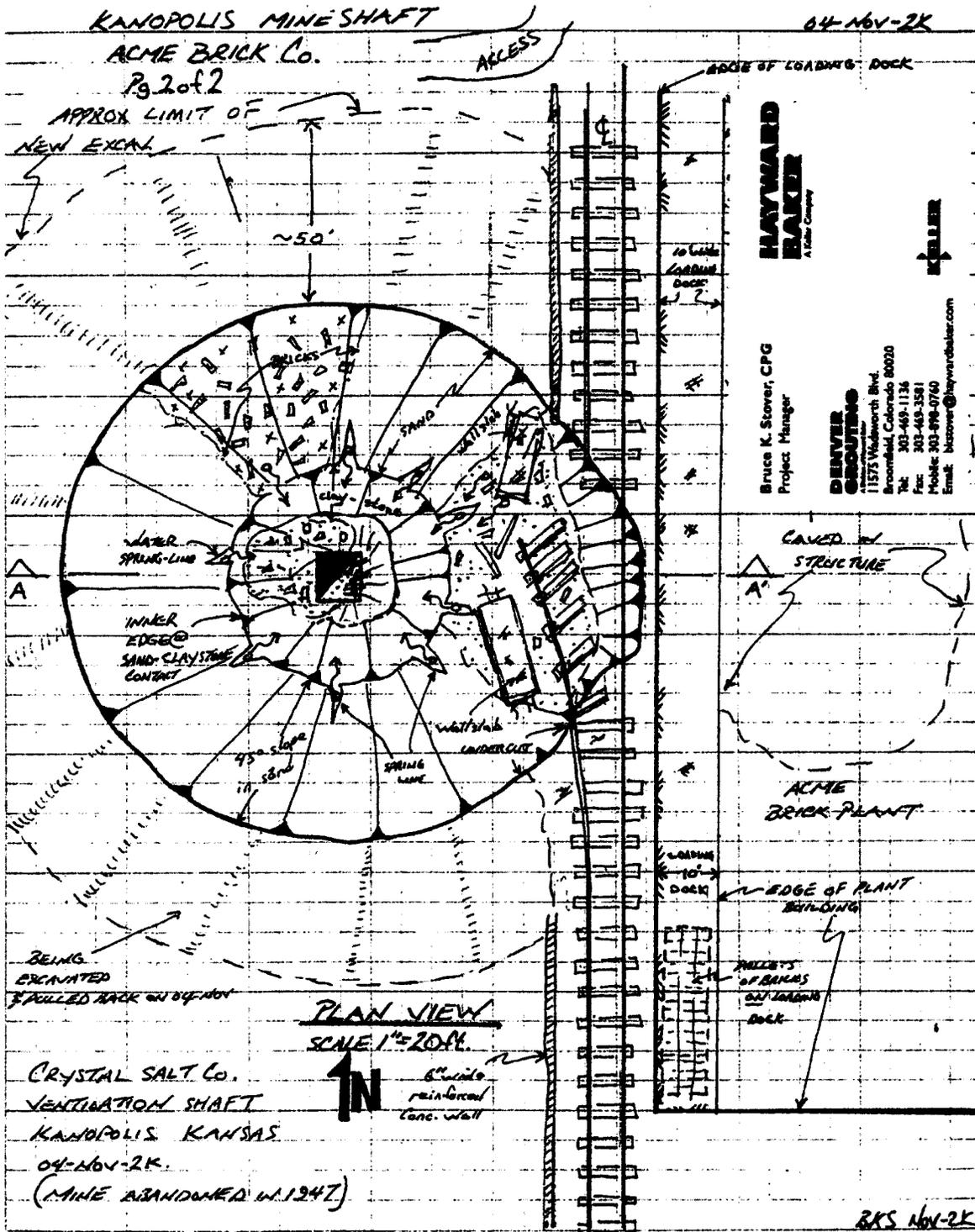


Figure 2.

CRATER STABILIZATION

Stability and viability of the brick plant foundations were in serious doubt after the shaft cave-in. The first issue was whether or not the plant could be protected from the rapidly expanding shaft crater. The edge of the plant floor and foundation were immediately adjacent to the crater on its east side. Unconsolidated loose sand was actively caving into the open shaft, threatening to undermine and destroy part of the building footprint (Figure 3).

A test-grouting program was developed to attempt to stabilize and strengthen the unconsolidated sand supporting the factory foundation adjacent to the crater. Compaction grouting and permeation grouting were conducted through a series of holes drilled through the foundation and into the clay stone bedrock 30 feet below. Compaction grouting stiffened up the sands, and increased resistance to sloughing between the closely spaced holes. Portland-cement grout was injected into the base of the sand at the bedrock interface to strengthen the sand and help control groundwater flow from the area beneath the plant.

The grouting prevented significant sloughing of sand from beneath the plant floor. Throughout the following three months that the shaft remained open, sand continued to slough from the crater walls, except in the area under the plant. On the west side, the crater enlarged from an initial radius of 30 to 40 feet to almost 100 feet. This amount of caving on the east side would have resulted in loss of a significant part of the plant.

DOWN-SHAFT INVESTIGATION

Concurrent with foundation grouting, a down-shaft video survey was conducted. An 85-ton motor crane with a clamshell bucket was used to clear away timber cribbing and debris blocking the shaft opening 50 feet below the surface (Figure 4). Once the obstructing debris was removed, a borehole camera was lowered through the exposed shaft compartment (Figure 5). The camera showed the shaft open to a depth of 670 feet, without any standing water level. Sand and bricks were seen at the bottom of the shaft, and fresh water could be seen draining directly into the salt mine.

A second down-hole camera was lowered into the shaft on December 5 and 6. This second survey attempted to get a better view of the shaft walls with a more sophisticated side-looking camera. On the first day, the camera reached a point 550 feet down shaft, at which point it was struck by debris falling in from above. Video signal was lost, and the camera was pulled up to make repairs to the power and signal cables.

This survey indicated some areas of timbering, but also several areas where the shaft walls were not visible. Falling water in front of the lens made interpretation of the images difficult, but it was clear that the shaft was quite large in dimension at several locations.

On the second day, the camera was lost when it reached a point 160 feet below surface. A large chunk of debris struck the camera squarely, completely smashing it off the cable. The energy from this impact destroyed the cable winch system in the logging truck as well.

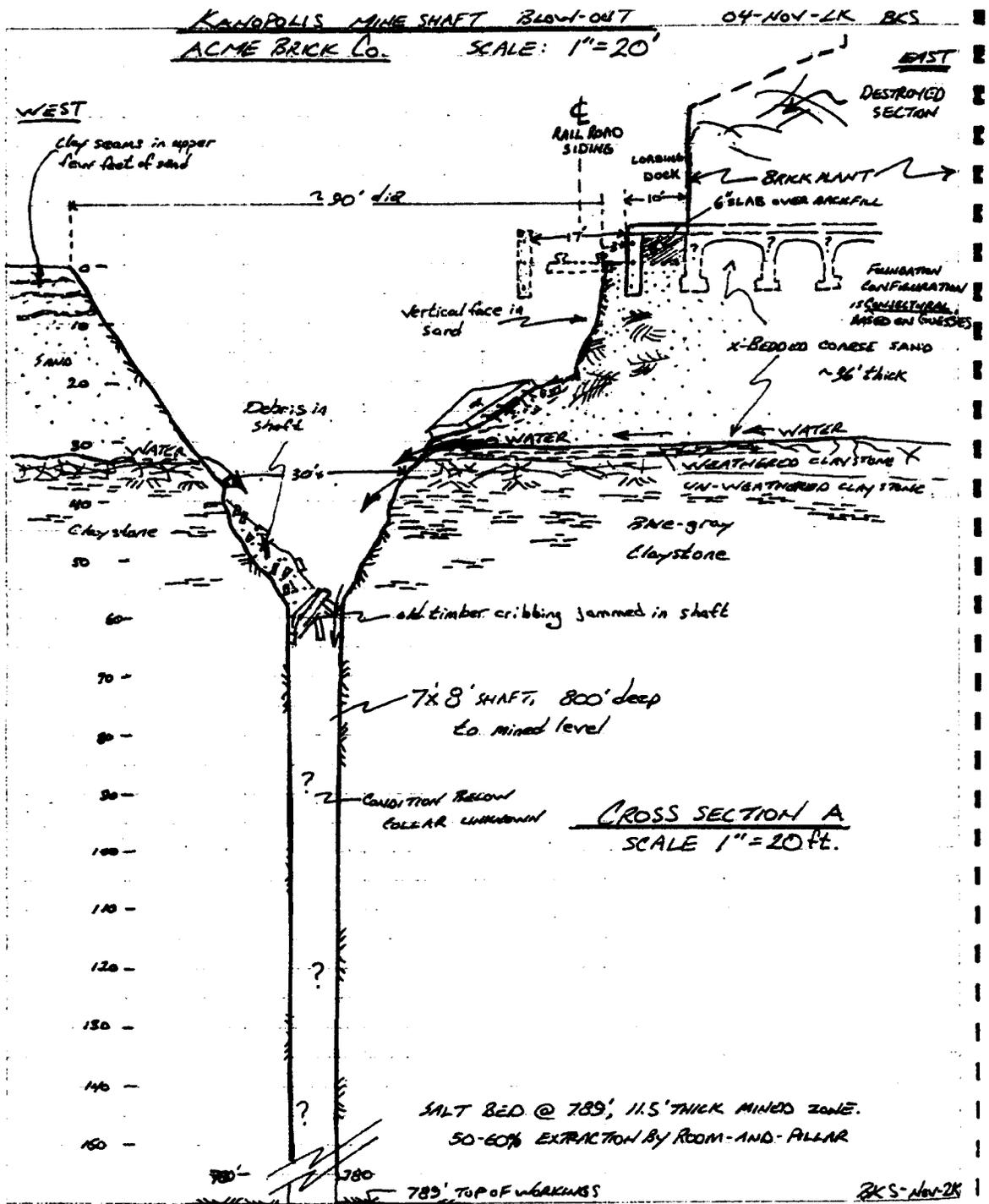


Figure 3.



Figure 4.



Figure 5.

A second logging truck was used to lower a weighted bar and sound the bottom of the shaft in more detail. This survey indicated a debris pile at the bottom of the shaft, with its top at 670 feet, and slopes extending at least another 30 feet.

During this period, the remaining cribbing at 50 feet in the bottom of the crater began to shift and tilt noticeably.

GROUNDWATER CONTROL

An attempt was made to control water inflows into the upper shaft crater. At the time a decision was made to proceed with a slurry wall surface water control approach, the timber cribbing remained in the shaft, concealing the presence of belled out sections where other groundwater inflows were entering the shaft at 71 feet and 90 feet. It was believed that the surface water inflows at the base of the unconsolidated sand were the main source of water. Several weeks later, the cribbing fell down the shaft, revealing other groundwater inflow zones. Had the cribbing not obscured these features, the surface water control program might have been eliminated, as other water inflows down shaft which could not be addressed by the slurry wall approach would have made the exercise ineffectual.

CLOSURE DESIGN

Several consulting firms worked together to develop a viable closure and reclamation plan. These firms had expertise in engineering, salt mine subsidence and closure alternatives, and mine shaft reclamation and grouting work. The objectives identified for the closure plan by the consultants and Acme included:

1. The closure had to be executable in a safe manner, minimizing risks to personnel, equipment, and property.
2. The closure design had to address environmental concerns related to groundwater aquifers, by preventing loss of fresh water into the brine pool, and protecting drinking water resources from potential brine movement up the shaft, to as practicable an extent possible under the circumstances.
3. The design had to minimize leakage of fresh water into the mine at the base of the shaft, in order to prevent further dissolution of salt and subsequent subsidence.
4. The closure alternative had to provide a reasonable factor of long-term surface stability, such that an acceptable degree of confidence to integrity of the brick factory could be achieved.
5. The closure design should incorporate available materials in order to control overall costs.

Several plans were considered, all having advantages as well as disadvantages. Acme Brick Company adopted the plan finalized by Stephen Phillips of Phillips Mining, Geotechnical & Grouting Inc. (PMGG), on 19-Dec-00. This plan is shown schematically in Figure 6. This concept called for backfilling the lower section of the shaft with large boulders and cobbles, in order to provide a stable, solid base for the remaining fill column. Subsequent fill would decrease in size from boulders to cobbles to small cobbles, then granular fill materials. The PMGG plan called for

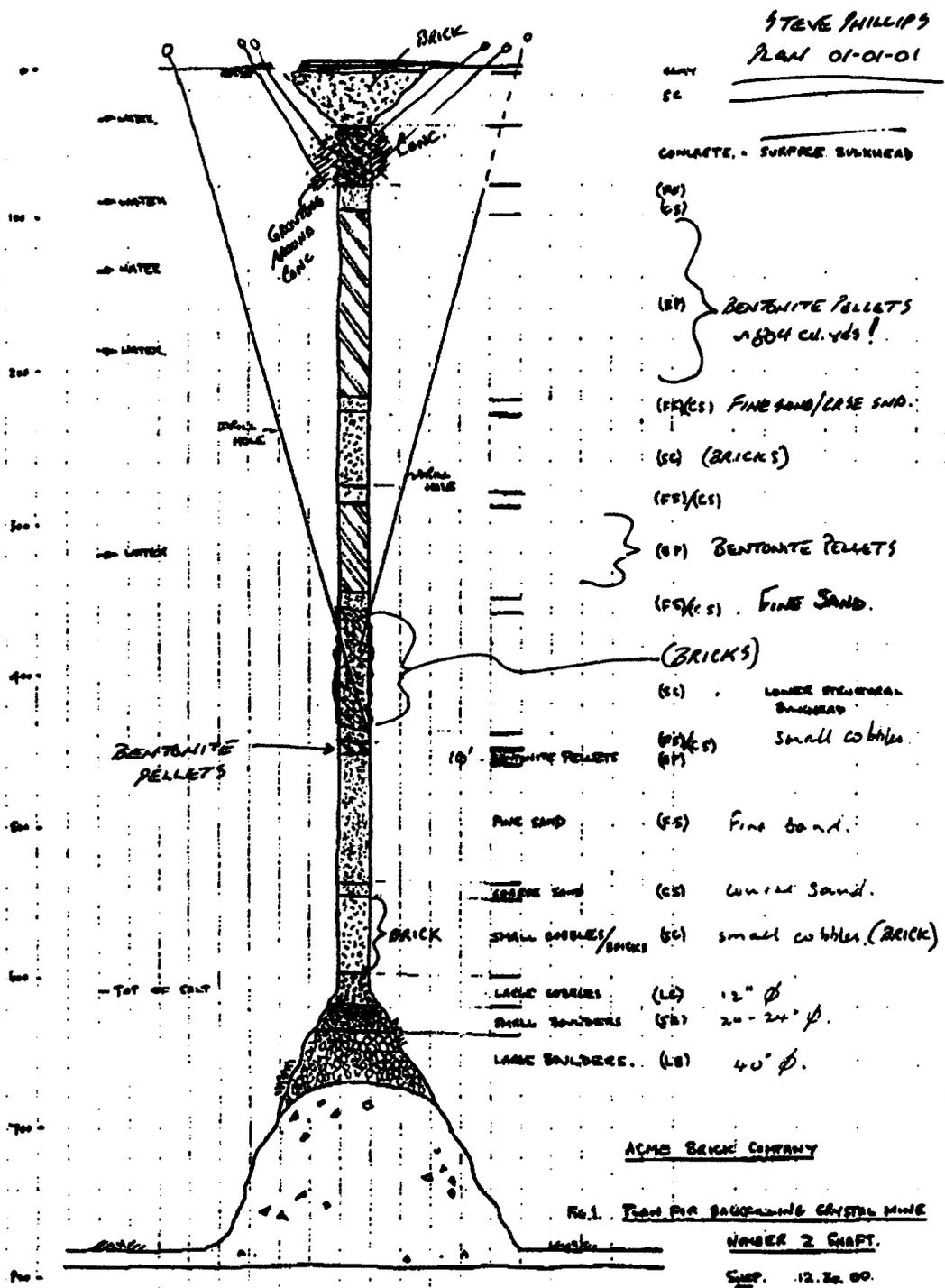


Figure 6.

bentonite seals to be placed into the shaft during backfilling. A grouted structural plug incorporated into the shaft below the lowest aquifer-sealing layer was designed to hold the backfill column in the shaft, preventing it from settling into the cavern believed to be at the bottom of the shaft. An upper structural concrete plug was to be cast in place on a ledge of resistant rock at the 71-foot level. The concept and details of the closure are described in the report prepared by PMGG.

SHAFT BACKFILLING

Shaft Cribbing Obstruction

Shaft backfilling was complicated by the remnant shaft cribbing lodged 50 feet below surface. The cribbing remnant was an intact section 19ft. long x 12ft. wide x 17ft high. This box-like structure was constructed of 10 X 10 timbers notched and set log-cabin-fashion, clad on the outside with interlocking steel sheet -piling. The cribbing continued to tilt and eventually fell farther into the shaft, revealing an enlarged ring-shaped undercut section at 71 feet (Figure 3). Groundwater could be observed flowing into the shaft at this location, and had caused erosion of the strata from 6 to 8 feet back from the original excavation line of the shaft. The cribbing had rotated sideways such that it obstructed the shaft opening almost completely. Calculations indicated its weight at over 47,000 pounds, and this, coupled with the reach needed to place a crane at a safe distance from the edge of the crater, made lifting it out of the shaft problematic. Additionally, it was deemed unsafe to fix or hook any cable or line directly to the cribbing section without the capability of an immediate release. The fear was that if the cribbing suddenly began falling farther in, it could possibly pull a crane or dozer into the hole.

An effort was made to try peeling and breaking the cribbing down, using a long, heavy pointed probe made from oil field pipe. The motor crane repeatedly dropped the probe onto the box, but the wet steel sheathing caused the point of the probe to skate off the tilted box, with little effect. Only a few timbers could be popped of the cribbing using this time consuming approach. Many alternatives to get backfilling materials past the obstructing cribbing were considered, including fabrication of a large steel tremy pipe which was to be inserted down the shaft between the obstructing cribbing and the shaft wall. Eventually the situation resolved itself, as the collar of the shaft continued to slough and grow larger. The cribbing continued to move deeper into the shaft, and continued to change position.

On 20-Decmeber-00 the cribbing was found to have fallen and tilted farther down, exposing a large part of the open shaft. A decision was made to begin dropping large rock, called for as the base layer of fill, through the shaft cribbing into the open hole (Figure 7). Hard, quartzite-sandstone rock was dumped from barrel-bottom tandem axle trailer trucks at a location well back from the crater, and then pushed by dozer closer to the edge of the opening. A large excavator picked up the rocks and spooned them into the shaft crater from a safe location back from the edge of the hole. This work proceeded, and within a half hour, part of the ledge holding the tilted cribbing was knocked out, causing the cribbing to fall farther into the shaft, upside down (Figure 8). This revealed an even larger cavern at about the 90-foot level. The cavern was undercut at least 10 to as much as 18 feet beyond the original shaft excavation lines.



Figure 7.



Figure 8.

With the base of the cribbing now facing up, rocks began to knock the timbers out of the box-section of cribbing. Within another half hour, most of the timbers were dislodged from the cribbing and fell one by one into the open shaft. Without the internal support of the timber, rocks sliding in off the sides of the shaft crater crushed the remaining sheet piling, causing it to fold up and fall into the shaft.

The sheet piling and timber fell all the way to the bottom of the shaft. This was verified by releasing a large boulder from the clamshell bucket of the crane directly over the center of the shaft. The boulder could not be heard to strike bottom. It is believed that the wet sand and bricks comprising the debris pile absorbed the impact, and that there was not enough sound energy to propagate all the way back up the shaft. This indicated that the shaft was completely open, and backfilling with the boulders commenced in earnest.

Shot Rock Base Fill

Trucking and placement of shot rock fill began on 20-December-00. Around 720 tons of rock were hauled and placed this day. Next morning, the shaft was sounded at a depth of 670 feet. Another 1,800 tons of rock was placed on 21-December, and the shaft sounded again on the morning of the 22nd. This sounding showed a depth of 600 feet, indicating a significant rise in the boulder fill. Another 755 tons were placed in the shaft by noon on December 22, after which work was halted for the Christmas Holiday. Rock placement resumed on 26-December, with another 1000 tons being hauled and placed.

On the morning of the 27th, the shaft was sounded again. This sounding showed a depth of 685 feet, 15 feet lower than the first sounding on the 21st, even though 4,500 tons of rock had been placed. This suggested that either the 600 foot sounding was taken on an obstructing timber or other debris above the true bottom of the shaft, or that the pile of rock had slid or settled farther down into a cavern much larger than originally anticipated.

Rock fill placement effort was re-doubled. Fifteen trailer trucks were brought online from three trucking companies to haul rock from Lincoln Kansas, 30 miles north of the site. Soundings during the first week of January-01 continued to show the top of the fill at from 670 to 640 feet below surface. Hauling continued daily from December 27 to Friday, January 5th, when the top of the rock fill was at 567 feet, a gain of 48 feet during the day. This was the first significant upward gain of the rock fill, suggesting the throat of the shaft above the cavern may have been reached. By the end of the shift, the top of the rock fill was at 518 feet, and the rock hauling operation ceased.

The cavern and lower part of the shaft took 25,310 tons of rock to reach 518 feet. All this rock falling hundreds of feet stripped out any timber sections that might have remained in the shaft. Water which later rose up in the shaft contained only shredded fragments of timber. No large pieces of timber were seen, because the shattered timber lying on bottom was covered by fill before the water began pooling in the shaft.



Figure 9.

Granular Backfilling Sequence

During the rock hauling and placement work, a feeder and conveyor system was assembled adjacent to the open shaft on the factory floor slab (Figure 9 and 10). This setup was designed to place granular materials into the shaft on a continual basis. Sand overburden from Acme Brick's clay mine was trucked to the plant site. A total of 1,257 tons of bulk bentonite $\frac{3}{4}$ inch pellets and $\frac{3}{4}$ minus chips were shipped in from Wyoming, and stockpiled onsite. Bentonite was used to form the impervious water sealing layers called for in the plan. Front loaders, working from stockpiles of material placed nearby, placed the various granular backfill materials into a large feed hopper on the conveyor.

Over the weekend of January 6th and 7th, a large amount of debris caved off the sides of the shaft. The sounding on Monday January 8th indicated the base of the debris at 490 feet. An estimated 840 yards of caved clay stone had come to rest above the rock fill. This 28 foot-thick layer of clay stone, once squeezed down by overlying fill, is believed to benefit the overall water sealing ability of the backfill column.

The sequence of backfilling materials and quantities from 490 feet upwards are shown in Figure 10. Original shaft volume was estimated to be 4,200 cubic yards, or 6.7 cubic yards per foot of depth. Careful soundings and measurement of volumes placed during backfilling were used to calculate an estimate of the actual shaft size. The shaft wall profile depicted in Figure 10 is a plot of average diameter computed from the amount of fill placed per-foot of fill rise. In the lower interval from 600 feet to 470 feet, the shaft took from 20 to over 30 cubic yards of fill to gain one foot of fill height. This indicates a rough diameter of around 30 feet, over twice the original excavated dimension.

A specific sequence of materials was placed by the conveyor system according to the PMGG plan. From 490 feet to 480 feet, 200 cubic yards of large cobbles and waste block were placed in the shaft, followed by 288 yards of pea gravel to 470 feet. From 470 to 407 feet, 1, 575 cubic yards of sand were placed by the conveyor system to bring the fill to a position for the first bentonite seal. Static water above the top of the fill was first detected at 365 feet, indicating 42 feet of standing water in the shaft, even before placement of the first bentonite layer. This suggests the sloughed clay stone layer from 518 to 490 feet may already have been compressed and squeezed down by the overlying fill, pooling water above it.

The larger than expected shaft size created a problem for carrying out the backfill design. A tremendous amount of additional bentonite would be required to achieve the designed thickness of the water seals. To avoid days of shipping delay and to keep backfilling going, a decision was made to use onsite clay materials to augment the water seals. Fifty cubic yards of pure bentonite were placed at a depth of 407 feet, followed by 60 cubic yards of brick clay and 588 yards of pea gravel to an elevation of 388 feet below surface. This first impervious layer was designed to seal water from running down the shaft into the salt intervals, as well as contain cement grout injected into the structural plug just above. Pea gravel was placed above the clay to form the base of the structural plug at 388 feet depth. On January 10th, standing water could first be seen down inside the shaft at 325 feet, indicating 63 feet of standing water above the top of backfill.

Grouted Structural Plug

A structural plug below the first suspected aquifer was specified in the shaft closure plan. This plug was intended to hold the backfill column and bentonite water seals in position, preventing them from settling down in the shaft beyond their intended positions. An aquifer inflow at 320 feet was known to exist in the shaft at the nearby Independent Salt Mine. The structural plug design called for brick bats to be placed into the shaft, followed by cement grouting through angled drill holes into the sides of the shaft. From 388 feet to 355 feet, 1000 yards of loose brickbats were run into the hole on the conveyor belt. The brick fell through 60 feet of standing water, which cushioned them sufficiently to prevent breaking and crushing from impact energy. This should have resulted in a fairly clean, pervious column of brick to grout with cement, however, constant caving and sloughing of the shaft walls was introducing significant volumes of clay stone to the fill.

Despite difficult drilling conditions associated with the unanticipated dimensions and nature of the shaft, the grouting plan was successfully executed in winter conditions during January and early February of 2001. Three drill holes collared well beyond the edge of the surface crater all intersected the brick column. A total of 290 yards of cement grout was injected into the brick plug through these three holes. Second stage drilling cored cemented brick, confirming the placement of grout into the structural plug. Discharge of displaced water through the relief hole during second stage grouting confirmed that cement grout was penetrating the interstices of the brick plug. At the conclusion of grouting, each hole was plugged and grouted to surface.

Lower Aquifer Seal

On 11-Jan-01 the lower aquifer seal was placed in the shaft using 206 cubic yards of pure bentonite. The pure bentonite was placed from 355 to 343 feet, followed by a sand-bentonite blend from 343 feet to 289 feet. Bentonite was blended from a separate feed hopper into the sand stream to give an approximate 15 to 20% bentonite-sand mix. Approximately 2,353 cubic yards of this blend was

placed, but the take per foot of rise ballooned to over 170 cubic yards near the top of this interval. The dramatic increase in material quantity is believed to represent the actual position of the aquifer zone.

Successful placement of this lower pure bentonite seal was later confirmed by core drilling. Eleven days after placement, a full 15 feet of hydrated bentonite was intersected and recovered in the drill core on the 22nd of January. Scattered fragments of caved clay stone were also found in the bentonite. During drilling, it was noted that there was some standing water in the drill string during core retrieval from the interval above the bentonite seal, but that below the bentonite, the drill string was free draining. This suggests that the seal was pooling water above it.

Annular Caverns Located

From 300 feet to 250 feet, calculated shaft diameter increased dramatically. For example, to raise the top of fill 9 feet from 289 to 280 feet, over 1,496 cubic yards of sand were placed, a take of 166 cubic yards per foot. Above 280 feet, 2,568 cubic yards of brick were placed, topping out at 219 feet. A zone of this interval near the 265 level took over 600 cubic yards of bricks to gain a 1 foot rise. These tremendous takes of fill are believed to represent a cavern formed in the area of aquifer inflows, from 300 to about the 270-foot elevation. This is further supported by the presence of large voids intersected here by core holes drilled for structural plug grouting. These voids were encountered even after backfilling had progressed well above the interval, indicating that the angle of repose of the backfill column was not completely filling annular spaces adjacent to the shaft. These un-filled, cavernous annular voids are believed to exist at 300 to 260 feet, 200 to 220 feet, and 120 to 140 feet below surface. They were intersected from 45 to 50 feet from the shaft centerline, and probably continue farther into the adjacent clay stone and sandstone strata.

Middle and Upper Aquifer Seals

A third bentonite water seal was placed in the shaft between the 201 and 180-foot level. This seal used 292 cubic yards of pure bentonite chips, followed by 600 cubic yards of brick clay, and 900 cubic yards of 20% bentonite-sand blend. It was placed near the narrowest part of the remaining shaft, as observed before it was flooded over with rising water.

Above the middle aquifer seal, the shaft dimensions became cavernous. Caving became nearly constant, and it took 12,320 cubic yards of sand to bring the fill from 180 to the 90-foot level, an average take of 136 cubic yards per foot. At the 90-foot level, the last bentonite layer was placed, using 397 cubic yards of chips. This was followed with 350 cubic yards of brick clay to further increase thickness of the seal.

Shaft Caving

Active, nearly constant caving and sloughing of the shaft had continued throughout the backfilling work. Loud booming sounds could be heard echoing up from the shaft, on a nearly continuous basis. The booming sounds occur when large sections of clay stone, falling off the roofs of caverns and sides of the shaft, hit the water surface with tremendous energy. As water rose in under the cavern roofs, huge waves could be observed rolling out from the undercut sections as slabs caved into the water. Some slabs were so large that, at night, persons in nearby homes reportedly felt ground vibrations from the impacts.

The clay stone rock is believed to have been air-slaking along the sides of the shaft. As time passed, the natural moisture in the soft clay may have been drying out due to exposure to the atmosphere. This change in moisture might have caused de-lamination along nearly horizontal bedding planes in the shale and clay stone in the shaft walls.

It became apparent on the evening of January 22nd that the shaft was caving faster than it was being backfilled. Nearly constant slab impacts could be heard from the 150-foot level, and there was a real threat that the propagating failure of the shaft walls would undercut and cause failure of clay stone rock supported the surface sand. This would result in loss of much of the brick plant foundation. Undercutting began to undermine the resistant ledge of rock targeted to support the upper structural concrete plug at 70 feet. Parts of this ledge began caving in the evening. Cracks were observed forming in the blue clay stone above this ledge, as the caverns began to increase the undercut under the upper walls of the shaft.

On the morning of January 23rd, the resistant ledge at 71 feet was gone. It had completely fallen away into the cavernous hole, increasing the danger of a massive collapse of the blue clay stone beneath the surface sand. There was now no physical structure or desirable shape on which to place the planned concrete plug. The walls of the cavern belled concave downwards, and would provide no grip or support for the concrete plug as settlement occurred. A decision was made to increase backfilling effort to two shifts per day, and abandon the planned cast-in-place concrete plug. Backfilling continued as fast as was possible with the crews and equipment available, and eventually succeeded in outpacing the caving to a point where flooding of the shaft stabilized the walls, saving the plant foundation.

Crater Flooding

Water level rose rapidly in the shaft after placement of the middle bentonite aquifer seal at the 201-foot level. From a pool level of 98 feet on the morning of January 24, water level reached the 30-foot mark at the sand-bedrock contact by midnight, on the 25th, a rise of 68 feet in 40 hours. The rapid flooding seemed to quell active caving of the shaft walls, and the integrity of the brick plant was maintained.

There had always been concern that water rising up the shaft into the unconsolidated sand might cause sloughing and rapid caving of the sand, however, this turned out not to be a problem. The existing shaft crater over the adjacent main shaft has nearly vertical sand banks around the pond, illustrating the potential of the materials to stand, even when adjacent to a water table. As water rose in the crater during backfilling, there was no appreciable caving of the sand banks. Constant pouring of fine sand and bentonite through the standing water created a thick muddy-water slurry. Hydrostatic pressure of this thick muddy water acting on the sand banks stabilized the materials (Figure 11). The elimination of flowing water at the base of the sand by re-flooding the aquifer also helped stabilize the sand.

Dewatering operations in the crater pool started on January 29th. In order to continue placing backfill without overtopping displaced water, a pump was set to discharge water into a large settling pond 350 feet away. The pump drew water out of the crater pond during backfilling, but could be shut off at night, as there was no longer any inflow to the shaft.



Figure 11.

Backfilling with the conveyor system continued until sand piles rose out of the crater pond. A series of sand piles was placed around the perimeter of the crater edges, for later grading into the pond (Figure 11). This final backfilling work in the crater was completed in February.

CONCLUSIONS

Backfilling work on the auxiliary shaft of the Crystal Salt Mine at Kanopolis illustrates a serious potential hazard associated with the shafts of abandoned salt mines. This is the second shaft at the Crystal Mine to cave suddenly and cause cratering of the surface. The main shaft collapse in 1972 formed a crater estimated to have a volume of 20,000 cubic yards. The auxiliary shaft that caved in October 2000 would eventually have formed a crater three times as large. A crater this large would have destroyed the kiln and much of the brick factory, and threatened homes in Kanopolis. It is clear, based on the amount of backfill required, that a large sinkhole had developed around the original mineshaft over a fifty year period. Fresh water running down the old shaft caused dissolution of salt and gypsum in the evaporite strata below 600 feet, forming a large cavern. Flowing groundwater from aquifer zones higher up in the geologic section eroded substantial annular voids well beyond the original shaft excavation lines, as discovered during core drilling. Caving and sloughing of soft clay stone behind the original cribbing increased the size of the shaft throughout its vertical extent. Fresh water leaking down these mine shafts has created void spaces below surface of over 60,000 cubic yards. This is disconcerting in relation to long term stability of the surface at the Crystal Mine.

Calculations show that 50 years of fresh water inflow at just 125 gallons per minute would have flooded the excavated volume of the Crystal mine four-times over. Fresh water should have flooded the mine and created a brine pool, which would saturate with salt and prevent fresh water from entering the workings to cause further dissolution. Clearly, fresh water has continued to enter the salt strata through the access shafts, creating large caverns below surface, and therefore the conclusion is water is somehow leaking from the Crystal Mine workings. Until brine is prevented from leaking out of the mine, there is a risk that fresh water can continue to seep down the three known access shafts and cause further salt dissolution.

Water could be leaving the salt mine through several pathways. The presence of geologic structures such as faults or other discontinuities, though discounted by many, should be investigated. The three known abandoned gas wells within the mine footprint should also be investigated to see if brine is leaking deeper into the basin through a failed casing or improperly abandoned well.

Fresh water seepage in the two shafts that have caved and been backfilled is now minimized, but probably still exists. The confirmation of a series of annular voids that remain un-filled casts doubt on absolute integrity of any man-made or natural water sealing layers in the shafts that have caved. Continued fresh water seepage will likely cause additional settlement of the fill columns in both caved shafts, rather than any sudden collapse or eruptive events that result in deep openings. The third shaft is in some unknown condition, and there is therefore some risk a similar collapse event as has occurred at the other two, could affect it in the future.

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