The Flooding of the Cominco Potash Mine and its Rehabilitation

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ABSTRACT

In August, 1970, a major water source was intersected during routine shaft grouting. Water and quicksand under very high pressure entered the shaft at a rate of 65 m^3 per minute. The mine and both shafts were flooded.

The breach was sealed simultaneously from within the shaft and through a relief hole drilled from surface. The mine was dewatered, rehabilitated and the equipment was restored. Production resumed two years after the accident.

INTRODUCTION

Potash has been mined in Saskatchewan on a continuous basis since 1962. There are presently ten potash plants in operation. Nine of these, including one operated by Cominco Ltd., extracted the ore by underground mining methods while one utilizes the solution mining process.

After the discovery of Saskatchewan's huge potash deposits in the 1940s, the following decade saw much effort spent on long drawn-out, costly shaft-sinking projects. The greatest obstacle which shaft sinkers were faced with was a succession of water-bearing formations, as many as ten in some areas, all the way from the Glacial Till near surface to the Dawson Bay Dolomite just above the salts of the Prairie Evaporite formation. Of these water-bearing formations, the one to prove the most difficult was the Blairmore Formation. It ranges in thickness from 60 m to 150 m and occurs at a depth from 375 m to 440 m in the Esterhazy area and from 520 m to 640 m west of Saskatoon. It consists of unconsolidated water-bearing sand, clay, shale and silt under pressures of up to 65 kp/cm^2.

Of the 17 potash shafts sunk in Saskatchewan, 15 have been completed, one is presently in the sinking stage and one had to be abandoned due to a major water inflow. Out of the 15 shafts so far completed, 6 encountered major water problems.

In 1952, the very first shaft was started near Unity, about 160 km west of Saskatoon. Great difficulties were encountered during the sinking operations and the shaft finally flooded in 1961 after having reached a depth of 550 m. Water and sand from the Blairmore formation filled the shaft to within 100 m of surface. After nine years of struggle the project was abandoned.

The PCA (Potash Company of America) No. 1 Shaft near Saskatoon was frozen from surface to the top of the Prairie Evaporite formation and lined throughout with concrete. In the Blairmore formation the concrete reached a thickness of 3 m. Within the ice wall, shaft sinking through the water-bearing formations created no major problems and the shaft was completed in 1958. However, before the end of the first year of production water began migrating through the freeze holes and penetrated the shaft lining. The mining operation had to be suspended, but it was possible to keep the water under control without flooding the mine. It took three years of grouting to seal the shaft lining.

The Yarbo No. 1 Shaft of the International Minerals and Chemical Corporation near Esterhazy was flooded twice to within a few meters of surface between 1958 and 1959 during attempts to grout the unconsolidated materials of the Blairmore. This formation was eventually frozen and the shaft was successfully completed in 1962, five years after sinking had started.

In 1966, when sinking operations of the Allan No. 1 Shaft, located about 55 km southeast of Saskatoon, had reached a depth of 590 m, the ice wall in the Blairmore ruptured along a coal seam and a water inflow of about 3 m^3/minute flooded the shaft. Placement of a concrete plug and additional freeze holes made the rehabilitation and completion of this shaft possible.

In 1967, when the K-2 shaft near Esterhazy had reached a depth of 900 m, it was flooded by water from the Dawson Bay Formation. A concrete plug, grouting and additional tubbing rings were needed before shaft sinking could be resumed and successfully completed.

In 1970, the entire underground operation of Cominco Ltd., including both shafts, was flooded. This occurrence is the subject of the following paper.

DESCRIPTION OF THE COMINCO MINE

Cominco Ltd. is a Canadian mining company with operations throughout the world. It is a major producer of lead, zinc, silver and fertilizers.

The potash mine is located about 40 km southwest of Saskatoon in the province of Saskatchewan in Canada. In this area potash is mined in the top seam of the Middle Devonian Prairie Evaporite Formation at depths of approximately 1,100 m. In July, 1965 preparation work for the simultaneous sinking of two shafts 152 m apart began.

In addition to freezing the water-bearing gravel of the Glacial Till from surface to 62 m, and the water-bearing sands and silts of the Blairmore from 517 m to 633 m, it was decided to freeze the water-bearing dolomites of the Upper Nisku between 640 m and 670 m as well; freeze holes were drilled to a depth of 685 m (Fig. 1). "Pre-abandonment" of the freeze holes was used instead of their usual abandonment after the completion of the freezing process. Shaft sinking caused no major problems and both shafts were completed in 1968.

The shaft lining from surface to 500 m consists of concrete 60 cm thick. A cast-iron tubbing column backed by high-strength concrete and sealed with a pikotage (wedge) ring at the top and bottom forms the lining through the unconsolidated materials of the Blairmore Formation from 498 m to 639 m. The water-bearing section of the Nisku formation was lined with high-strength concrete of 425 kp/cm^2 compressive strength and 110 cm thick from the bottom of the tubbing column to the final depth of the freeze pipes at 685 m. The remainder of the shaft lining to the top of the Prairie Evaporite consists of high strength concrete varying in thickness from 80–90 cm.

The No. 1 Shaft has a diameter of 5.65 m and a final depth of 1,145 m. It is used as a production and service shaft and for exhaust air. A tower-mounted, four-rope Koepe hoist and two 22 t skips in balance hoist ore and transport materials and personnel.

The No. 2 Shaft has a diameter of 4.93 m and a total depth of 1,090 m. It is equipped with a temporary headframe and hoist for emergency exit only and serves as fresh air supply shaft.

Production started in January, 1969 with three Marietta continuous miners, three gathering-arm loaders, eight diesel and battery-operated haulage trucks (20–22 t capacity), three feeder breakers, conveyor belts, two crushers, two 5-ton scooptrams and a large number of electrical control centers, transformers, service vehicles and other auxiliary equipment.

Premature roof failures led to the introduction of a system of parallel entries with narrow yield pillars where the collapse of relief drifts formed stable roofs in the protected entries.

Mine openings extended over a length of 34 km when, on August 27, 1970, a major water inflow occurred in No. 2 shaft. Water flooded the mine and both shafts, bringing mining operations to an abrupt halt.

FLOODING OF THE MINE

During routine grouting of the concrete lining of the No. 2 Shaft, a major water source was intersected about 50 cm below the lowest tubbing ring at a depth of 639 m. Water and sand under very high pressure entered the shaft through a 35 mm drill hole in a 50 mm standpipe in the concrete shaft lining at a rate of about 4 m^3/minute (Fig. 2).

An immediate attempt to halt the water inflow by attaching a shut-off valve to the standpipe failed. Within three hours the standpipe had broken loose and within six hours a hole, about 75 mm in height and 350 mm in width, had developed through the shaft lining. The water inflow had increased considerably. Since the enormous inflow of water and quicksand could not be stopped, the major pieces of underground equipment were moved into protected areas and about 10 hours after the first inrush of water the mine was evacuated.

Preparations were made to bring the water inflow under control from within the shaft by the construction of a guillotine gate and by grouting. All work in the shaft was extremely difficult. Not only was there the jet of water and sand but there was also the roaring noise and the tremendous suction of air created by the mass of water hurtling from the 640 m level in a free fall of 440 m to the shaft bottom forming a natural compressor. A heavy bulkhead was installed at the collar of No. 1 Shaft to counteract the air flow in No. 2 Shaft and to make it possible for workmen to enter the shaft. In addition, whenever critical work was performed, brine was pumped down the No. 1 Shaft to reduce the suction in No. 2 Shaft.

A heavy steel plate equipped with a pipe manifold and high pressure shut-off valves was positioned over the break, jacked tight and bolted to the concrete wall. With the help of the valves it should have been possible to control the water inflow while the leak was sealed by grouting. Two 250 mm heavy-duty wide-flange I-beams, 5 m long, were bolted to the three bottom rings of the tubbing column. These two beams formed the guides for another set of heavy steel beams, which provided the frame for the shut-off plate. A 200 mm pipe manifold with twelve 50 mm high-pressure valves was welded to a 40 mm steel plate 915 mm high and 870 mm wide (Fig. 3). This plate was bolted to the frame and the whole assembly could slide in the guide beams like a guillotine gate. This gate assembly was pushed into position over the break and secured with two 50-ton hydraulic jacks that were braced against the opposite shaft wall. An attempt to install a third jack had to be abandoned. Although much of the water came through the valves, the pressure and volume of water outstripped the valve capacity and water still forced itself out around the plate.

Five days after the initial water inrush, the brine in the

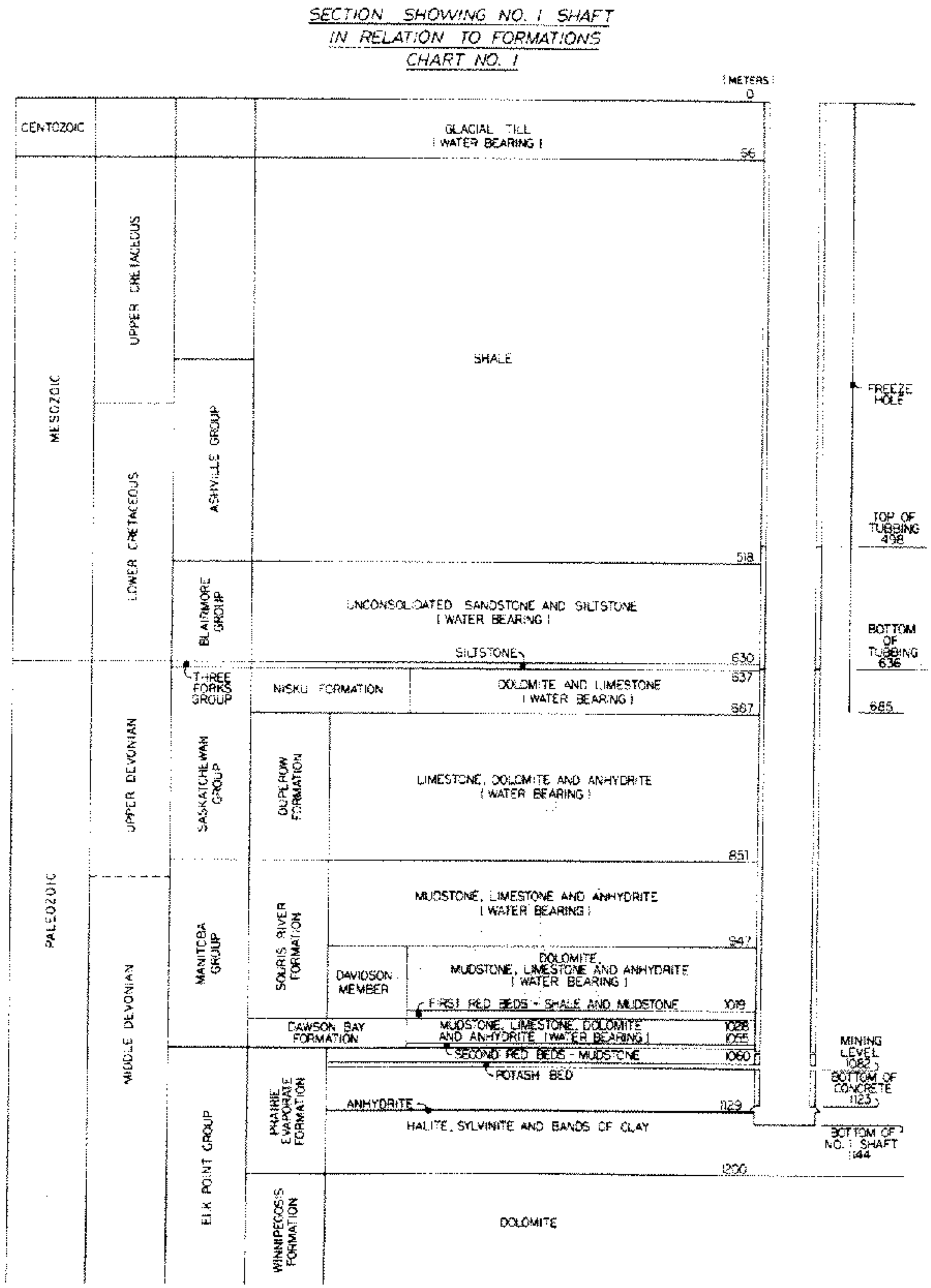

Figure 1. Section showing No. 1 shaft in relation to formations.

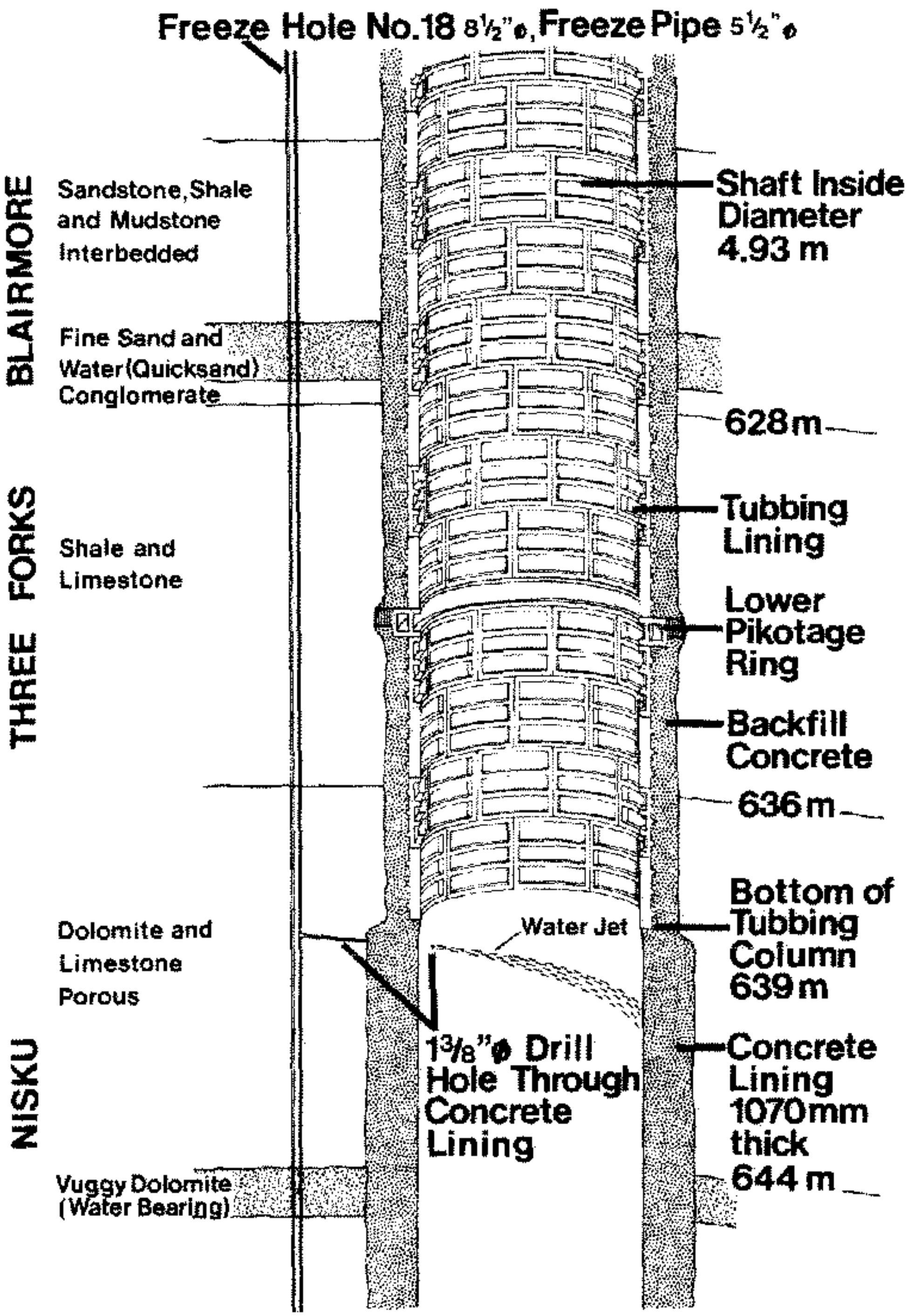

Figure 2. Cominco Shaft No. 2. Break through concrete lining at depth of 639.43 meters.

mine had reached the roof level cutting off all air circulation between the two shafts and making it very quiet around the headframe of No. 1 Shaft. When the water began rising in the shafts, attempts to seal the gaps around the shut-off gate were terminated and the time still available before the water reached the break was used to drill injection holes through the tubbing and install an additional grout line in the shaft. Of the three holes drilled, two had to be abandoned, but one reached a depth of 18 m. This hole was then connected to one of the grout lines and the surface pumps. The second grout line was connected to one of the twelve valves of the pipe manifold, and the remaining valves were shut off.

During the first three days following the accident the rate of water inflow was greatly underestimated. It was not possible to enter the mine to obtain measurements. However, it was soon discovered that the rising water would short-cir-

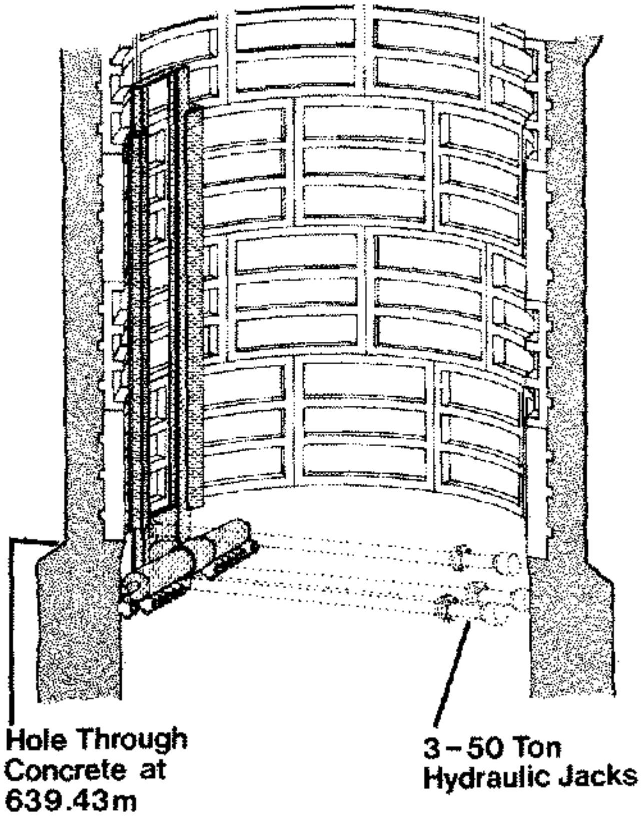

Figure 3. Guillotine gate, support guides and hydraulic jacks.

cuit the telephones located throughout the mine. Since the location and elevation of all telephones were known, it was possible to calculate the rate of water inflow by monitoring the telephones. It then became obvious that the available time was not sufficient to seal the break from within the shaft only, and it was decided to drill a relief hole from the surface (Fig. 4).

An oil rig was mobilized and set up to drill a relief hole from surface to intersect the area of the break. Because of room restrictions the hole was spudded 9 m away from the freeze hole circle. It was therefore drilled on an angle towards the shaft and then deflected to come to within 60 cm of freeze hole No. 18 at a depth of 639 m. Moving the drill rig to the site, setting it up, drilling the hole, deflecting it with turbines and installing a casing, took six days. By this time the water in the shaft had risen over the break. After completion of the hole to 650 m and installation of a casing to 637 m a charge of 5 kg of explosives was placed at 639 m and detonated. Pumping tests showed that the blast had created a connection between the surface relief hole and the shaft.

The water had now reached a level of 338 m and 275 m in No. 1 and No. 2 Shafts respectively; the difference of 63 m was due to the different specific gravities of the brine in the two shafts. Brine was pumped into No. 2 Shaft to overcome the formation pressure and to reverse the flow through the breach. When the brine level in Shaft No. 1

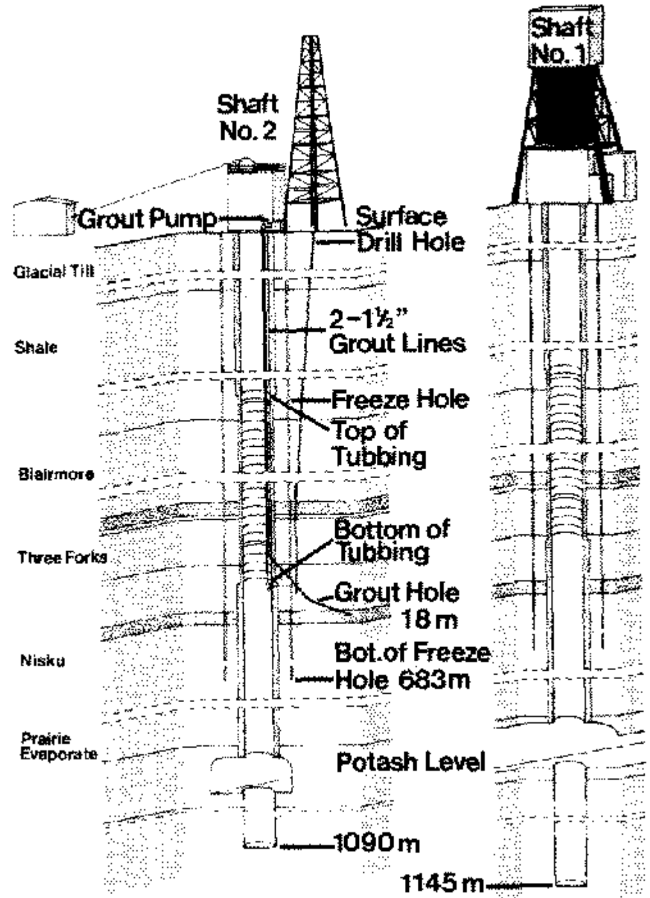

Figure 4. Shafts No. 1 and 2 and surface drill hole.

reached 272 m this had been accomplished and a drop in the brine level indicated a flow from the shaft into the formation. Now cement was injected through the two grout lines in the shaft. The brine carried the cement with it into the formation. Twenty-four hours later, cement and small amounts of sand, bentonite and calcium chloride were pumped into the surface relief hole to plug the breach in the concrete shaft lining behind the steel plate. 2.2 t of cement were injected into the formation through the two shaft grout lines and 615 t of cement was pumped in through the relief hole to seal the concrete lining and stabilize the ground around the shaft. Through two additional surface relief holes, 17.2 t and 2 t of cement respectively were injected into the formation.

Shortly after the initial cement injections the water make in the shafts was reduced considerably, as can be seen from the inflow chart/(Fig. 5) and it could be assumed that the breach in the concrete lining had been sealed.

DEWATERING

Dewatering in No. 1 Shaft was undertaken with Byron Jackson submersible shaft sinking pumps. Each pump was 10 m long, 56 cm in diameter, had a motor of 335 KW at

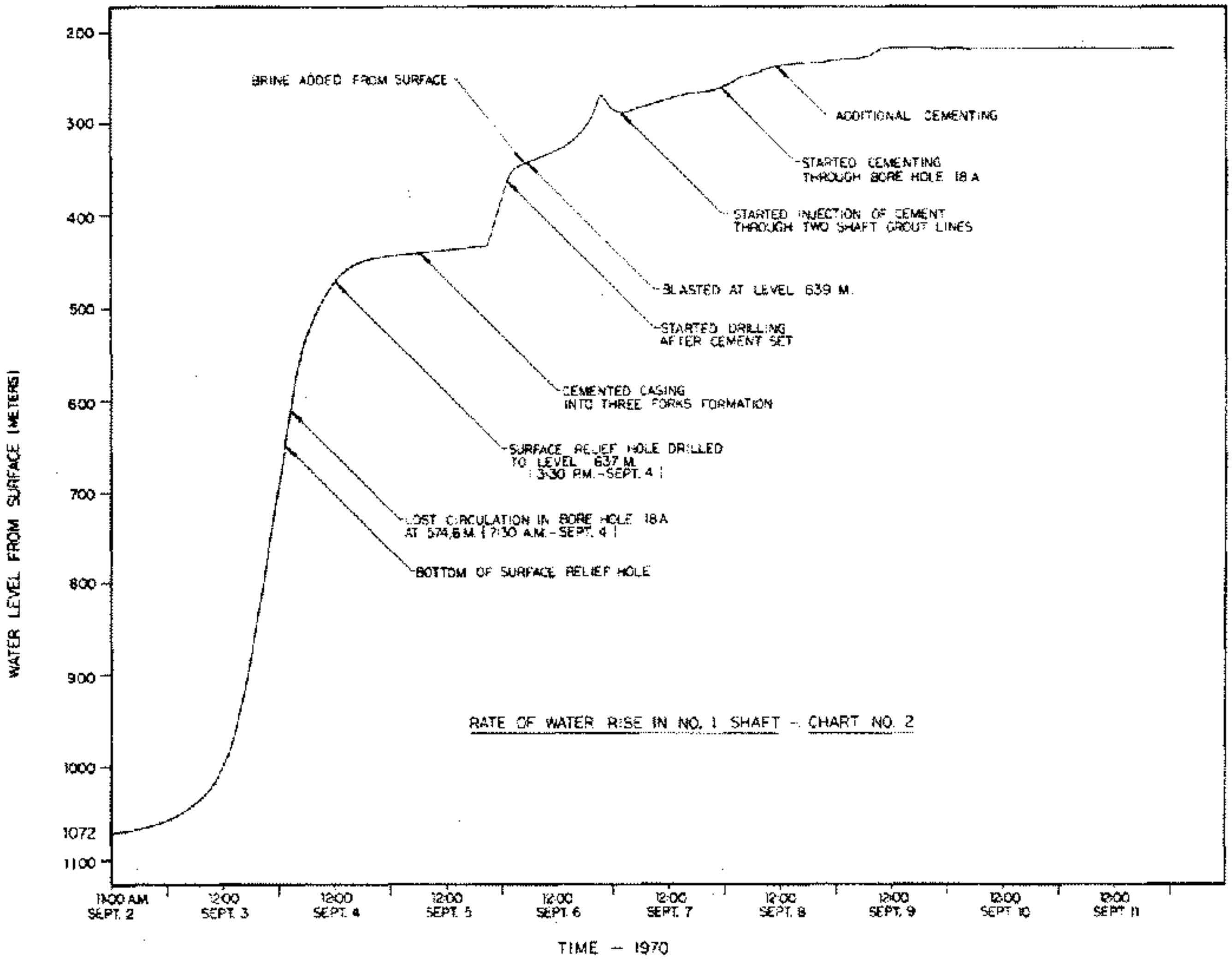

Figure 5. Rate of water rise in No. 1 shaft.

2,300 volts and a capacity of 3.5 m^3/minute at a head of 250 m. Three auxiliary hoists, several winches and a pump discharge line to the surface brine pond were installed before dewatering could begin on September 22nd (Fig. 6). On that day, the water level was 215 m from surface in No. 1 Shaft and 178 m in No. 2 Shaft.

A Byron Jackson lead pump and a 200 mm discharge pipe 137 m long were attached to a hoisting rope and could be lowered and raised by an auxiliary hoist. The upper end of the discharge pipe could be connected to a T-joint in a pump line mounted on the shaft wall. The lead pump was submersed and as the water level dropped, the 200 mm pump line was extended and bolted to brackets in the shaft lining. At a depth of 213 m the first stage pump was installed. This was a Byron Jackson pump mounted inside a closed pipe can, 900 mm in diameter and bolted to the shaft wall. The lead pump assembly was then lowered and the discharge line connected to the first pump can. This procedure was repeated and three more stage pumps were installed at 434 m, 655 m and 876 m below surface.

This system worked well except for the considerable problem of water-proofing the 2300 volt cable connection to the Byron Jackson pumps due to the brine conditions and the pump vibrations.

In No. 2 Shaft the guillotine gate was exposed on October 25th. There were no leaks from around the plate. Eight core holes were drilled through and around the plate to test the effectiveness of the seal. The breach was completely plugged. The pipe manifold was then removed and the plate was bolted to the concrete wall. During the next two months, grouting of the formation from the bottom of the tubbing to the wet Nisku Zone at a depth of 652 m was undertaken through the shaft lining.

The lead pump was finally placed in the sump of No. 1 Shaft and by December 17th the brine had been lowered to the potash level. The concrete foundations at the shaft bot-

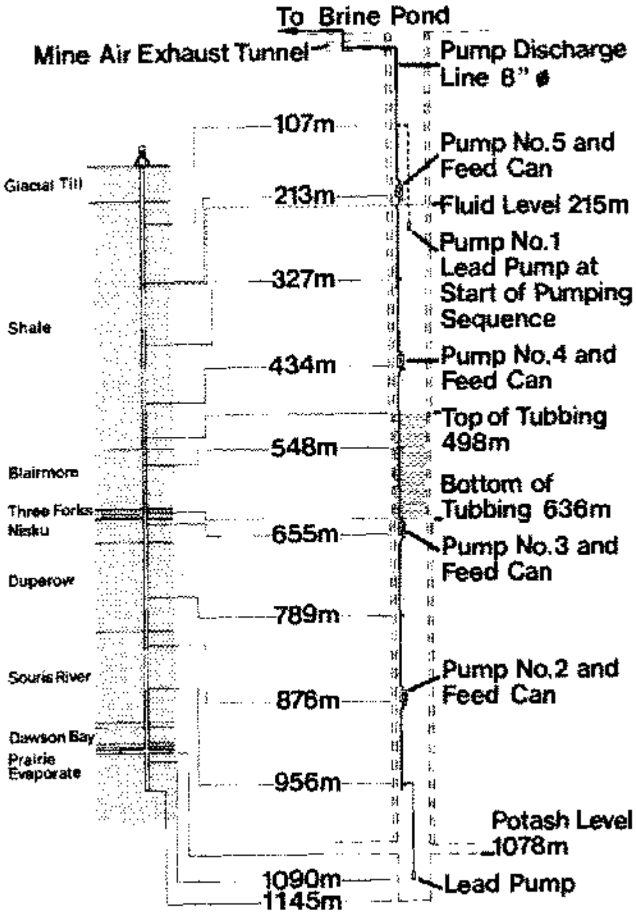

Figure 6. Pump set-up in Shaft No. 1.

tom were then examined by scuba divers, who found no areas of major leaching.

The drifts in the immediate shaft area were checked and secured from a small raft. Heavy leaching had occurred only in the drift through which water had passed from No. 2 to No. 1 Shaft. About 1 m of salt and potash had been washed away from walls and roof. Erosion was especially pronounced where roof bolts had been installed, but was most severe in the area of No. 2 Shaft. The original opening around the shaft bottom had been enlarged to a cavity 17 m in diameter. A platform was constructed to permit work on the roof (Fig. 7).

Due to the natural dip of the ore body, most of the mine is below the shaft station. Thus, a 70 KW Flygt pump with an output of 8 m^3/minute at a head of 30 m was installed on a raft to move the brine through a 200 mm pipe to the shaft sump, from where it was brought to surface with the Byron Jackson pumps.

The main access to the mine was completely filled with fine sand, and therefore an alternate route had to be selected for the pump line. While no leaching of the roof away from the shafts had occurred, the walls had been severely damaged by water which widened existing cracks.

Generally, wall slabs were removed by drilling and blasting. In some areas the small yield pillars of three-entry systems had been reduced to the extent where they did not function as pillars any more and some drifts had to be backfilled and abandoned. A number of pillars were reinforced by bolting.

EQUIPMENT REHABILITATION

No corrosion on steel frames of equipment or other steel structures had occurred. However, metal alloys showed various degrees of corrosion. Some components made of aluminum alloys had completely disintegrated. As soon as possible, all gear boxes and motors were filled with oil to prevent further corrosion. One of the three Marietta Miners was in the shaft area, where rehabilitation work could start immediately. All bearings, all hydraulic motors, pumps and hoses and all electrical controls had to be replaced. The two 4,160 volt 375 KW main motors and the 4,160 volt 150 KW pump motor had to be rewound. The machine was completely dismantled, cleaned and re-assembled.

Since it took longer to reach the other two Marietta Miners, those parts of their gears which had been exposed to air had also been corroded in addition to the damage done to bearings, hydraulics and electrical controls. All other equipment was dismantled, cleaned and re-assembled. Fortunately, only a few pieces of equipment had been damaged by roof falls, but poor walls in conveyor entries necessitated the removal and reinstallation of most conveyors. Most diesel engines were beyond economical repair and were therefore replaced.

Electrical components and cables were most severely damaged. All load centers and transformers were unsalvageable. All 4,160 volt motors had to be rewound because the coils harbored small pockets of brine which could not be removed. However, 95% of the 550 volt motors could be returned to service with no more than re-balancing, change of bearings, cleaning and painting.

All cables from 550 volt and 4,160 volt trailing cables to the 13,800 volt main power distribution cables, were either ruptured or so completely saturated with brine that they could not be re-used. Of the shaft cables, which include the 13,800 volt main power supply cables and the control and communications cables, only the two 13,800 volt supply cables survived and are still in use.

CONCLUSION

Of all the options discussed immediately after the flooding the one selected, and hence the one described in this paper, proved successful in sealing the break and dewatering the mine.

A total of 515,130 m^3 of brine had to be removed before clean-up and rehabilitation of underground mine openings and equipment could begin. To provide access to the mine

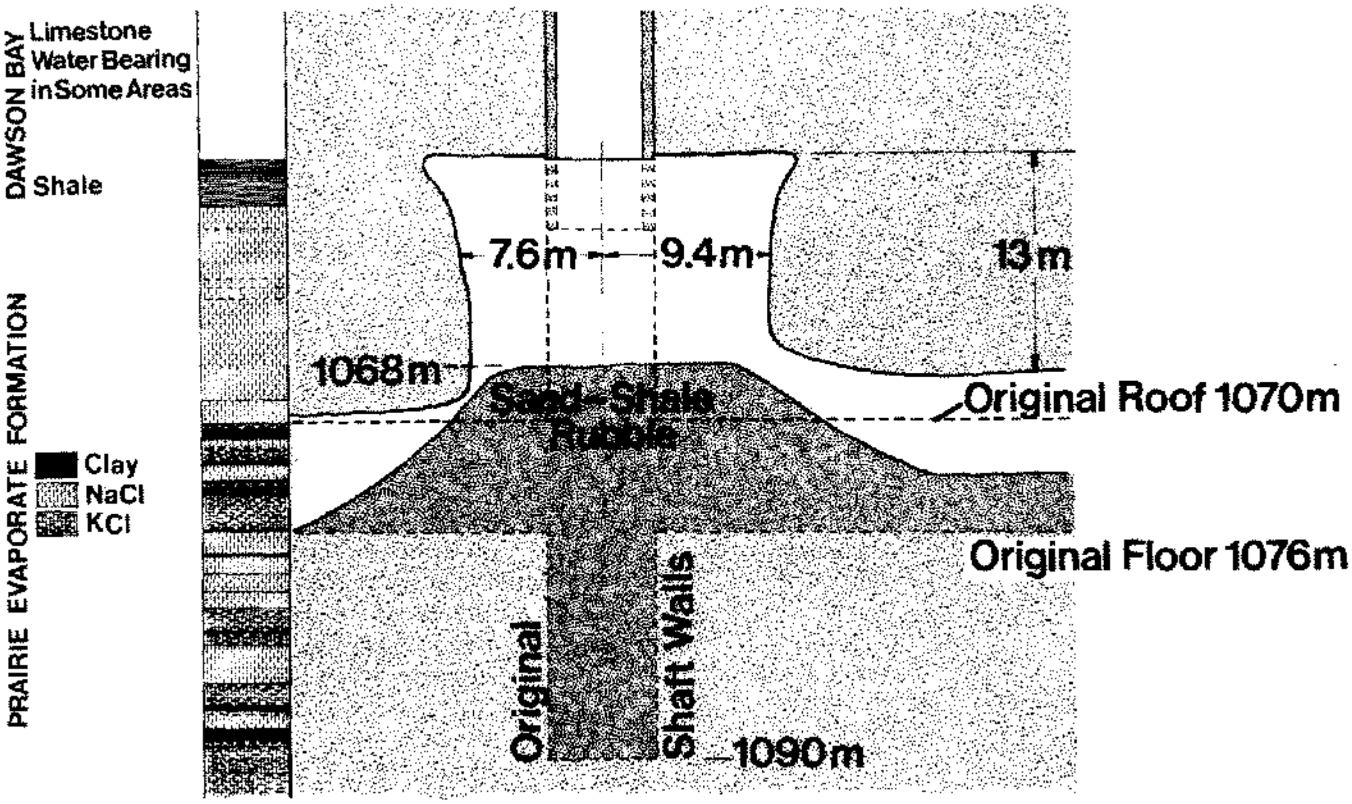

Figure 7. Washout at bottom of shaft No. 2.

15,000 m³ of fine quartz sand and mud had to be removed. One low-lying area was not dewatered but was abandoned.

By June 21st, 1971 all pumping from the mine openings had been discontinued. Based on the total of 515,000 m³ of brine pumped and taking into consideration normal water make in the shafts and also any brine pumped in from surface, the rate of water inflow during the flooding of the mine was in excess of 65 m³ per minute.

The first mining unit was ready to operate in April, 1972 and was employed to drive a decline to the bottom of No. 1 Shaft. Reconditioning of a 4,000 t storage bin, the installation of surge bins and main-line conveyor systems was completed during the summer of 1972. Rehabilitation of the remainder of the equipment was completed in August, 1972 and production commenced in September, two years after the flood occurred.