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Open Pit Dewatering at Pine Point

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INTRODUCTION

Ground dewatering during open pit mining is a common practice. It is usually necessitated by the practical considerations of mining equipment and methods and because of geotechnical reasons.

Operating in a location experiencing relatively long and cold winters produces additional problems. This is the situation at the Pine Point Operations of Cominco Ltd. It is not unique but, as mining frontiers advance further north, the experience gained at Pine Point becomes of increasing interest to those involved in these developments.

This paper is not intended to be a text on hydrogeology or aquifer investigation but rather a description of dewatering procedures used successfully at an unusual northern open pit mining operation.

GENERAL

The open pit lead and zinc mine owned by Pine Point Mines Limited and operated by its majority shareholder, Cominco Ltd., is located near the southern shore of Great Slave Lake at latitude 60° 49' North and longitude 114° 28'

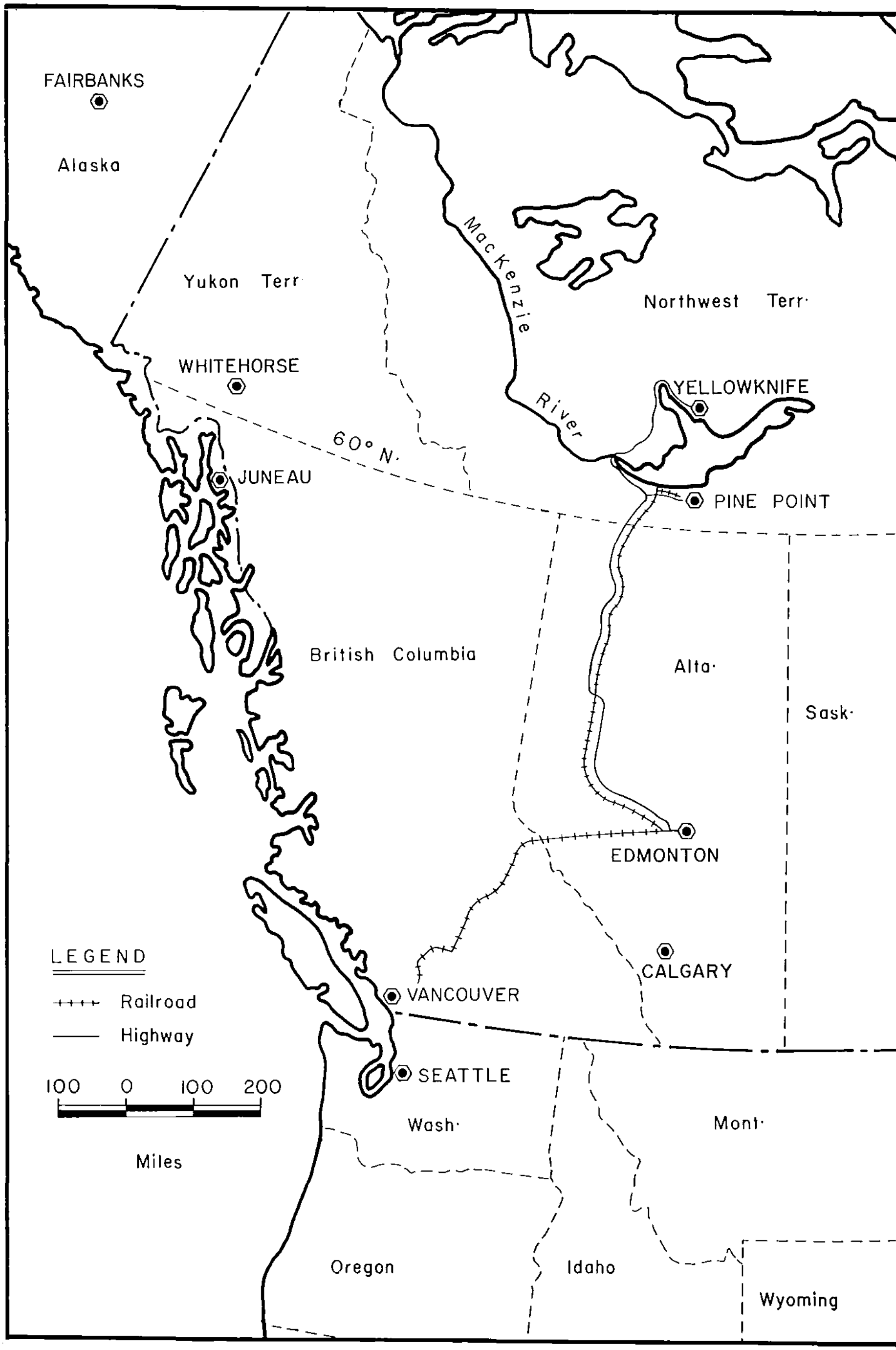

Figure No. 1 Location Map

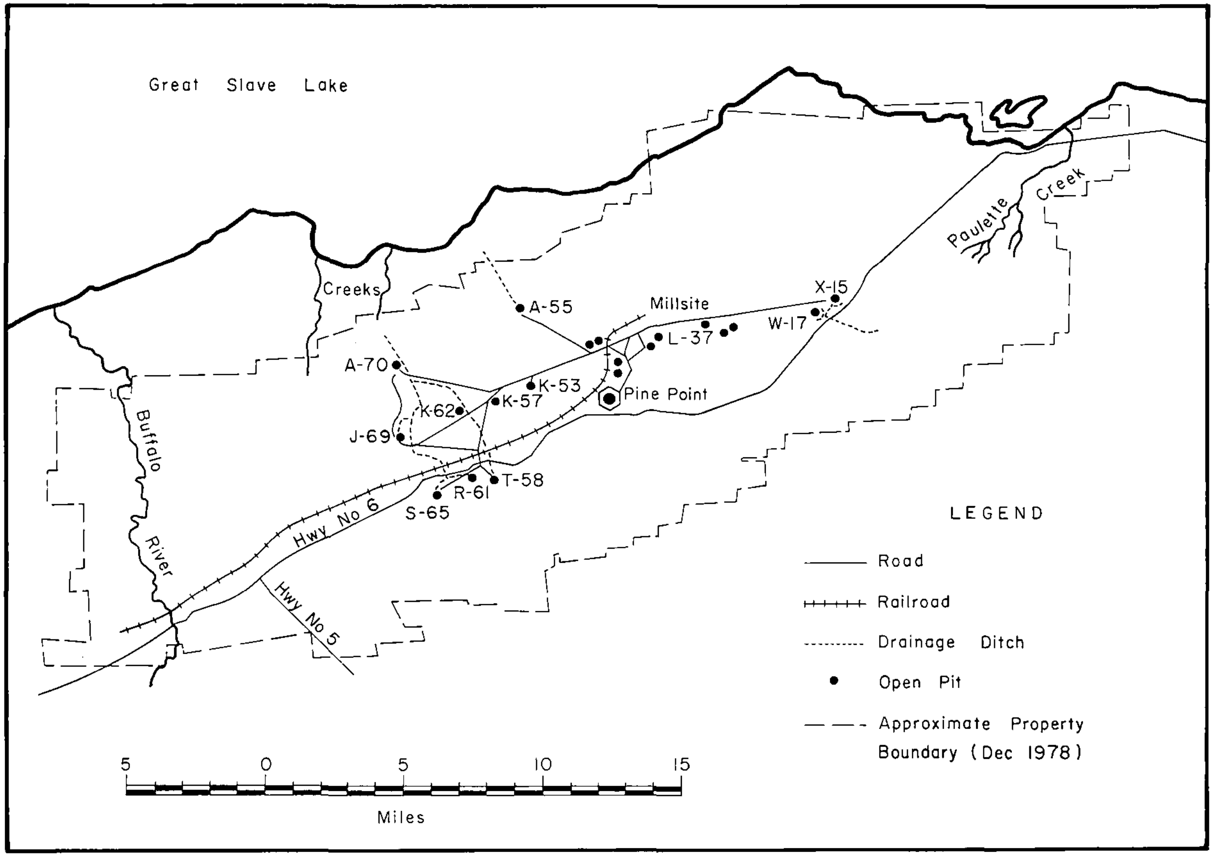

Figure No. 2 Property Map of Pine Point Mines Limited

West (Figure No. 1).

Mining involves the open pit extraction of relatively small, isolated orebodies (Figure No. 2). The pits are generally circular or elliptical in plan with lateral dimensions ranging from 400 to 3,000 feet and depth averaging 175 feet below surface, with a maximum depth to date of 327 feet in one pit. Production started in 1965 and has attained a level of about 11,000 tons of ore and 20,000 tons of waste rock and overburden per day. The strip ratio is increasing and has resulted in the recent acquisition of a dragline to supplement existing truck and shovel stripping capability. Small scale underground mining was performed close to the millsite between 1970 and 1977 and will be resumed at that location and in other areas west of the millsite when economic conditions permit.

Mining activity started in the then known area of ore reserves close to the millsite and has progressively moved further from this area as these reserves were depleted and mineral exploration activity proved reserves in other areas of the mine property. Constraints imposed by production equipment logistics, mill head grade requirements, and varying metallurgical properties necessitate the operating of as many as six open pits at any time. Simultaneous mining of pits scattered over a relatively large area produces unusual operating problems. These are compounded when most of these pits require dewatering installations and drainage ditch systems.

NATURAL ENVIRONMENT

Surface Topography and Vegetation

The mine property is located in an area which is generally low lying and poorly drained. The ground slopes gently towards the south shore of Great Slave Lake, about six miles north of the millsite. The change in surface elevation over this distance is from about 700 to 515 feet above mean sea level. Low gravel ridges, muskeg areas, swamps, and shallow lakes cover the area.

Surface expressions of karstic features include intermittent creeks, natural springs, and sinkholes.

The active mining area, some 20 miles east-west and five miles north-south, lies between the Buffalo River to the west and Paulette Creek to the east. These rivers, together with the Little Buffalo ten miles further east, form distinct surface drainage systems. Other systems are generally poorly defined.

The area lies within the boreal forest and vegetation consists of stunted spruce and pine with birch and aspen occurring on the gravel ridges. Open areas of scrubby willows, sedges, and grasses are common. Trees seldom attain commercial quality. Very slow growth rates reflect the harsh environment.

Climate

Relatively long winters and short, dry summers are experienced. The annual number of frost free days averages 80 and sustained periods of below minus 30 degrees Celcius air temperatures occur from December to March. Light northerly winds are common throughout this period.

Annual precipitation is low, averaging about 13 inches of water equivalent. Much of this is in the form of snow which, during the spring thaw in late April or in May, flows over the frozen ground to seasonal creeks and towards Great Slave Lake. Ice on the major lakes and rivers breaks up and is carried down the Mackenzie River in June.

The climate is classed as semi-arid.

Geology

Surface outcrops are very rare in the region. Overburden, consisting of sandy glacial till with occasional gravel beds and areas of varved clays and cemented fine sands which are known locally as "hardpan", varies from 10 to 150 feet in depth. This material is often overlain by an organic, peaty layer of muskeg varying in depth from one to ten feet. Localized areas of permafrost have been encountered in the overburden but are not common.

General geology is shown in Figures No. 3 and No. 4. Lead and zinc mineralization of the Mississippi Valley type occurs within the Devonian formations. The ore deposits are associated with a barrier reef complex in this formation and host rocks are medium to coarse grained recrystallized dolomites. Rock types within the formation also include

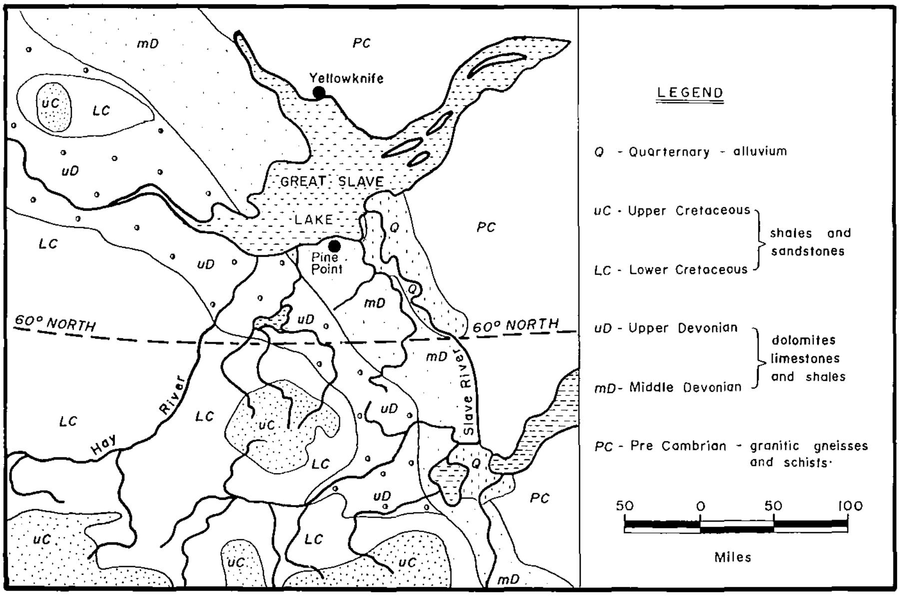

Figure No. 3 Regional Geological Map

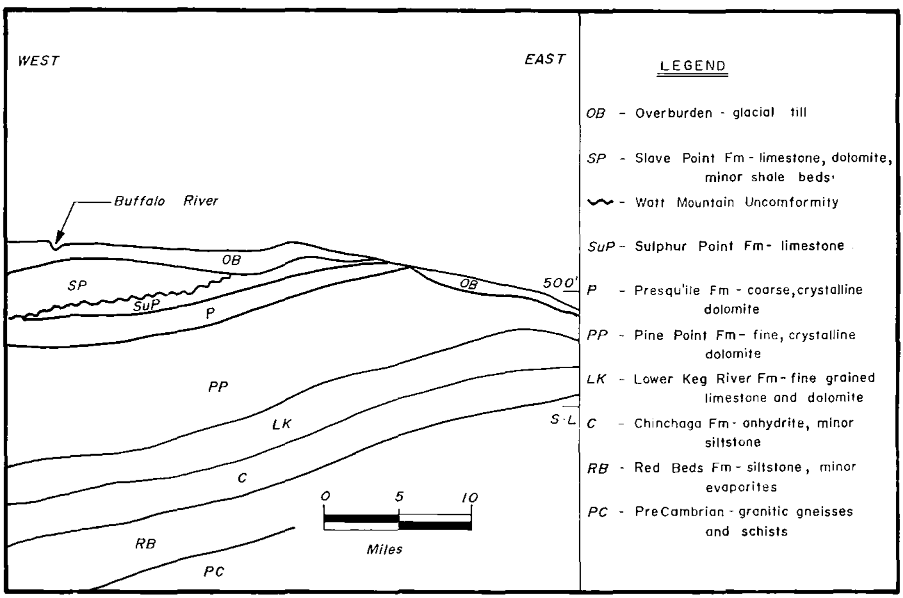

Figure No. 4 Generalized Geological Section limestones, shales, and mud and sand seams. Karstic features such as sinkholes, solution channels, and cavities are widespread. Sinkholes are filled with sands and various brecciated material and often contain ore grade mineralization.

Strata dip gently to the southwest, folding is minor, and major fracture zones reflecting tectonic movement in the basement have been identified. Distinct bedding planes and vertical fracturing are common.

Detailed descriptions of the geology of this area have been published (1).

Hydrogeology (by K. U. Weyer)

The natural groundwater table in the Pine Point area varies in depth below surface from a few feet to about 60 feet.

Perched water is common within the overburden in the "hardpan" areas. The abundant small lakes are usually shallow and often have fine clay bottoms. These and the areas of perched groundwater are often unaffected by major ground dewatering programmes.

Studies of regional groundwater flow are active (2, 3). It appears that flow through the aquifers of the Devonian formation is from south to north with a major area of recharge being the Cretaceous formations of the Caribou Mountains 150 miles to the south of the mining area (Figure No. 3). Significant discharge and recharge zones have been identified along the Buffalo River in zones of faulting and significant fracturing and in other areas.

The lithology of the Pine Point complex varies considerably and continuous separate aquifers are difficult to identify. The overall formation is considered an extensive major aquifer. The gently dipping strata result in varying aquifer conditions across the mining property. The aquifer is considered unconfined to the east and increasingly confined to the west where overlying shale and clay beds occur. Artesian flows have been encountered in the western and northwestern parts of the property. Natural springs occur in these areas.

The porosity of the limestones and dolomites themselves is relatively low. Groundwater flow is considered to be mainly along solution channels, bedding planes, and fracture zones. Aquifer characteristics determined by pumping tests are described later.

Chemical analyses of natural spring water and of deep well pump discharges have indicated two distinct "types" - salty and sulphur water (2, 3). The range of analyses of groundwaters near the open pits is shown in Table No. I. Their differing chemical and isotope characteristics reflect different groundwater flow systems. To the south of the mining property limestones and dolomites are underlain by evaporite beds of salt and gypsum. These are absent in the vicinity of the ore deposits. Natural discharges of salty water and brines containing up to 340 grams per litre T.D.S. and with specific conductivities greater than 80,000 micromhos per centimetre have been found in some areas within the region (2).

Table No. I
Range of Analyses of Pumped Groundwater (2, 3)

pH	7.0 - 8.0
Suspended solids	0 - 200
Total dissolved solids (T.D.S.)	1300 - 4300
Hardness, as $CaCO_3$	1000 - 2000
Dissolved anions	
- chloride	20 - 300
- sulphate	1000 - 1500
Dissolved cations	
- calcium	150 - 500
- magnesium	75 - 200
- sodium	20 - 100
- potassium	2 - 10
- copper, iron, lead, zinc	less than 0.1
Total copper, iron, lead, zinc	less than 1.0 each
Specific conductivities	
- salty water	3000 - 6000
- sulphur water	1000 - 2000

Note: All values are parts per million, except for specific conductivities, which are in micromhos per centimetre, and for pH.

The temperature of pumped groundwater appears to be consistent through the seasons and varies throughout the mining area from about two to five degrees Celcius.

DEWATERING SYSTEMS

Most of the orebodies occur below the natural groundwater table and within the major aquifer. Without dewatering, mining would be difficult and hazardous in the summer and probably impossible in the winter.

Dewatering, or the localized depression of the groundwater table, is accomplished by pumping with deep well pumps located in wells drilled around the perimeter of each open pit. These pumps operate continuously and develop a cone of drawdown in the groundwater table centred on the pit. Upon completion of mining, the pumps are removed and recovery of the water table occurs. The rate of drawdown and of recovery depends on several factors, including the pumping rate, the ultimate drawdown depth, the local hydrogeological conditions, and the proximity of other dewatering operations.

Observation of surface drainage systems such as lakes and creeks and of localized areas of perched water within the overburden indicates that drawdown has very little effect on these. This water results from natural precipitation. Small lakes immediately adjacent to pits having active deep well dewatering systems often show no significant change in water levels during the dewatering programme. Surface run-off and drainage systems are diverted from active pit areas and this water is usually collected in the pit perimeter ditches which serve the well discharges.

With the area being semi-arid, the accumulation of surface precipitation within open pits does not produce significant operating problems and special facilities are not required to handle these small quantities of water. Water formed during the spring thaw and resulting from infrequent light summer rain showers usually percolates though the pit floor to the depressed water table.

In-pit sump pump operations are sometimes used during final pit mining when the depressed water table is reached and economic considerations, or production schedules, preclude the drilling of additional wells.

Development

Perimeter dewatering systems were initiated on the advice of Legette, Brashears and Graham of New York in the late 1960's (4). Papers on the development of open pit dewatering at Pine Point have been written by Calver and Farnsworth, and by Vogwill (5, 6).

Perimeter deep well dewatering systems have been successfully used for pits within the unconfined aquifer. Future mining developments will be within the confined aquifer on the western part of the property and underground below the natural water table. These will require modification of aquifer investigation methods and of dewatering system design and implementation.

Design

Aquifer characteristics in the areas of planned open pit mining are determined by performing pumping tests.

Procedures have been previously described by Brashears and Slayback, Calver and Farnsworth, and Vogwill (5, 6, 7). Basically, controlled pumping is performed in a test well and resulting changes in elevation of the groundwater table monitored during drawdown until a storage depletion trend is attained and during recovery after cessation of pumping. The total cost of performing a 14 day pumping test is approximately $15,000 (Can.), excluding well drilling costs.

Data are analyzed using the straight-line method of Cooper and Jacob (8) and the distance-drawdown method of Thiem (9). Use of these techniques assumes that the aquifer conforms to certain basic hydraulic and geological properties. Many of the pit dewatering programmes have been in areas of unconfined aquifer conditions and designs based on test results have resulted in satisfactory dewatering performance. Analysis of pumping test data from areas of partially and fully confined aquifers is modified to take into account leaky artesian conditions. Field data are matched to a type curve and values for well functions and leakage factors obtained (6).

The purpose of the analyses is to obtain local values for the transmissivity and storage coefficient of the aquifer. From these, water table drawdown can be determined for various rates of deep well pumping. Total drawdown and rate of drawdown are matched against the mining production schedule for the pit.

The number of wells required to perform the dewatering programme is calculated, considering the following factors:

1. average well yield, related to
   (a) initial test well drilling and pumping test experience, and
   (b) practical and economic considerations of maintaining an inventory of pumps of various capacities;

2. loss of 10 percent of the wells because of ground collapse; and

3. 80 percent effective pumping rate because of interruptions from power failures, pump failures, and general maintenance requirements.

Factors 2 and 3 result from experience gained during the dewatering of eleven pits since 1968.

Aquifer characteristics obtained from pumping tests performed to date are shown in Table II.

Table No. II
Aquifer Characteristics in Open Pit Areas
as Determined by Pumping Tests

Pit	Transmissivity (U.S. gpd/ft)	Storage Coefficient
J-44	60,000	0.025
N-42	54,000	0.016
O-42	72,000	0.035
M-40	50,000	0.016
X-15	35,000	0.006
W-17	69,000	0.050
T-58	77,000	0.001
R-61	37,000	0.001
K-57	50,000	0.001
K-62	68,000	0.050
J-69	70,000	0.050
A-70	68,000	0.002

Note: U.S. gpd/ft = U.S. gallons per day per foot

After the number of wells has been determined, well locations relative to the final pit rim are chosen. Factors considered during well siting include:

1. location of sinkholes. Collapse material within these usually consists of boulders and rock fragments within

a matrix of sand, gravel, and clay. To maintain well holes in this material, casing and well screen would be required. The cost of such well construction compared with non-cased holes in relatively competent limestone and dolomite, and the relatively low yield of wells in such material, precludes siting them within sinkholes.

2. existence of patterns of anisotropy within the regional aquifer characteristics. These are often indicated during the pumping tests; two lines of observation holes, usually perpendicular to each other, are used during the test. Directions of preferential groundwater flow are also often indicated during investigation of the geological environment. Lineation of fracture patterns, fault zones, and facies types indicate such directions. Well holes are sited within zones that will provide maximum yield.

3. possibility of drawdown interference between adjacent wells. The extent and shape of the drawdown cone for any well varies according to the local aquifer properties and, of course, the duration and rate of pumping. Experience at Pine Point has indicated that a minimum spacing of 300 feet between well holes is effective in producing drawdown over the lateral extent of most pits without producing significant interference between wells. A few widely spaced wells seldom produce the required drawdown unless the water table has already been significantly lowered by pumping at an adjacent pit.

4. the design location of the final pit rim and the perimeter drainage ditch. Location of the latter depends on local surface topography. In most areas this is relatively flat and, together with the frequent occurrence of swamps and small lakes, makes ditch layout very critical. Flow rates must be such to ensure that discharged water does not freeze during the long, cold winters. Well holes are located at least 185 feet from the pit rim and sufficiently close to the drainage ditch that discharge pipe lengths are not excessive. The 185 feet accommodates a pump service road 25 feet wide, an allowance for minor pit design changes, and for possible slumping of the overburden. Typical arrangements are shown in Figures No. 5 and No. 6.

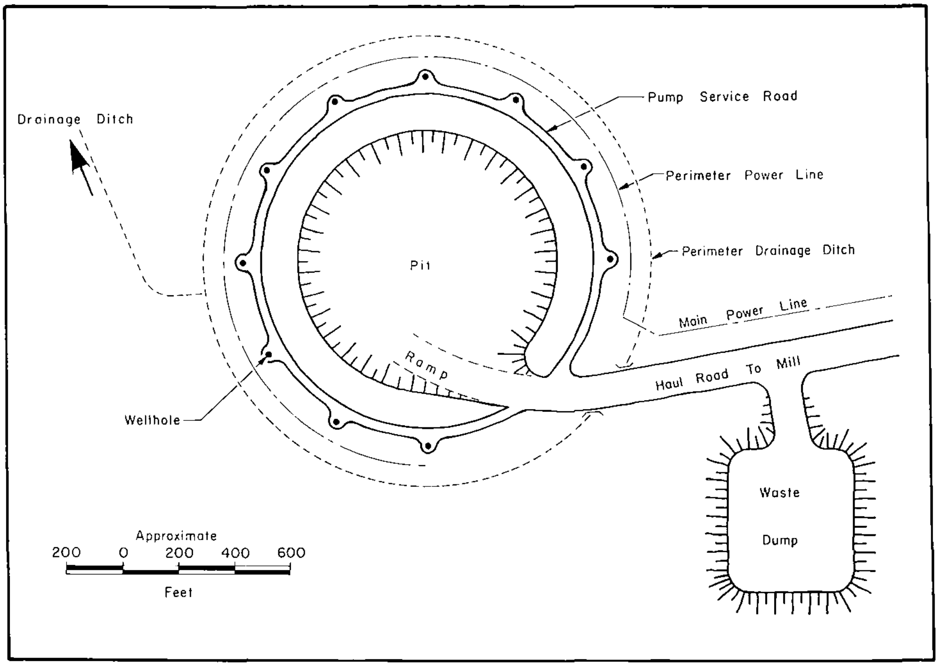

Figure No. 5 Typical Well and Ditch Arrangement

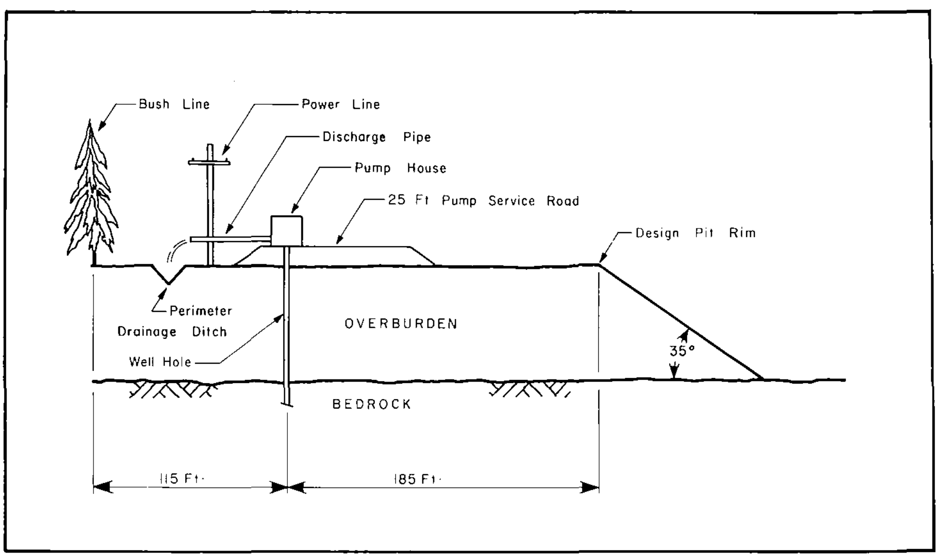

Figure No. 6 Section of Typical Pit Rim Arrangement

5. the total pit perimeter length. On small, deep pits it has been necessary to drill a double ring of wells on surface and, in some cases, to supplement these during pit mining with wells drilled on the outer edge of the in-pit ramp.

Well depths are usually between 400 and 500 feet, depending on the ultimate pit depth. Experience has shown that drilling to 200 feet below the pit bottom elevation results in sufficient penetration of the aquifer to give well yields compatible with pumps sized to fit the wells and to achieve the desired drawdown at the pit centre.

Well Drilling

Well drilling is contracted and, to minimize the effect of mobilization costs, sufficient drilling is performed in a single annual programme to satisfy the next year's pit development and mining. Since 1968 annual well drilling footage has averaged 8,000 feet.

Initially, wells were drilled 12 1/4 inches in diameter. Pumps were in the size range of 40 to 100 horsepower. Problems with crooked wells and the need to use larger pumps led to larger wells. All wells are now drilled 14 3/4 inches in diameter. This size is believed to be the optimum after considering typical well yield, relative drilling costs, and hole stability. Dependence on a few large diameter wells is avoided.

The development of drilling methods has been described by Vogwill (6). Current practice is to drill a 14 3/4 inch hole through the overburden, which averages 50 feet in thickness, and 20 feet into the bedrock. This hole is then reamed to 17 inches in diameter and 16 inch steel casing installed. The hole is then drilled to its final depth, using a 14 3/4 inch tricone bit. No casing or well screen is installed.

The hole is drilled to about 150 feet, well into the water table, using up to 300 U.S. gallons per minute of water. Drilling mud is used only through the overburden and only when this is composed of unconsolidated material that would otherwise collapse. Beyond about 150 feet, air is introduced at up to 1,200 cubic feet per minute at 250 pounds per square inch. Water from the circulating pump is reduced according to the quantity of water made naturally within the hole. Drilling foam (soap) is injected when necessary to assist in cuttings removal.

On completion of drilling, the hole is flushed until clear water is produced, usually after one to two hours. Secondary development of wells was attempted early in the dewatering programme but is no longer considered necessary. The dolomites and limestones are well fractured and vuggy.

The rig used successfully for the past eight years has been an Ideco H-25 with a dual stage 70-95 foot Cardwell telescoping derrick. Collaring on bedrock is slow because of the lack of pulldown. Every attempt is made to drill vertical holes and contracts have been let on an hourly rather than footage rate. Close technical control is supplied by Cominco personnel. The drill string configuration used to ensure straight holes includes a 9 inch diameter drill sub, shock sub, and rib collar between the bit and the 6 inch drill pipe. The shock sub and rib collar, with 11 1/2 inch ribs, are each 10 feet long.

Average drill performance for a 500 foot hole with 60 feet of casing and a move of 300 feet between set-ups is:

Move, rig up, and tear down	8 hours
Install casing, including welding	2 hours
Drill	14 feet per hour
Blow out hole	2 hours

1978 drilling costs were $26 (Can.) per foot. Including site preparation and rig mobilization from central Alberta, the overall cost was $35 per foot for a 12 hole, 6,000 foot programme.

Pump Roads and Pads

For access for well drilling and for the installation and maintenance of pumping equipment, a 25 foot wide road is built to each well site. This, and an approximately 100 foot square pad at the well site, is constructed from nearby gravel sources or, in their absence, from waste rock from the nearest pit or waste dump. Three to four feet of material is usually required to construct a service road across the often wet and soft ground surface.

This work is performed by mine production crews, or by a local contractor when development areas are distant from active mining areas.

Pumps

Several different types of submersible and lineshaft pumps have been used. Consideration of purchase, installation and operating costs over the past 12 years has resulted in the selection of the two types now in use. Details of these are summarized below:

1. Lineshaft pumps--

   Peerless Pump Division of F.M.C. Corporation, 7-stage, 12HXB bowl assembly pump with a 125 horsepower Westinghouse vertical hollow shaft motor, 3/60/575, 1,800 revolutions per minute with a non-reverse ratchet. Oil lubricated lineshaft complete with inner column. Also, similar pumps with 150 and 200 horsepower motors.

2. Submersible pumps--

   TRW Pleuger Canada Ltd., P104 2-stage pump with Pleuger 100 horsepower, 3/60/575, 3,450 revolutions per minute, water filled wet stator submersible motor. Also, similar 3-stage pumps with 130 and 150 horsepower motors.

It has been found that to best suit location conditions where the majority of wells yield 800 to 1,200 U.S. gallons per minute and the total dynamic head averages 250 feet, pumps in the range of 100 to 150 horsepower are required. A few wells are drilled within open pits and water is discharged through lengthy 8 inch lines. For these, several 200 horsepower Peerless lineshaft pumps are maintained.

In the past, sump pump arrangements for final bench mining have involved installing a well pump in a pump stand fabricated on the property from 16 inch well casing. Discharge to surface was through an 8 inch steel line installed along the edge of the driving ramp and, where possible, up and over the completed benches to the pit rim. Recent practice has been to use sump pumps manufactured by Flygt Ltd. with a flexible rubber discharge line about 200 feet long, connected to a steel line. These pumps can be readily moved within the pit as operating conditions dictate and do not require to be set vertically within a pump stand. For shallow pits, the flexible line can be quickly lowered over the pit rim. This is both faster and safer than the previous practice of installing steel pipe lines. Performance characteristics required for sump pumps are usually low volume and high head.

Pump Installation and Maintenance

In recent years, an average of 50 to 60 wells have been operating at five or six separate open pits. Between 10 to 20 new installations and 20 to 30 removals for pump or riser pipe maintenance are necessary per year.

This work is performed under the supervision of one mine shift boss by the following crew:

- one mobile crane operator
- two pump installation men
- two supply and general labour men
- one maintenance and general labour man

The repair and replacement of pump parts is performed within the mine machine shop and requires the full time services of one repairman. One electrician is employed full time for installation and routine maintenance. This does not include the installation of power lines and transformers or major repair work such as rewinding motors.

For a new pump installation, the pump, 8 inch riser pipe for submersibles, or inner and outer pipe column and shafting for lineshaft pumps, motor or switchgear shack, and surface discharge pipe are delivered from the millsite storage yard to the wellhead by the two supply men. For this they use a 5-ton flatbed truck equipped with a hydraulic lifting boom. The crane operator and two installation men assemble and install the well pump and pipe. The 8 inch riser pipe and the outer column for lineshaft installations are supplied in 20 foot lengths of standard schedule 40 pipe with threaded couplings.

Average installation time for the three man crew for a pump set at 400 feet is six hours for a submersible and 18 hours for a lineshaft pump. An extra man is usually required when installing the latter type.

A daily pump check, involving the operating condition of every well pump and the lubricating reservoir for lineshaft pumps, is performed by the maintenance and general repair man. This usually takes about five hours per day. Polar

35 oil (Imperial Oil Limited) is used for lineshaft lubrication. For the remainder of the eight hour shift, this man performs routine maintenance and cleaning of recovered pipe and shafting.

The pump crew work a 5-day, Monday to Friday, steady day shift schedule. On afternoon and night shifts and on weekends, the operating status of each pump is checked visually by the mine production shift boss. A system of operating status coloured lights, described later, is mounted at each wellhead. Electrical problems are reported to the shift electrician for immediate attention. Other problems are noted in the shift log book and in the event of major problems in critical operating areas, the pump crew and shift boss are called out on overtime. These occur infrequently.

The shift boss is also responsible for checking the condition of drainage ditches and culverts. This is especially important during the period of high surface run-off in the spring.

It has been found that the Peerless lineshaft pumps can operate continuously for about three years. Replacement of bowl assemblies and bearings can extend their useful life by one to two years. The most frequent maintenance required involves the replacement of the inner or outer column, or of the shafting. This can be caused by wear from shaft misalignment or from sand in the discharged water or by corrosion from the water. The frequency of such maintenance varies considerably from six months to two years. Vertical mounted motors are very dependable and serve several successive pump installations.

Pleuger submersible pumps have been used for the past three years. The need for pump maintenance has been insignificant to date. As with lineshaft pumps, the frequency of replacement of riser pipe through wear or corrosion varies considerably. Electrical problems with the pump motor or the jacketted cable have been few. Electrical repairs to the submersible motor require return to the Canadian assembly plant.

Occasionally, corrosion of the riser pipe causes a pump to be dropped to the well bottom. Use of a fishing tool, designed and fabricated on the property, has been very successful in recovering these pumps.

Power Supply

Power is supplied to each pit at 12,500 volts. At appropriate locations around the pit perimeter, 450 KVA transformers are located. Each transformer supplies power at 550 volts to four well installations via jacketted ground cable.

For lineshaft installations, the wellhead is covered by a pump shack formed from 10 foot diameter multi-plate culvert. The shack is fitted with a removable metal roof with an access hatch to allow servicing of the well installations by crane. It houses the motor and electrical switchgear. Motor generated heat keeps the area sufficiently warm and frost-free in the winter and simply leaving the door and roof hatch open in the summer keeps it cool enough to prevent switchgear malfunction because of rising ambient temperatures.

For submersible installations, the switchgear is housed in a small wooden enclosure adjacent to the wellhead.

A coloured light system is mounted on each pump shack or switchgear enclosure. Each light indicates the status of the pump: red - operating, orange - timing device activated, green - not operating and attention required, no light - inactive. This system enables a quick, visual check to be made at any time from the top of the open pit access ramp by production personnel.

All switchgear, in addition to standard motor control relays, is equipped with automatic, timed, restart relays. These operate following power outages and are timed to minimize peak start-up loads and to allow the complete draining of discharge pipes and riser pipes to occur before motors are restarted. Check valves are not installed in the riser pipes and surface discharge pipes are installed for gravity drainage to ensure that all pipes drain when the pumps stop. This is necessary to prevent freezing of lines during winter. Switchgear for pumps at each pit is usually timed for delayed automatic restarting at two minute intervals.

Drainage Ditches

Drainage ditches serving individual well discharges are excavated around the perimeter of each pit. These lead to main surface drainage ditches that direct the water to the nearest natural surface drainage system (Figure No. 6).

Currently, about 25,000 feet of perimeter ditch, discharging into 100,000 feet of main surface drainage ditch, is in use. These ditches service five operating pits. Between 10,000 and 20,000 feet of new ditch is excavated each year. This work is seasonal and is performed by a local contractor.

Ditch size is designed to accommodate the anticipated maximum flow from the area served and varies from four feet wide and four feet deep to eight feet wide and five feet deep. The surface topography generally has a gentle grade sloping to the north towards Great Slave Lake and major cuts are seldom required. Through experience it has been found that a ditch grade of 0.3 percent or greater and a surface flow rate of not less than 2 1/2 feet per second is sufficient to prevent freezing during the long winters.

Ditches are usually excavated in the muskeg and overburden by a three cubic yard capacity backhoe mounted on wide pad tracks. In soft, swampy areas a backhoe mounted on a low ground pressure, all terrain vehicle is used. Recent excavation costs have ranged from $1.50 to $2.00 (Can.) per cubic yard.

Recharge and return flow to the karstic limestone from drainage ditches is not usually a problem. Precipitation of carbonate and sulphate minerals from the water appears to seal the ditches (2). Clay and fine material from the overburden and muskeg also tends to restrict seepage. Occasional gravel zones within the overburden are by-passed and to date all gravel ridges encountered have been distant from active mining areas. No lining or artificial sealing of ditches has been practised.

Regular, unlined multi-plate steel culvert is used under mine roads since most ditch systems are only used for pit drainage for three to four years. On completion of mining in each area, ditch and culvert systems are left to help in the general removal of spring surface run-off. They are usually dry during the summer and winter months. Those culverts under the public highway which primarily serve discharge from several pit areas and will have long operating lives have recently been replaced with asphalt lined multiplate culverts. It was found that after 5 or 6 years discharged groundwater had significantly corroded the previous unlined culverts.

Costs

Dewatering costs are a significant portion of the direct open pit mining costs at Pine Point, comprising 16 percent of the total in 1978 (Table No. III). A summary of those dewatering costs is shown in Table No. IV and is typical of recent years.

The scope of the dewatering programme in 1978 is summarized below:

Average number of pumps operating	46
Maximum number of pumps operating	57
Ratio of submersible to lineshaft pumps	1:1
Average pumping rate (U.S. gallons per minute)	46,300
Average operating horsepower	5,280
Well drilling (feet)	6,000
Number of well sites prepared (roads and pads)	12
New drainage ditch excavated (feet)	19,500
Existing drainage ditch cleaned (feet)	11,000
Number of 100 foot long culverts installed	3
Personnel - staff	3
- pump crew (excluding electricians and mechanics)	6

In addition to the practical operating reasons for dewatering before mining, such as the potential problems of increased tire wear and frozen muck piles in winter, the increased costs of drilling and blasting wet rock are important. Blasting costs, per ton broken, when water resistant explosives are used are approximately three times those resulting from using ANFO type explosives for dry blasting. Operating under wet conditions with the aid of sump pumping also decreases overall mining productivity.

WATER TABLE AND DEWATERING MONITORING

Water table elevations are measured weekly in active pit dewatering areas and once or twice per year at various sites throughout the mining property.

Fisher M-scopes are used to measure water levels in test holes drilled within active pits by production blasthole

Table No. III
Distribution of 1978 Direct Mining Costs

	Percent
Drilling and blasting	10
Loading, hauling and dozing	54
Haulroad maintenance and construction	5
Dewatering	16
Stockpiling at millsite	10
Supervision	5
	100

Note: General mining parameters:
- waste moved - 7.5 million tons
- ore moved - 3.3 million tons
- average haul distance to millsite - 6.3 miles

Table No. IV
Distribution of 1978 Dewatering Costs

	Percent
Electrical power	57
Electrical maintenance	3
Ditches and culverts	4
Pump roads and pads	5
Well drilling, including mobilization	12
Pump installation	4
Pump maintenance	9
Design, monitoring and supervision	6
	100

Note: These do not include the costs of pumps, switchgear, transformers, or power line installation.

drills. When inactive well holes are available at a pit and are considered beyond the immediate influence of nearby active pumping wells, continuous water level readings are obtained by installing Stevens Type F automatic recorders. Analysis of the charts obtained from these recorders allows assessment to be made of the changes in water levels resulting from power interruptions or changes in pump performances.

Individual pumping rates are measured monthly or whenever significant changes occur in a rate as determined by visual inspection of the discharge and by changes in the pump motor power demand.

The evaluation of pumping rates and changes in the water level at each active pit is used to assess dewatering progress and as the basis for changes in system capacity and design.

Water levels measured regularly in exploration diamond drill holes throughout the property allow regional water table contour maps to be maintained. These indicate the regional drawdown and recovery resulting from changes in the pit dewatering systems.

Pump discharge water is sampled at the start of dewatering of each pit area and at six month intervals thereafter. Samples are usually taken downstream from the junction of a pit perimeter ditch and the main drainage ditch. They therefore represent the combined water flows of each of the wells in a pit dewatering system. Additional samples are taken in the natural drainage systems that receive well discharge water. Analysis of these samples permits the quality of discharged water and its effects on natural surface waters to be monitored.

DEWATERING PERFORMANCE

Generally, pit dewatering systems have achieved the anticipated results in water table drawdown in most areas. Experience gained early in the dewatering programme has resulted in the incorporation of the factors discussed previously in the design of individual pit dewatering systems.

Drawdowns and recoveries experienced at various open pits are summarized in Table No. V. Significant regional drawdown effects have been observed and have influenced the

Table No. V
Water Table Drawdown and Recovery at Open Pits

Pit	Avg. Distance From Pumps to Pit Centre	Average Pumping Rate	Duration of Pumping (months)	Drawdown at Pit Centre	Recovery to Dec. 31/78	Remarks
J-44	590	6,700	Nov/68-May/72 (42)	102	36	Maximum recovery of 46 feet shown by Nov/72. Increased millsite pumping has since lowered water table 10 feet.
O-42	730	3,200	Nov/68-June/72 (43)	68	10	Recovery ceased in late 1972 because of effect of millsite pumping.
N-42	550	1,600	May/68-Mar/69 (11)	74	10	Same as above.
M-40	730	1,300	June/72-Oct/74 (28)	56	0	Drawdown assisted and then maintained by millsite pumping.
X-15	1,440	3,400	July/68-Dec/73 (66)	95	-	Drawdown assisted by W-17 pumping. Center to centre distance X-15 to W-17 is 5,000 feet.
X-15	-	0	Jan/74-Oct/77 (46)	+ 59	-	
X-15W	750	1,800	Nov/77-Dec/78 (13)	+ 28	-	

Table No. V - Continued

Pit	Avg. Distance From Pumps to Pit Centre	Average Pumping Rate	Duration of Pumping (months)	Drawdown at Pit Centre	Recovery to Dec. 31/78	Remarks
W-17	950	18,000	Oct/71-Aug/77 (70)	224	-	Drawdown additional to 29 feet produced by early pumping at X-15. Maximum pumping rate was 23,000 U.S. gallons per minute (Aug/77).
W-17	950	14,000	Aug/77-Dec/78 (16)	0	41	Reduced pumping maintained for drawdown effect at X-15W.
T-58	-	0	Jan/76-Mar/77 (15)	23	-	Result of R-61 pumping. Centre to centre distance T-58 to R-61 is 4,200 feet.
T-58	800	7,400	Apr/77-Dec/78 (20)	+ 86	-	Pumping rate 9,650 U.S. gallons per minute in Dec/78. Drawdown assisted by R-61 pumping.
R-61	800	4,675	Jan/74-Dec/78 (60)	136	-	Pumping rate 9,100 U.S. gallons per minute in Dec/78. Drawdown assisted by T-58 pumping.

Table No. V - Continued

Pit	Avg. Distance From Pumps to Pit Centre	Average Pumping Rate	Duration of Pumping (months)	Drawdown at Pit Centre	Recovery to Dec. 31/78	Remarks
K-57	680	6,100	July/71-Aug/75 (48)	152	75	Recovery initially effected by K-62 pumping and then by T-58, R-61 and J-69.
K-62	-	0	July/71-May/75 (46)	50	-	Result of K-57 pumping. Centre to centre distance K-62 to K-57 is 6,800 feet.
K-62	800	6,400	June/75-Oct/76 (16)	+ 79	80	Recovery in 1978 only 15 feet because of effect of pumping at T-58, R-61 and J-69.
J-69	-	0	July/71-Oct/77 (75)	47	-	Result of pumping at A-70, K-62, T-58 and R-61.
J-69	800	12,000	Nov/77-Dec/78 (13)	+ 93	-	Pumping rate 15,000 U.S. gallons per minute in Dec/78.
A-70	870	9,925	Feb/76-Sept/77 (19)	98	72	

Notes: (1) Distances, drawdowns and recoveries in feet.
(2) Pumping rates in U.S. gallons per minute.
(3) Inter-pit drawdown effects determined from regional water table contour maps.
(4) Refer to Figure No. 2 for relative open pit locations.

drawdown in various groups of pits, viz. X-15/W-17, R-61/T-58/S-65, K-57/K-62/J-69/A-70, and 0-42/N-42/J-44 (Figure No. 2). Within the constraints of production equipment availability and millfeed metallurgy, mine production has been scheduled to take maximum advantage of the regional dewatering effects in adjacent pits.

The regional drawdown effect of deep well pumping in the townsite for domestic water and the millsite for process water has been observed at the open pit and underground mining operations within about 15,000 feet of the mill and townsite.

In recent years dewatering performance in the western part of the property in areas of semi-confined groundwater conditions has indicated some inadequacies in pumping test procedures and analysis. Slower than anticipated drawdown has resulted from changes in storage characteristics and the effect of regional groundwater flow during prolonged dewatering. Modifications to pumping test procedures, more rigorous pre-dewatering hydrogeological investigation, and better observation and analysis of early dewatering performance are planned.

ENVIRONMENTAL EFFECTS OF DEWATERING

Dewatering operations at Pine Point are assessed and monitored by the Water Resources Division of the Federal Government's Department of Indian and Northern Affairs. Controlling legislation includes the Northern Inland Waters Act and Fisheries Act.

The quantity and quality of discharged water, changes in the natural surface drainage system, and changes in groundwater levels and flow patterns are monitored. Regional environmental surveys have been commissioned by Cominco Ltd. and the results of these supplement observations made by Government officials.

Effects of the dewatering operations on local fauna and flora appear to be minimal and are not reasons for major concern. The region is very sparsely inhabited and there are no other well pumping operations for domestic or industrial water supply in the area.

SUMMARY

Open pit dewatering by localized drawdown of the groundwater table has been practised successfully for 12 years at Pine Point. Deep well pumping discharge rates have increased from 20 million to 60 million U.S. gallons per day during that period. Pumping has been predominantly from an unconfined, relatively thick, laterally extensive aquifer.

In the future, mining will be increasing in areas of semi-confined and confined groundwater conditions. Dewatering system design will require more rigorous hydrogeological investigation and it is anticipated that total pumping rates will increase. The latter could attain 100 million U.S. gallons per day by 1985. Limitations in power supply and the increasing cost of locally generated power will increase this already significant portion of the mining cost. Improvements in present techniques and implementation of new mining and dewatering techniques will be investigated.

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