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Controlling Mine Water

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ABSTRACT

As mines go deeper there's the prospect of pumping more water from greater depth at higher unit costs. For efficient pumping, direct costs are now likely to be $0.20 to $0.30 per million foot gallons. But water inflow can increase total costs and decrease production in many important indirect ways.

This paper lists eight groups of ways which could be used to reduce pumping. Most would reduce inflow. Most could be used in both open pit and underground mines. All but three of the 29 items have been demonstrated in mining. Current and foreseen conditions urge operators to reconsider these and add to the list. The new methods suggested are mining from the bottom up and reducing mass permeability with chemical or bacteriological precipitates.

INTRODUCTION

For those who work wet mines or plan to, the carrot of potential savings and the stick of increasing costs point to the prudence of reducing pumping energy. If water is needed and used, the objective should be to produce it at least cost, which generally means least pumping.

Groundwater resources are increasingly valued and protected. To mine without affecting groundwater in any way would be ideal. Plans which are feasible to reduce inflow may help obtain permission to mine and to maintain good local relations.

Manufacturers strive to make more efficient pumps. Here we review ways intended to control water more efficiently. Only the mine operator can do that.

GENERALIZED COST APPROXIMATION

Power alone, at $0.04 per kilowatt hour, contributes about $0.17 per million foot gallons to pumping costs, with reasonable allowance for electrical and mechanical losses in an efficient plant. Other direct costs, including recovery of capital cost of the system may increase that by 50 per cent. So we may expect direct costs of 20 to 30 cents per million foot gallons pumped by well designed, sizable plants, without special problems such as gritty or acid water. Many pumping plants, to be sure aren't so well planned and others handle water of poorer quality.

The direct costs of pumping can be bad enough, especially when we realize that inflow continues whether the mine produces or not. To emphasize we might say inflow continues at least 525 600 minutes of each year.

So far we have talked about cost of pumping per unit of water handled. Now let's turn attention to the total cost of water inflow per unit of mine product. This can be very different and the total cost of production is next to the bottom line.

Actual costs were reported seven years ago by a company working two mines near Grants, New Mexico. The two mines were comparable except that one was wet and the other dry. Each ton of ore hoisted from the wet mine cost more than twice as much as one from the dry mine. The more efficient methods and equipment used in the dry mine could not be used in the wet. Even where rock is strong, indirect costs of inflow can be high. Table 26.2.2 of Chapter 26, Mining Engineers Handbook AIME, NY, 1973, shows 17 indirect ways in which inflow can increase mine costs and there is no reason to feel that this enumeration is complete. At many wet mines the evaluation of these indirect costs should be both enlightening and stimulating.

DEMONSTRATED METHODS OF WATER CONTROL

Table 1 is based on correspondence and conversation with others, literature study and the author's observations over a period of several decades.

METHODS JUDGED TO MERIT APPLICATION

1. No mining from the bottom up as indicated in Figure 1 is known to have been undertaken primarily to minimize inflow.* Two requirements and two possible disadvantages are foreseen:

* Unusually thorough planning is required. At least a large part of the mineral deposit must be explored adequately with special attention given to water occurrence. Decision should then be based on a comparison of advantages and disadvantages.

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* When water broke into the West Driefontein Mine in South Africa October, 1968, the open space in the lower mine and a heroic pumping effort provided 23 days of grace during which 4 concrete plugs, to withstand high pressure, were built to prevent flooding the entire mine.

The Frood Mine near Sudbury, Ontario, was mined from the bottom up. The lower part of the mine was virtually dry. However, the author doubts that this was an important planning consideration.

* To get the mine into production without taking water from nearby wells, shafts would have to be sunk without substantial effect on the water table. That might or might not be the least costly way.

* First expenses for shaft plant will be greater but total pre-production cost may be less because it is not necessary to pump at high rate for a long time to lower the water table before mining can be begun. Shaft plant would be completed in a single step rather than piecemeal, as is usual at deeper mines.

* Mining from the bottom up would make it more difficult to go back to the deeper part of the mine to recover any low grade fringes not extracted originally.

Where the conditions are really favorable for it, the advantage of mining from the bottom up could be substantial. Bottom-up mining is likely to merit careful consideration where several of the following conditions exist:

* Rate of water inflow to the upper levels would be very large. Inrushes may increase it to rat which could hardly be pumped.

* As is common, ground becomes tighter with depth so that potential flow into deeper parts of the mine is less and can be estimated with more confidence.

* Good ore can be produced from the lower part of the mine, thus helping to recover investment

* The conventional alternative would dry up many wells for a long time.

Expectable advantages include:

* The total pumping energy and total volume of water should be reduced considerably because:

   1. Maximum pumping rate would last only through the latter part of the mine life rather than throughout it.

2. While pumping is at its maximum rate the head could be reduced instead of increasing as is usually the case as the mine is deepened. Where a large part of the inflow is caught near the surface, this advantage is reduced. See Figure 10.

3. Depression of the local water table would be postponed and would not last as long as normally. Depression may not be as deep nor affect as large an area.

* Until heavy pumping is begun, the operator has more flexibility. He is more likely to survive an interruption of production.

* Any lower space which can be kept open provides more time to get crew out of danger, perhaps to stop an inrush or if not, to retreat in better order.

* The lower part of the mine will become an ideal settling basin to clarify water when the pumping rate increases. Thus high pump maintenance, construction of large underground settling basins or installation of filters is avoided. Settling basins on the surface might be reduced or eliminated.

METHODS WHICH HAVE BEEN DEMONSTRATED BUT LITTLE USED IN MINING

Clay grouts are used effectively to reduce the permeability of alluvium and some stronger rock. Their special advantages include:

1. Properly mixed clay grouts do not "bleed" or give up water to adjacent shale or clay. They are useful in plugging pores and fractures in those rocks and clay-coated fractures in harder rock.

2. Masses of clay-grouted ground can be deformed without fractures being opened.

3. Because clay is not granular it can be used effectively in medium sand.

4. Where suitable local clay or material which can be made suitable with minor additions, is available, large quantities of grout can be provided at moderate cost.

Probably the most spectacular application was to reduce flow below the Aswan High Dam, which is built on a deep, wide valley fill of silt, sand, and gravel. Clay grouting is probably used by civil engineers more commonly in Europe than in America.

On a first attempt to mine on a 300-acre tract near Leadwood, Missouri, St. Joseph Lead Co., now St. Joe Minerals Corporation, was repeatedly flooded with water and mud from fractures enlarged by solution and partly clay filled. Repeated cement grouting did not solve the problem. In the early 1940's, 450,000 tons of desanded mill tailings were injected from the surface through 763 existing diamond drill holes. Thereafter the ore was mined with minor grouting from underground as work advanced

Pregrouting has been developed and used with excellent results by the South Africans in preparation for sinking many of their recent large, deep shafts. In comparison with shaft sinking, the pregrouting is inexpensive. Pregrouting can begin even before details of shaft planning are altogether complete and be continued while the surface plant is being built. This minimizes delays for grouting from the shaft bottom. See Figure 2.

PLUGGING CONDUITS THROUGH WHICH MINES HAVE BEEN FLOODED

On at least five occasions, conduits through which mines have been flooded have been plugged under water In each case the source and the conduit were too large for any pumps which it was practical to install If sufficient pumps had been put to work, the rapid inrush of water would have been expected to erode and enlarge the conduits. Under these circumstances ther is the opportunity to introduce a mass of concrete or grout into the conduit when water in it is virtual still. To avoid dilution, grout can generally be placed by tremie.

The first of these known recoveries was at a mine in Belgian Congo probably in the 40's. An account of this accomplishment from the Belgian mine manager contributed to the recovery of the Friedensville shaft in 1952, and that method in turn was improved and modified for use in Indiana in 1960. See Figures 3 to 9.

The recovery of the Levant tin mine in Cornwall with the placement of a concrete plug on the sea floor in 1965 was a spectacular undertaking. Most of the work was done by divers from small work boats.

The stopping of the conduit through which water from the Cumberland River entered the Moodie Mine, a small fluorspar mine in Kentucky, was similar to the Levant plugging but apparently quite independent of it.

METHODS NOT KNOWN TO HAVE BEEN APPLIED IN MINING

Some time ago the author began looking for ways of reducing rock permeability for use in mining and some types of underground construction. The following were considered desirable features:

* Treatment should affect substantial masses of rock or broad areas of rock surface. Ideally the treatment should go to all points where fluid movement is troublesome. It should be at some depth within the rock mass, not only at the surface.

* There should be some control over the time and place of the action.

* Treatment should not be hazardous to those applying it or others. It should protect rather than harm water supply.

* Treatment should be useful under mine conditions, including temperature and dilution by still or running water in large or minute conduits, some with clay, etc.

* Useful treatment must be an improvement over methods we have, generally based on cost or effectiveness.

Dr. John B. Patton, Director of the Indiana Geological Survey called attention to the chemical and bacteriological treatment given water before it is injected for the secondary recovery of oil. The purpose of treatment is to prevent rock pores and fractures from being plugged. This was studied with the help of Professor W.D. Lacabanne, Petroleum Engineering, University of Minnesota. Several years later practice developed by the Chowchilla Irrigation District in California to seal leaky concrete mains, was studied. They found that a simple chemical precipitate tends to attach itself firmly to surfaces over which water movement is rapid. In a surprisingly short time, leakage was stopped. In some ways this is like the formation of scale in pipe, which is sometimes caused and to a degree controlled, to reduce corrosion.

Further investigation in a series of tests at increasing scale is suggested.

Surely any competent effort should add to the items shown in Table I.

Table I

METHODS FOR WATER CONTROL

METHODS	EXAMPLES (for bibliography see SME (AIME), 1973, Mining Engineers Handbook for references)
1. Reduce, postpone or avoid inflow.	
a) Locate shafts or excavations in least permeable ground.	Naica, Kimballton, San Antonio
b) Mine from bottom up.	As at West Driefontein
c) Work under water by dredging, mining with draglines, leaching in place, Slurry Trench.	Alluvial gold, tin, sand, gravel, phosphate, Shirley Basin uranium, foundations in ground difficult to dewater and to support.
2. Protect workings from inflow.	
a) Leave enough solid ground between the mine and water.	Wabana (Newfoundland), Submarine coal in Durham (England) and Nova Scotia, metal mines in Ontario, Quebec.
b) Leave pillars on fissures to prevent or minimize movement.	South Africa gold mines

METHODS	EXAMPLES
c) Plug or case test holes or survey and don't mine near them.	Plugging is required in many localities. Most salt mines are especially careful.
3. Divert, drain or intercept water near surface.	
a) Divert rivers, drain lakes.	Griffiths, Black Lake, Caland, Bancroft, Steep Rock Lake, Biwabik
b) Cover intakes with concrete or ponded slime, with great care.	Leadwood, Bancroft
c) Clear slopes, build drains, plant trees in low, flat areas to increase evapo-transpiration.	Bancroft
d) Catch water in shafts or on an upper level to prevent it going deeper in the mine.	Most wet shafts; Champion Mine, Michigan
e) Intercept water in shallow wells.	Homer Wauseca (See Figure 10)
4. Keep water from shafts with impervious linings.	
a) Pregrout from the surface, then test and grout from the shaft bottom.	Many recent South African shafts, e.g. Kinross (See Figure 2)

METHODS	EXAMPLES
b) Sink with grouting from the shaft bottom only.	Venterspost, Friedensville, Deep Ruth, Meremec.
c) Freeze, sink and set lining.	European coal mines, Saskatchewan potash, some Carlsbad potash shafts.
d) Bore, usually with mud, and place casing.	Beatrix Shafts (Netherlands), Grants, Carlsbad.
e) Drop shafts, stationary slip forming.	Chicago Metropolitan Sanitary Commission.
5. Reduce Permeability of the Rock Mass	
a) Grout with cement slurry.	Port Radium, Deep Creek.
b) Plug solution channels with desanded tailings and grouting.	Leadwood
c) Plug pores or fractures with clay.	Aswan Dam and others especially in Europe.
d) Plug with chemical or bacteriological precipitate.	No trial known in mining.
6. Drain water through an adit.	Many wet mines in hilly places.

METHODS	EXAMPLES
7. Use Special Practices to Aid Control, to Reduce or Prepare for Surprises.	
a) Compartment the mine to confine inrushes and minimize damage.	Leadwood, Nova Scotia coal mines
b) Mine from bottom up to provide space for water and time to build protection.	As at West Driefontein
c) Regularly get informed outside opinion.	
d) Regularly drill test holes in advance of work.	
e) Regularly plot, record pertinent data on water occurrence and protection, plan and test procedures.	
f) Maintain material, tools and trained crew, ready to carry out protectice procedures.	

METHODS	EXAMPLES
8. Procedures Which Have Been Used in Emergencies.	
a) Working from the surface, plug a large conduit under water.	Levant (Cornwall), Moodie (Kentucky)
b) Working from the surface through pipe or drill holes, plug a large conduit in the mine.	Belgian Congo, Friedensville, Figs. 3 to 8. Indiana Gypsum mine, See Figure 9
9. Dispose of water more conveniently as by dropping it into a conduit, dropping or pumping it into an aquifer against lower pressure.	Chief Consolidated

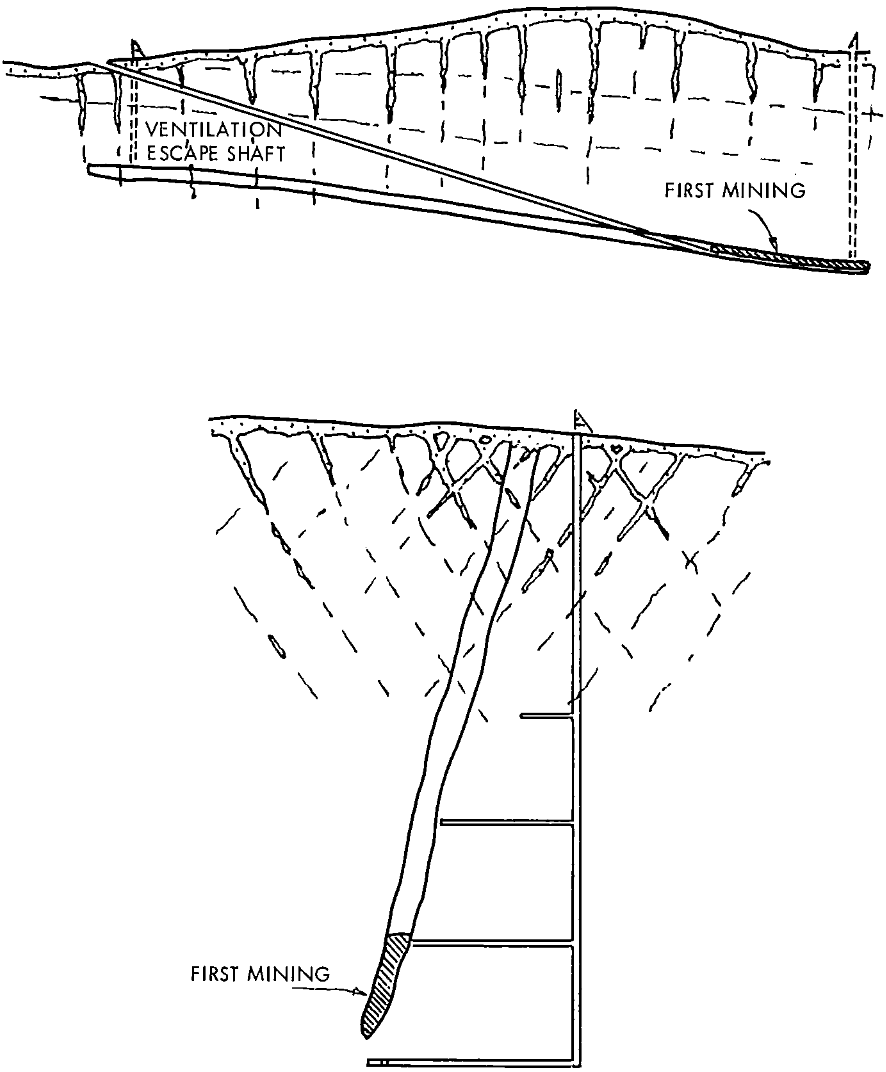
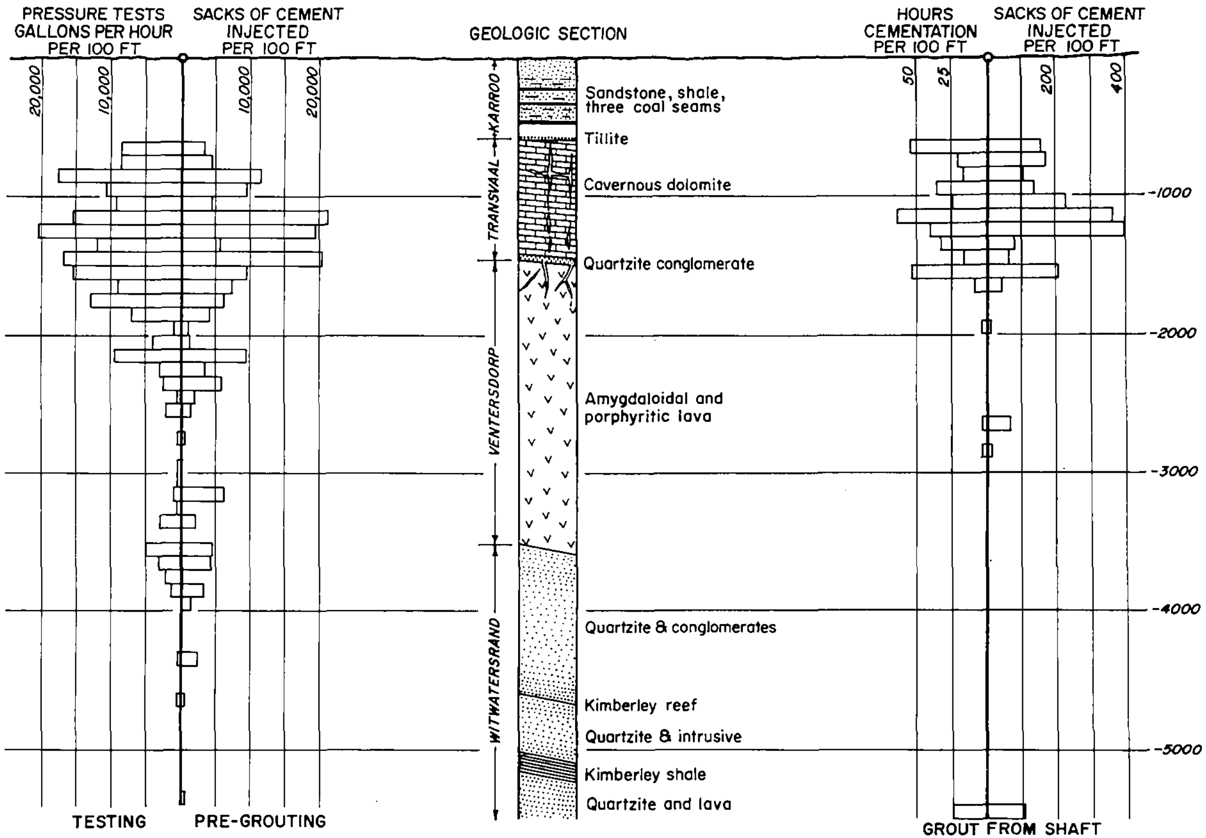


FIGURE 1

FIRST MINING IN TIGHTEST GROUND TO MINIMIZE INFLOW, DRAWDOWN AND TOTAL PUMPING



WATER OCCURRENCE, CEMENT INJECTED AT TWO SHAFTS
KINROSS MINES LTD.

FIGURE 2

After Munro, Craig and Pritchard-Davies

FIGURE 3

FACE OF 700 CROSSCUT, 100 FEET NORTH OF FRIEDENSVILLE SHAFT SHOWING SOME 50 TEST-GROUT HOLES

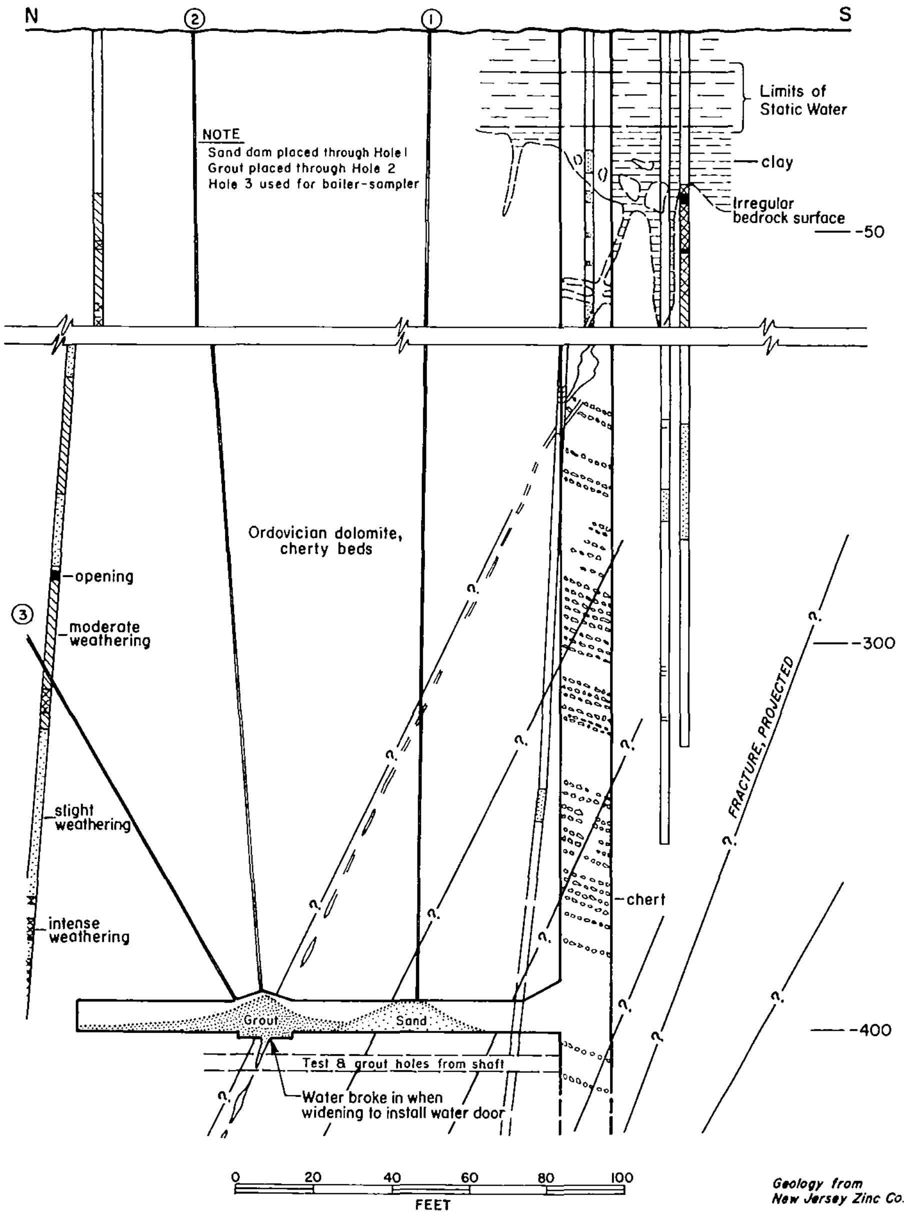


FIGURE 4

SECTION ACROSS FRIEDENSVILLE SHAFT SHOWING PROCEDURE FOR PLUGGING 400' LEVEL BREAKOUT

FIGURE 5

PLEXIGLASS MODEL FOR PLANNING RECOVERY
OF FRIEDENSVILLE SHAFT

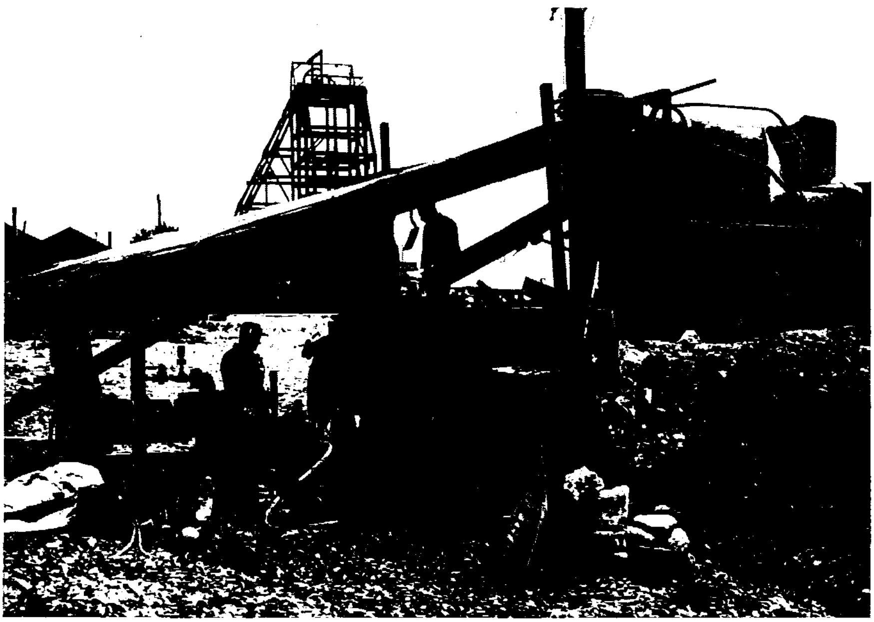


FIGURE 6

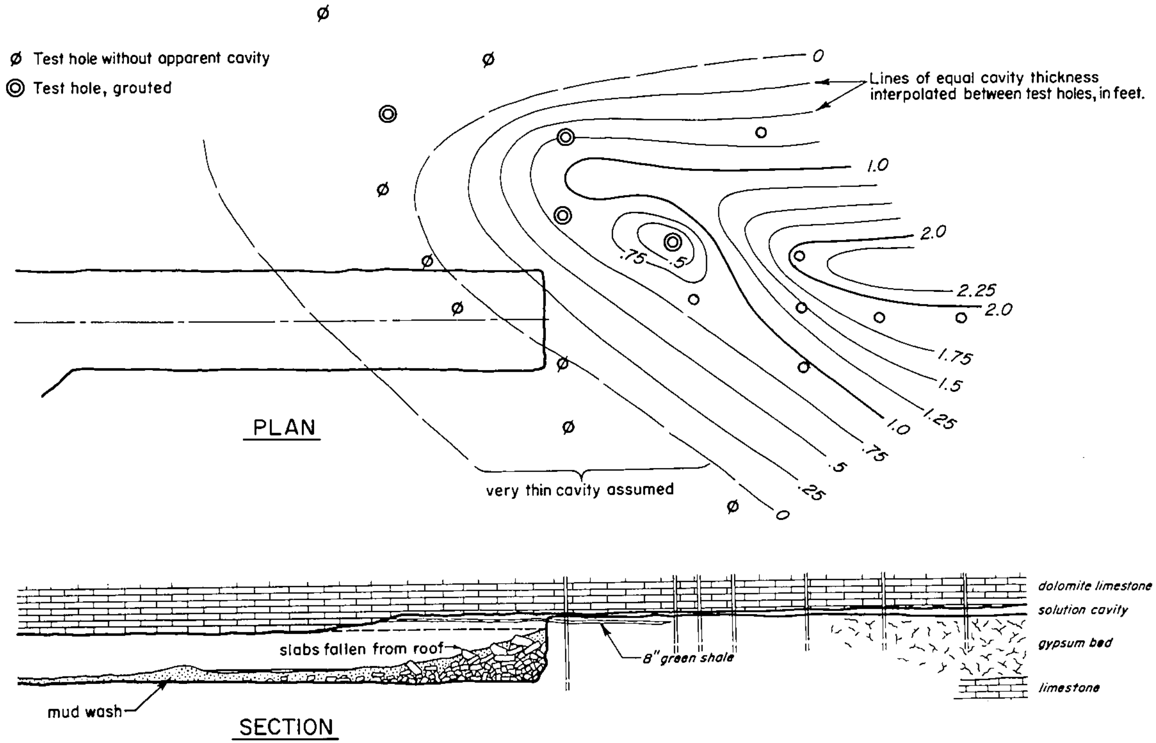
AGITATOR AND GROUT PUMP FOR PLUGGING FLOOR
OF 400 LEVEL, FRIEDENSVILLE SHAFT

FIGURE 7

GROUT PLUG IN FLOOR OF CROSSCUT, LOOKING TOWARD SHAFT
NOTE HALF DOZEN TEST-GROUT HOLES POINTED TO BASE OF PLUG

FIGURE 8

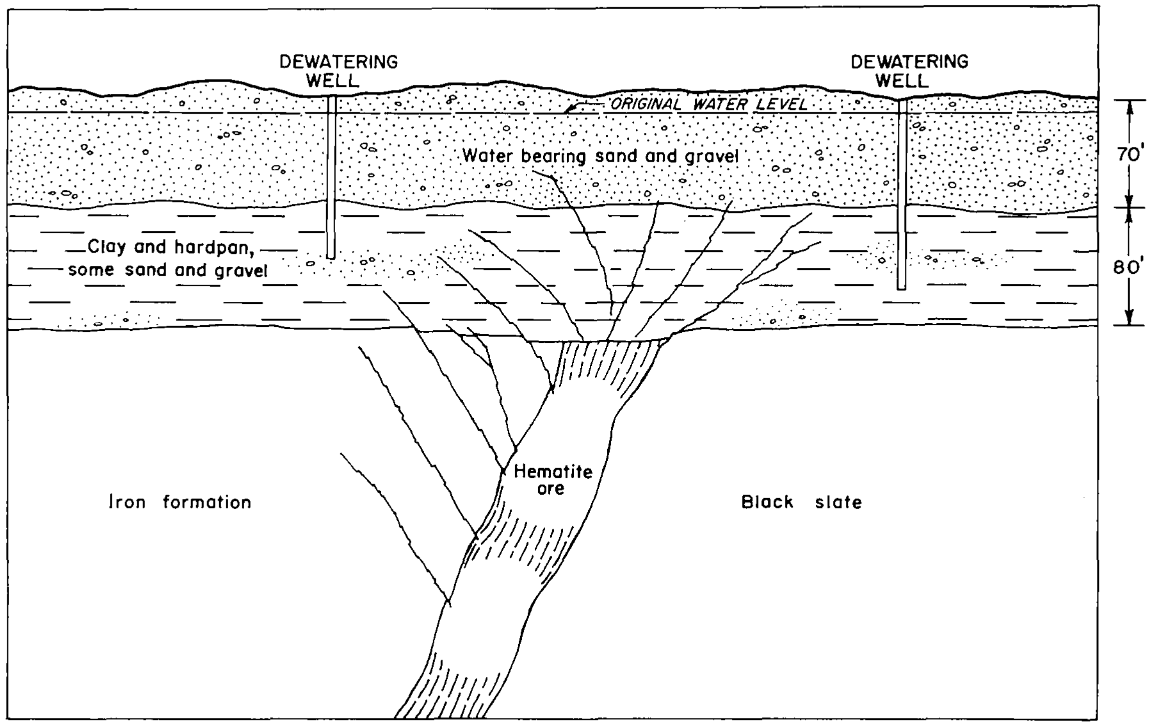
CONE OF LOW STRENGTH GROUT PLACED ABOVE PLUG
FRIEDENSVILLE SHAFT



PLAN & SECTION SHOWING HEADING IN GYPSUM BED, TEST HOLES, OBSERVED & INFERRED SOLUTION CAVITY, AND GROUT PLACEMENT

FIGURE 9

0 20 40 60 80 100
FEET



SKETCH OF DEWATERING WELLS OF HOMER WAUSECA MINES, IRON RIVER, MICHIGAN

Not to scale

FIGURE 10