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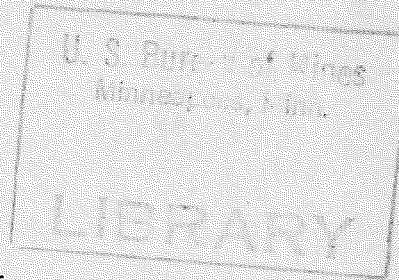
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**SURVEY OF
UNDERGROUND HYDRAULIC
COAL MINING TECHNOLOGY
(Volume 1 - Final Report)**

WILLIAM C. COOLEY

**United States
Department of the Interior
Bureau of Mines**



USBM Contract Report (Contract HO242031)

OCTOBER 15, 1975

**TERRASPACE, INC.
304 NORTH STONESTREET AVENUE
ROCKVILLE, MARYLAND 20850**

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The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies or recommendations of the U. S. Interior Department's Bureau of Mines or of the United States Government.

FOREWORD

This report was prepared by Terraspace, Inc., Rockville, Maryland, under USBM Contract Number HO242031. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Twin Cities Mining Research Center with Mr. Orlo McNary and (after July 3, 1975) Mr. John W. Chester as Technical Project Officers. Mr. David J. Askin was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 17, 1974 to September 30, 1975. This report was submitted by the author on October 15, 1975.

The personnel participating in the survey included Franklin L. Beck, Senior Engineer, Barbara A. Stevens, Librarian and Secretary, Richard F. Dewey, Consultant, and Donald B. Hume, Consultant. Russian translations to English and additional consultation were provided by Dr. Andre L. Brichant. The author acknowledges their assistance as well as the cooperation of the many organizations and persons who provided data for inclusion in the survey.

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EXECUTIVE SUMMARY

This report includes a review of all relevant data on underground hydraulic coal mining technology collected during the contract, as well as data on U. S. coal seam conditions, analysis of the applicability of various hydraulic technology in U. S. coal mines, economic comparisons, conclusions and recommendations.

The report is published in four volumes:

- Volume 1 - Summary Final Report
- Volume 2 - Data on Underground Hydraulic Coal Mines
- Volume 3 - Data on Hydraulic Mining Equipment and Components
- Volume 4 - References and Bibliography With Abstracts

It is concluded that the use of monitor mining with roof caving and gravity fluming has high potential for use in pitching multiple-seam coal deposits (20° to 90°) in areas of Colorado, Wyoming and Washington. Monitor jet pressures of 2000 psi and water flow rates of 1500 gpm are possible. This system may also be applied in gently pitching seams (3° to 20°) in Colorado, Wyoming, and certain locations in Appalachia and Arkansas. The system has advantages with respect to health and safety, and also productivity and economy, particularly in thick seams (over 12 ft.) of soft friable coal, where productivity may reach 20 to 30 tons of raw coal per man-shift. If coal can be flumed from above drainage level to the portal, mining costs may be in the range \$5 to \$10 per ton of raw coal, based on 1975 prices.

It is recommended that a hydraulic mining demonstration using monitor jets and fluming should be conducted in Colorado, Wyoming or Washington. Economics would appear to favor the Thompson Creek mine in Colorado, or the Carbon River field in Washington for early development because of the higher value of their metallurgical coal. However, monitor jet experiments should be conducted to optimize the monitor pressure and nozzle diameter and to determine the coal breakage rates attainable in various potential coal deposits. A major benefit of a demonstration within the U. S. would be to permit the U.S. coal mining industry to observe first-hand the equipment and procedures used in hydraulic mining and to learn its potentialities and limitations.

All equipment required for a hydraulic mining demonstration can be obtained in the U. S. with the possible exception of monitors, multi-stage coal pumps (if they are required), and small roadheaders for driving entries in thin or medium thickness (4 to 12 ft.) pitching seams, which generally overlie thicker seams. A water cannon roadheader has potential advantages for this application.

It is also recommended that research and development be conducted on remote-controlled hydraulic monitor jet mining methods for use through small unmanned borehole entries for application in pitching and also flat seams. This technology could have wide application to coal seams throughout the U.S. and may also be adapted for mining of uranium or other underground minerals, potentially improving productivity and safety. Unfortunately few deposits of coal in the U. S. (except for steeply-pitching seams, or thick seams near the surface) are well adapted for mining through vertical boreholes. Gently-pitching raise holes or horizontal boreholes appear to be more efficient for extracting coal from typical U. S. coal deposits.

The use of hydraulic transport through hoses and pipes has high potential in the near future for improving health, safety and productivity in underground coal mining, particularly in the thin flat seams of Appalachia and the mid-west.

The use of high pressure (over 5000 psi) small diameter jets for cutting coal should preferably be combined with mechanical breakage. It has potential application in longwall machines and continuous miners for reducing dust, improving health and safety, and increasing the size of coal lumps. It is unlikely that major improvements in system reliability, productivity or economy will be made by this method.

Studies should be conducted to optimize hydraulic methods for mining pitching anthracite seams in Pennsylvania.

1.0 INTRODUCTION

Hydraulic mining in its broadest sense includes mining in which:

1. Water jets are used to cut or break minerals; and/or
2. Water is used to transport broken solid minerals as a slurry.

Hydraulic mining may occur on the surface or underground. Surface hydraulic mining of placer deposits of gold occurred in California and Alaska, but disposal of spoil now prevents its use in most areas. However, large hydraulic monitors to strip overburden for open pit mines are used in parts of the Soviet Union.

Extensive development of underground hydraulic mining of coal has occurred primarily in the Soviet Union and in other countries, including Japan, China, New Zealand, Poland, Czechoslovakia, Germany, England, and Canada.

The objectives of this survey have been to determine the state-of-the-art in underground hydraulic coal mining systems, to identify related key elements of technology and operating parameters (and especially whether and under what conditions such systems can be applied to the mining of American coal deposits) and to develop recommendations for future hydraulic mining research.

This report contains a summary of all data collected and analyzed in connection with the program as well as conclusions and recommendations with regard to applications and research in the United States.

The work reported here is based primarily on a review of the world published literature, but also includes data collected by personal contacts and correspondence with foreign sources. Extensive literature from the USSR has been translated from Russian to English for this survey. However, the quantity of Russian literature is so great that judgment had to be used in selecting the most relevant for translation.

Generally Russian data has not been translated and data from other sources has not been included if:

1. It is not directly related to underground hydraulic coal mining
2. It is obsolete or superseded by more recent material
3. It is too specialized to be of practical significance to U.S. mining conditions
4. It relates to coal preparation plants or long-distance slurry pipelines
5. It relates to solvent extraction or leaching of minerals.

Although considerable hydraulic technology is used in dredging, hydraulic stowing, in hydraulic transport of overburden, in mining of phosphates, tin, etc., and in hydraulic hoisting of nodules from the ocean floor, the scope of this study did not permit comprehensive search or review of all the literature unrelated to coal.

2.0 DATA ACQUISITION, STORAGE, RETRIEVAL, AND ANALYSIS PROCEDURES

2.1 Data Acquisition

Data for this survey were acquired primarily by literature search. This was supplemented by correspondence with organizations and individuals in the United States and in other countries, including the USSR, Germany, England, Czechoslovakia, New Zealand, Canada and India.

Approximately 50 relevant documents already were available in the Terraspace library. Many new sources of data were found by library search in the U.S. Interior Department library and the Library of Congress. Many relevant papers were in the Russian language, particularly in the journals Ugol and Ugol Ukrainy which were searched for the years 1964 to 1975. A search was made of new Russian books listed by Russian title in the catalogs published by the Kamkin Bookstore in Rockville, Maryland. Several references were found by this method, including the most significant book of all, entitled "Underground Hydraulic Mining of Coal," by V.A. Okhrimenko, A.I. Kuprin, and I.G. Ishchuk, published by Nedra Publishers in Moscow in 1974. This book is a mining engineering textbook intended for engineers who will work on underground hydraulic coal mining in the USSR. This book was completely translated into English except for Chapter 1, which deals with basic fluid dynamics.

Dr. Andre L. Brichant performed most of the Russian to English translation which was required, including preliminary title translation, screening, and abstracting. Additional Russian translation was performed by Literature Research Corporation of Centreville, Virginia. Editing of translations was performed by Drs. Andre L. Brichant and William C. Cooley.

Additional reports on developments in the United Kingdom were obtained by the U.S. Bureau of Mines from the National Coal Board. Reports were obtained from the USSR by correspondence with Mr. G.P. Chermenskiy at the Khmelnitiski Technological Institute in the Ukraine. Reports, books, and data were available from prior personal visits by W.C. Cooley and D.B. Hume to the USSR.

An attempt was made to arrange a visit to the USSR, but the request was rejected by the USSR agency Machinoexport on the basis that hydraulic coal mining equipment was not yet available for export (Ref. 747). Shortly thereafter in November 1974 it was announced (Ref. 795 and 796) that the USSR Ministry of Coal Industry had signed an agreement with Mitsui Mining Company of Japan and Kaiser Resources Ltd. of Canada regarding export of hydraulic coal mining technology. In a recent paper by Parkes and Grimley (Ref. 1100), it was announced that Kaiser has the right to sub-license hydraulic technology to others in Canada, the United States, and Australia.

Data on typical U.S. coal seam conditions was obtained by visits to offices of the U.S. Geological Survey in Reston, Virginia and Denver, Colorado and coal maps were obtained for various locations in the U.S. Also a visit was made to the Mid-Continent Coal Company No. 5 Mine in Carbondale, Colorado to observe mining conditions in a pitching (13°) coal seam.

2.2 Data Storage and Retrieval

In order to aid in analyzing and searching the data sources, a Termatrix information storage and retrieval system was set up using components supplied by Remac International Corporation of Gaithersburg, Maryland. The system includes the following elements:

1. An accession file of "items" (documents, reports, letters, brochures, etc.), each given an accession number from 0001 to 9999 and filed in a legal size manila folder. Not all numbers have been used in sequence.
2. An accession card file (5" X 8" cards) bearing the accession number, author, title, source, date, abstract (if available) and key words. If an item was originally in a foreign language, a letter following the accession number denotes the language (R - Russian, C - Czechoslovakian, and J - Japanese). The word "translated" appears on the accession card if it has been translated into English.

3. A list of key words identifying the color and a two-digit number of the Termatrex card for that key word
4. A file of plastic Termatrex cards, one for each key word in the list of key words with each identified by color and two-digit number. Each card is punched with holes at the proper coordinates to identify the accession numbers of the items which relate to that key word. The first two digits of the accession number identify the vertical (Y) coordinate of the perforation and the last two digits - the horizontal (X) coordinate.
5. An Answer Reader which is a light table equipped with a horizontal and vertical slide scale to permit reading the X and Y coordinates where optical coincidence permits light to show through holes in one or more Termatrex cards which are placed in position on the reader. The accession number of each relevant item is read from the X and Y scales for each hole where light shows through the one or more Termatrex cards.

The method of use of the system is as follows:

1. The list of key words is searched to select the one or more key words about which data is desired and to identify the color codes and numbers of the pertinent key word (Termatrex) cards.
2. The one or more Termatrex cards are placed on the Answer Reader and the accession number of all relevant items are noted.
3. The accession numbers are used to pull accession cards from the 5" X 8" card file and/or to pull accession items from the accession file.

A list of the key words used to retrieve data is given in Volume 4, with the numbers of all accession items which relate to each key word. (The accession number in each case must be a four-digit number; therefore Ref. 491 is understood to have accession number 0491.)

2.3 Data Analysis

The accessioned material was searched and studied in order to collect, organize, and sort information to permit generalization, classification, tabulation, analysis, and evaluation.

The major efforts were to collect relevant data on each hydraulic coal mine in the world, to collect design, performance and cost data on the various pieces of equipment and components which have been used or could be used in hydraulic coal mining, and to collect data on coal seam conditions in various areas of the United States.

3.0 GLOSSARY AND DEFINITION OF TERMS

Since hydraulic mining has not been widely applied in English-speaking countries, the terminology has not become standardized. Therefore it has been necessary, particularly in the material translated from Russian, to attempt to establish a standard terminology. Since some of the terminology evolved during editing and review of the translated material, there are some inconsistencies in the translated material. However, the following glossary identifies the most significant English words which are recommended for use, including some relevant words which are not uniquely applicable to hydraulic mining.

- airlift - a method of hydraulic hoisting in which compressed air is injected into slurry in a discharge pipe to utilize gravity flow from the bottom of a slurry sump.
- bremsberg field (or gravity slope field) - a network of underground openings permitting collection of minerals by gravity fluming. Usually the pitch angle of the openings is between 3° and 8°.
- canopy - a flexible lattice, lacing or mesh used to prevent roof rock from becoming mixed with coal.
- cavitation - the generation of vapor bubbles or cavities in a liquid (e.g., in a pump suction or liquid jet).
- coal pump - a suction pump for pressurization of a coal-water mixture; also called a coal sucker. Usually, it is a centrifugal pump, but in some cases a piston or plunger pump is used for finely ground particles (usually for long distance pipelining).
- continuous jet - a steady flow jet produced by a nozzle supplied by an approximately constant pressure source (e.g., a pump or continuously-acting pressure intensifier).
- dip - the angle at which a seam, bed, stratum, or vein is inclined downward from the horizontal (also called pitch).
- feeder - a device for injecting mineral into a pipeline or sluice at a controlled rate (e.g., screw feeder, bin feeder, drum feeder).

flume (or sluice) - a solid trough or channel, usually segmented, for carrying an open channel flow of a solid and liquid mixture. It may be made of metal or wood and may be lined with an abrasion resistant or friction-reducing coating or lining. It may be installed on the mine floor or recessed in a ditch or canal.

fluming (or sluicing) - the process of hydrotransport of a solid-liquid mixture by gravity flow in an open channel (a flume, sluice, or ditch), possibly combined with gravity flow through pipes.

hardness - the resistance of a material to crushing. Usually Soviet data on coal and rock is reported in terms of the Protod'yakonov hardness F , which is approximately 1 percent of the unconfined compressive strength in kg/cm^2 .

hydraulic borehole mining - the mining of minerals from an underground deposit by the use of liquid jets and hydraulic hoisting through a borehole to the surface.

hydraulic hoist - a system for hoisting a solid-liquid mixture from a mine.

hydraulic-mechanical mining system - one in which mineral is cut by a liquid jet but transported by mechanical means (e.g., conveyor or mine car).

hydraulic stowing - the process of filling the goaf with solid material which is transported as a solid-liquid mixture.

hydrobreaking - the disintegration of material by a water jet.

hydromechanization - the process of equipping a mine to permit hydraulic haulage of minerals.

hydromine (or hydraulic mine) - a mine in which minerals are hauled and/or hoisted as a mixture of solid and water.

hydroseal - a mechanical device which seals a pipe into a drill hole and permits water pressurization of a seam (also called a packer).

hydrotransport - transport of solid loose materials in a flow of liquid (water); also called hydraulic haulage.

- hydroventilator - a water turbine powered fan for local ventilation.
- hypsoetry - measurement of elevations with reference to sea level.
- incline - a non-vertical shaft cut within a pitching mineral seam, usually on dip (also called a slope).
- isohypse - a line on a map showing constant elevation (e.g., of a seam surface) referenced to sea level (also called a contour line).
- isopach - a line on a map drawn through points of equal thickness of a seam.
- jet cutter head - a mineral cutting element which uses high pressure jets alone to disintegrate a mineral.
- kerf - a groove cut in a material (eg., a slot cut by a liquid jet or by two or more jets), also called slot or slit.
- level - a mine field division with respect to dip, extending on strike.
- lift - the volume of mineral extracted in one step during a mining process (also called advance, pull, web, or slice; the word advance has been used in our translation of Ref. 736. However it should not be confused with the direction of mining - in advance or retreat. Therefore the word lift is preferable).
- lock hopper - a charge-exchange chamber for batch feeding of mineral into a slurry pipeline by water pressurization.
- mechanical-hydraulic mining system - one in which mineral is cut mechanically but transported hydraulically.
- mining machine - a machine for cutting or breaking minerals (also called a roadheader, mining combine, complex, aggregate, or continuous miner).
- monitor - a portable nozzle system for ejecting a water jet to break minerals, also known as a hydromonitor or hydraulic giant.

nozzle discharge coefficient - the ratio of actual nozzle flow-rate to the theoretical nozzle flowrate for isentropic flow from the initial to the final pressures of the actual nozzle.

panel - a mine field division on strike extending up-dip or down-dip.

pipe range - a system or network of pipes for distributing liquid (water).

pitch - the angular inclination to the horizontal (also called the dip, inclination, slope, grade)

pressure intensifier - a device for increasing the pressure from a continuous source of liquid pressure (usually by means of two pistons of different area).

pressurized hydrotransport - the process of haulage of a solid-liquid mixture in a closed pipe. Pressure may be supplied by gravity or by a pump.

productivity - mass of mineral output (usually raw coal) per worker per unit time, to be distinguished from production rate; also must distinguish whether referenced to monitor operators, face workers, all underground workers, all men at mine, etc.

pulsating jet - a jet with time-varying jet velocity which never drops to zero (as from a pulsating monitor).

pulsed jet - a jet of limited time duration, usually with time-varying jet velocity during the pulse and appreciable time between successive pulses (as from a water cannon).

slope - an inclined shaft

slot - a groove cut in a material, as by a traversing nozzle system producing one or more jets (also sometimes called a kerf or slit).

slurry - any mixture of solid particles (including run-of-mine minerals) in a liquid.

specific energy - the energy required to disintegrate a unit volume of solid.

- specific water absorption - the amount of water absorbed in a (coal) seam per unit area and per unit pressure difference when pressurized (e.g., by a hydroseal).
- stopping face - the surface of a mineral which is being mined.
- story - a subdivision with respect to dip of a mine field panel.
- strike - the direction or bearing of a horizontal line in the plane of an inclined structural plane (e.g., the plane of a seam). It is perpendicular to the direction of the dip.
- stump - a volume of mineral left to support the roof.
- up-raise borehole monitor - a monitor for making raise holes and/or washing out coal in retreat.
- water cannon - a cyclic machine for producing pulsed jets of water. It may be powered by water in an open cycle or hydraulic fluid in a closed cycle to store energy in compressed gas, and then accelerate a piston to extrude a pulsed water jet.
- web - the material left unbroken between two adjacent slots or kerfs cut by liquid jets (also called pillar).

4.0 CLASSIFICATION OF HYDRAULIC COAL MINING SYSTEMS

A hydraulic coal mining system may be classified with respect to the method for pre-loosening coal (if any), the method for breaking coal, the method of face and main haulage, and the method of hoisting. When monitor jets are used to wash coal from the face, in some cases (with hard or water-impermeable coal) it is desirable to pre-loosen the coal by water infusion into the seam (through a hydroseal) or by drilling and blasting.

Table 4-1 shows a method for classifying hydraulic mining systems. It is seen that the various systems can each be classified by a four-digit number. For example, System 1111 uses no pre-loosening, with a pump-fed monitor, gravity fluming and coal pump hoisting. This is the most common type of system in the USSR. The system 1731 is the system under development by Consolidation Coal in the U.S. which uses no pre-loosening, with a continuous mining machine, pump-pressurized haulage through a hose, and coal pump hoisting. The system 1117 is used by Kaiser Resources Hydraulic Mine No. 1 in British Columbia (Ref. 1100). It uses no pre-loosening, with a pump-fed monitor, and gravity fluming from the face and also to the mine portal.

Table 4-1
CLASSIFICATION OF HYDRAULIC COAL MINING SYSTEMS

- A. Method of Pre-loosening Coal
 - 1. None
 - 2. Water Infusion
 - 3. Drill-and-Blast

- B. Method of Removing Coal From Face
 - 1. Monitor Supplied by Pump
 - 2. Monitor Supplied by Pressure Intensifier
 - 3. Jet Cutter Head on Mining Machine
 - 4. Jets Combined with Mechanical Breakers on Mining Machine
 - 5. Pulsating Jets (e.g., pulsating monitor)
 - 6. Pulsed Jets (from water cannon)
 - 7. Mechanical Cutter Head Only

- C. Method of Face and Main Haulage
 - 1. Fluming
 - 2. Gravity-Pressurized Slurry Pipe or Hose
 - 3. Pump-Pressurized Slurry Pipe or Hose
 - 4. Mechanical Loading (e.g., shuttle cars with conveyor or mine cars)
 - 5. Combination of Mechanical Loading of Lump Coal with Fluming of Fines

- D. Method of Hoisting
 - 1. Coal Pumps
 - 2. Airlift
 - 3. Combined Coal Pumps and Airlift
 - 4. Batch Feeder
 - 5. Skip
 - 6. Conveyor
 - 7. None (e.g., main haulage to portal)

5.0 BASIC TECHNOLOGY

5.1 Nozzle Flow Relationships

The basic parameters of a water jet are the nozzle diameter and the pressure, which determine the flow rate and jet power. The effective range of a jet increases with the nozzle diameter. Therefore in order to break coal at a large range of 10 to 25 meters, monitors with nozzle diameters of the order of 20 to 30 mm are needed with a pressure of the order of 100 atmospheres (in this report, one atmosphere is used interchangeably with one kg/cm² or 14.2 psi). When small nozzles of the order of 3 mm diameter or smaller are used for jet cutting, the most effective range is generally much less than 200 nozzle diameters (60 cm or 2 ft). They are traversed across the coal face to cut slots.

The variation of jet power with nozzle diameter and pressure is shown in Figure 5-1, assuming a nozzle discharge coefficient of 1.0. The variation of water volume flowrate with nozzle diameter and pressures is shown in Figure 5-2, assuming nozzle discharge coefficients near 0.95. The volume flowrate varies as the square of nozzle diameter and as the square root of pressure. The jet power varies as the square of nozzle diameter and as pressure to the 3/2 power.

A typical monitor with a pressure of 100 kg/cm² (1420 psi) and a nozzle diameter of 25 mm (1 inch) has a flowrate of 240 m³/hr (1050 gpm) and a jet power of 900 horsepower (670 kw). A typical jet cutter head may use several nozzles of 1 to 3 mm diameter at pressures of 400 kg/cm² or higher. Each 2 mm nozzle at a pressure of 10,000 psi (705 kg/cm²) requires about 100 horsepower.

5.2 Jet Dispersion

As a water jet escapes into air, turbulent mixing causes the jet to spread and mix with air, reducing the average jet velocity. The reduction of jet pressure with range is a complex function of the nozzle design, the inlet flow geometry (which controls the turbulence level entering the nozzle), the nozzle surface roughness, and the Reynolds number of the flow. The use of flow straightening vanes in the inlet section followed by a straight flow damping section ahead of the nozzle is desirable to minimize jet dispersion. Data on jet dispersion have been published by Nikonov (Ref. 665)

Figure 5-1
 JET HORSEPOWER vs NOZZLE DIAMETER
 AT VARIOUS PRESSURES

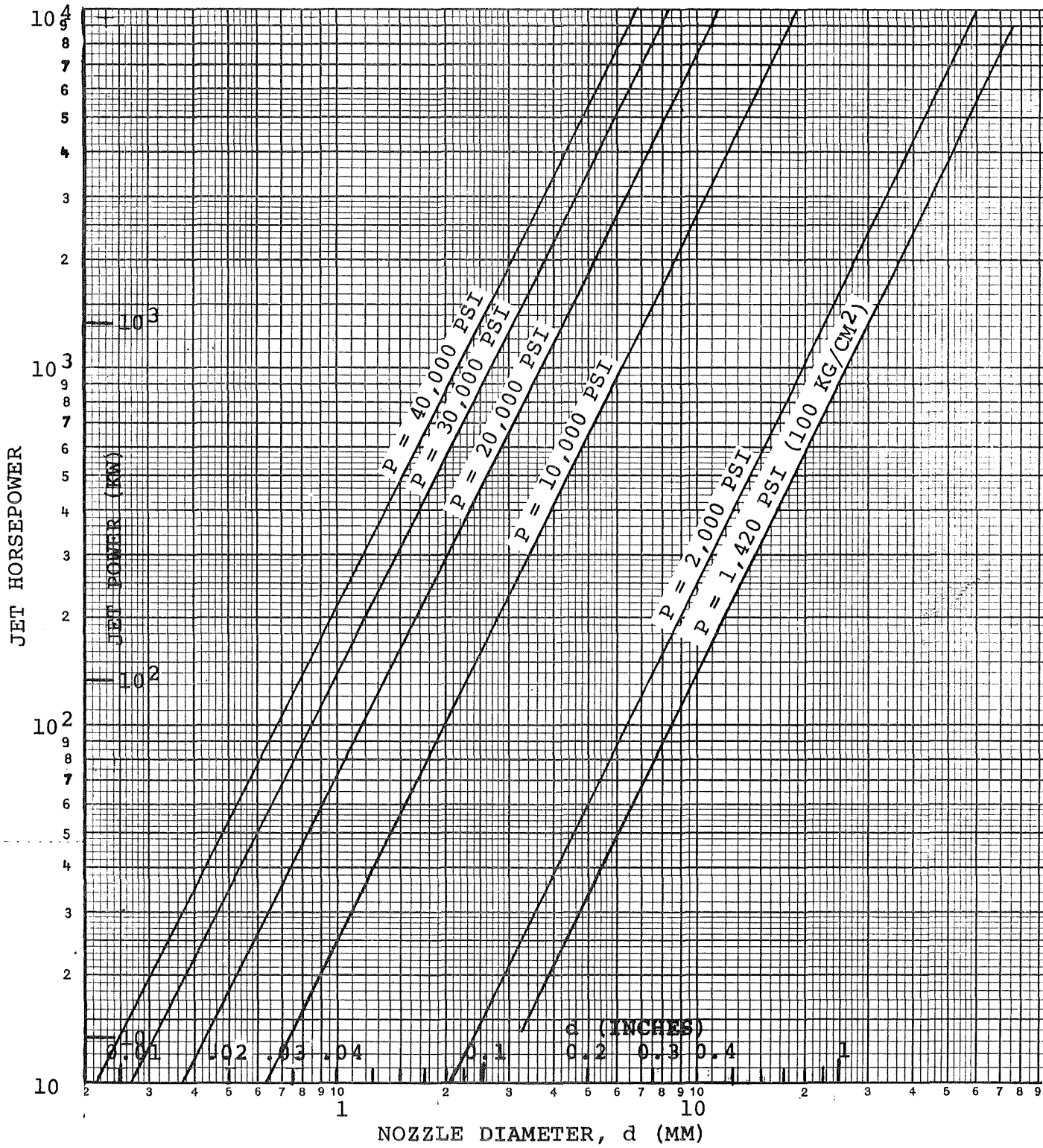
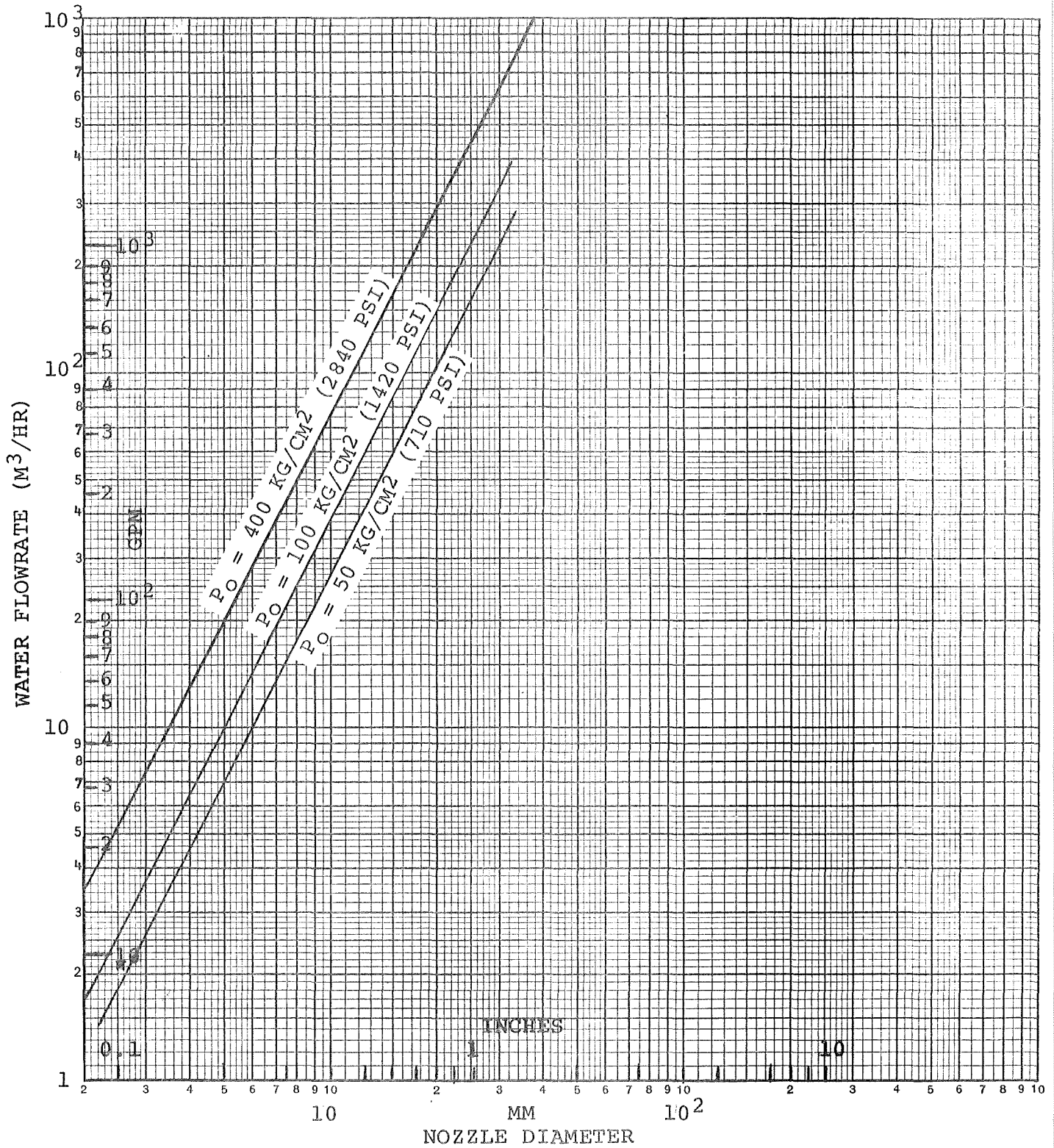


Figure 5-2
 WATER FLOWRATE AS A FUNCTION
 OF NOZZLE DIAMETER AND PRESSURE



and by Shaylovskiy (Ref. 975). A review of the jet cutting literature by Cooley is included in Ref. 1079. Data on jet dispersion from a well designed German monitor have been published by Benedum, et al (Ref. 387). By improvements in the design of their monitors and nozzles, the effective range for breaking coal was increased from 8 m to more than 25 m.

5.3 Jet Cutting and Disintegration of Coal

When a high pressure jet is directed against coal, there are two main mechanisms of failure of the material. The first is granular erosion and the second is fracture (called hydrobreaking) under shear or tensile stresses aided by water permeation into pores and cracks. The erosion mechanism is quite inefficient because it breaks coal into very small grains with high specific energy because of the large surface area produced per unit volume. Hydrobreaking disintegrates coal into larger pieces with lower specific energy. Therefore coal disintegration by a continuous jet of small diameter (less than 5 mm) is best accomplished by cutting slots of minimum total volume with a rapidly traversing jet, followed by breakage of the coal between slots by the action of water pressure, gravity, roof pressure stresses, mechanical methods, or combinations. Jet cutting of slots should be accomplished with a standoff distance from nozzle to coal of less than 100 nozzle diameters, if possible.

A pulsed jet from a water cannon directed at one spot on a coal face, first erodes a central hole, then breaks out a roughly conical crater. Not more than two or three shots should be made to one point because the jet action becomes less effective due to increased range, turbulent mixing, and water cushion at the bottom of the crater. Usually successive shots against coal or rock should be spaced several inches apart, depending on jet energy and coal or rock strength.

A monitor with a nozzle diameter greater than 15 mm typically is used to undercut a deep slot under a lift of coal, then sweep the face in passes parallel to the undercut to break out layers of coal in large pieces. Breakage is nearly 10 times as effective as cutting slots. If possible, the undercut should be made in a soft or friable band of coal directing the jet parallel to the bedding plane. When possible a monitor jet should also be aimed approximately parallel to the cleat plane for most effective breakage. A jet cutter head with small diameter jets usually cuts slots and then is followed by a mechanical tool to assure breakage of the coal web between slots.

5.4 Hydrobreaking of Coal by Monitor

The most widely applied method of coal disintegration by water jets is the use of a monitor. Nozzle diameters of 15 to 35 mm (0.59 to 1.38 inches) are used at typical pressures from 50 to 125 kg/cm² (710 to 1780 psig). The standoff distance (range) from the nozzle to the coal may be from about one meter to 25 meters. When a monitor is used for driving development headings in coal, breakage occurs from only one face. Therefore smaller nozzles, higher pressures and shorter ranges are generally used than when cutting lifts of coal from production faces, where breakage can occur from more than one face. For the same pressure and nozzle size, the production rate on development is generally about 40 percent as high as on a production face.

Monitors are usually used at pressures and flow rates which provide enough water to wash the coal from the face and permit gravity fluming. Water to coal ratios of 3 to 7 by weight are typical in Soviet hydromines. Lower values are possible with steeper slope of flumes or with the use of a feeder-breaker to control flowrate to a flume.

5.5 Effect of Coal Properties on Hydrobreaking Production Rates

The primary properties of coal affecting its ease of disintegration are the coal hardness (which is related to compressive strength) and its permeability to water (which is affected by porosity, joints, cleats, lamination planes, plasticity, the state of stress, and the direction of water permeation). In general, coals with an intermediate degree of metamorphism are easier to break than coals of low or high rank, but there are exceptions. Breakage of coal from a free surface is generally more effective if the jet is directed approximately parallel to the plane of cleats and laminations. If the jet is directed at 90° to the cleat plane, the breakage rate is decreased by 55 to 65 percent (Ref. 668, p. 12).

As a first order approximation, it was initially found (Ref. 661) that the minimum jet pressure required to cut coal effectively should exceed a value of about one half the compressive strength or 50 times the Protod'yakonov hardness number F (which is approximately 1 percent of the unconfined compressive strength). However, exceptions to this rule were found and therefore a water infusion test method was developed in the USSR (Ref. 450, later superseded by Ref. 666) to measure the ability of coals to be broken by a monitor jet. The method requires drilling a hole in the coal seam, installing a hydroseal (or packer), infusing

water under pressure, and measuring the pressure required to fracture the seam and the pressure variation with time. The specific water absorption of the seam is determined and correlated with the monitor jet pressure required for effective breakage. Since water is infused in all directions into the seam, an average value of specific water absorption is obtained which allows for anisotropic permeability.

It was found (Ref. 666) that for seams with specific water absorption Ψ_0 greater than 0.0050 cm/atm-sec, hydro-breaking is recommended at a pressure of 100 atm without pre-loosening of coal.

For coal with Ψ_0 from 0.0025 to 0.0050, the coal should be pre-loosened by water infusion under pressure and mined with a monitor pressure of 100 atm or less. For coal with Ψ_0 less than 0.0025, pre-loosening requires drill-and-blast methods followed by monitor washout at a pressure of 50 atm.

The specific water absorption of a coal seam generally decreases and its hardness and resistance to hydro-breaking by a monitor jet generally increase with depth in a mine (Ref. 666).

Nikonov (Ref. 666) gives the following equation for the production rate (metric tons/hr) for a monitor (at 1 to 8 m range)

$$W = 3.1 \times 10^{-3} P_0 Q \sqrt{\Psi_0} \quad (5.5-1)$$

where P_0 = nozzle pressure, kg/cm²
 Q = flowrate, m³/hr
 Ψ_0 = specific water absorption of the coal seam, (cm/atm-sec).

This equation corresponds to a production rate proportional to jet power (equations based on coal hardness are given in Ref. 738, p. 7).

Experimental data taken with a type GMRTS monitor with 19 mm nozzle are shown in Figure 5-3.

The stronger the coal and the lower its value of Ψ_0 , the larger the specific water consumption (m³/metric ton) required for breaking. Figures 5-4A and 5-4B show the variations for production and development faces, respectively. At a given jet pressure, a strong coal gives a high specific water consumption (low slurry concentration). Therefore

Figure 5-3
 MINIMUM MONITOR PRESSURE REQUIRED AS A FUNCTION
 OF SPECIFIC WATER ABSORPTION OF COAL SEAM
 FOR VARIOUS PRODUCTION RATES FROM A PRODUCTION FACE

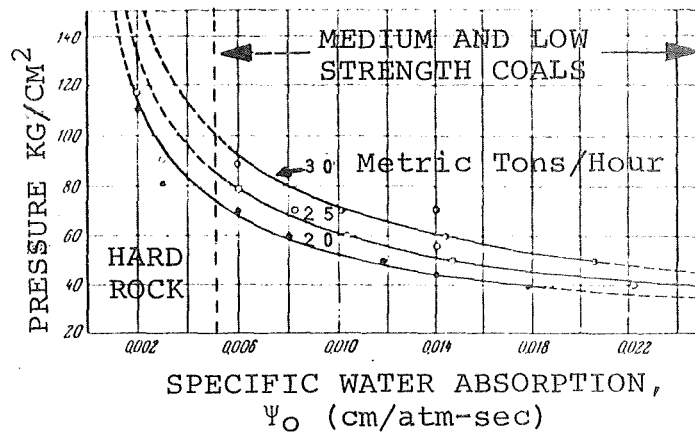
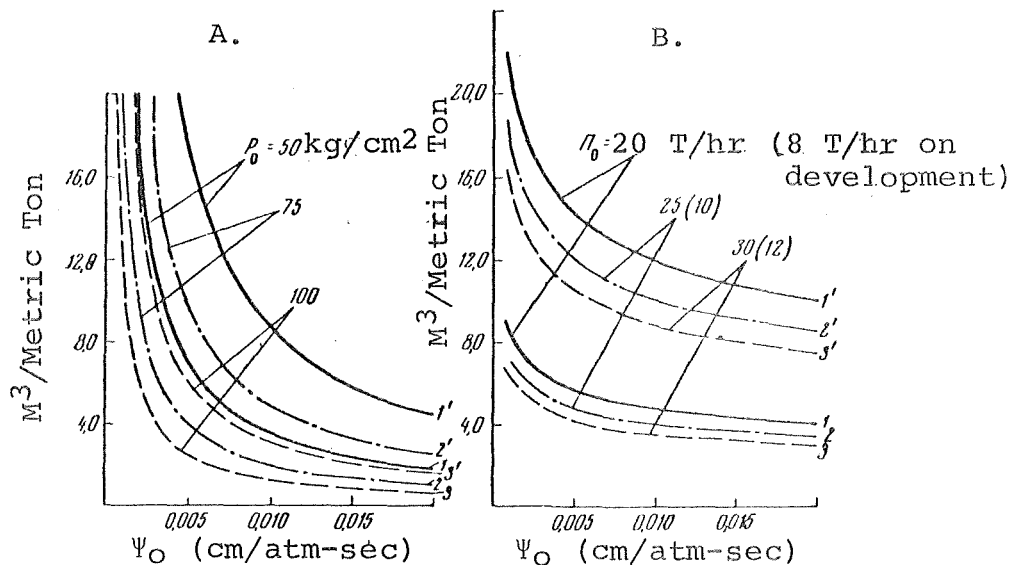


Figure 5-4
 SPECIFIC WATER CONSUMPTION FOR HYDROBREAKING
 IN PRODUCTION (1, 2, 3) AND DEVELOPMENT (1', 2', 3') FACES
 AS A FUNCTION OF SPECIFIC WATER ABSORPTION OF THE SEAM



a jet pressure should be used which gives acceptable slurry concentrations for fluming and pumping. Desirable slurry concentrations are 30 percent to 50 percent coal by volume for efficiency in hydraulic hoisting. However, lower concentrations may be required when mining hard coal, when water pressure available is too low, or when excess water is needed to accomplish fluming (e.g., to move large lumps, or with non-uniform feed rates into flumes of low pitch angle). Typical ratios obtained in hydraulic hoisting with coal pumps are water to coal ratios by weight of 5 to 7.

5.6 Jet Cutting of Slots in Coal by Small Diameter Jets

Nikonov and Goldin (Ref. 661) have published data on the depth of slots cut in coal by jets from small diameter traversing nozzles. The Protod'yakov hardness (F) of the coal was from 0.3 to 3.0 (compressive strength from 30 to 300 kg/cm²). The nozzle diameter d_o was 0.7 to 10 mm at pressures P_o of 50 to 500 kg/cm² and traverse velocities V_T of 0.05 to 5.0 m/sec. The dimensionless slot depth h in nozzle diameters was found to be

$$\frac{h}{d_o} = 0.50 \left[\frac{P_o}{100F} - 0.2 \right] \left(\frac{V_o}{V_T} \right)^{0.5} \quad (5.6-1)$$

where P_o = jet pressure
 $100F$ = compressive strength
 V_T = traverse velocity
 V_o = jet velocity

For minimum energy consumption and maximum slot area cut per unit time, the optimum jet pressure was 1.5 to 1.6 times the compressive strength. The optimum traverse velocity for cutting slots in hard coal ($F = 1.8$ to 2.3) was

$$V_{T0} = \frac{V_o}{175-23d_o} \quad (5.6-2)$$

where d_o is the nozzle diameter in mm and the jet velocity V_o in m/sec is given by

$$V_o = 13.3 \sqrt{P_o} \quad (5.6-3)$$

where pressure P_o is in kg/cm².

Nikonov and Goldin also reported tests in cutting hard coal with dual-jet cutters having two nozzles at an included angle of 16° on a strut which extended into a kerf in the coal face. They found that hard coal ($F = 1.8$ to 2.3) required a jet pressure of 300 to 320 kg/cm^2 with nozzle diameters of 1.2 to 2.0 mm . The optimum traverse velocity for the dual jet cutter was given by

$$V_{TO} = 0.02P_o(d_o + 2.9). \quad (5.6-4)$$

For hard anthracite, the slot spacing should be 12 to 15 cm and the slot depth at least 25 to 27 cm for the web (pillar) between slots to break under jet action alone. The web can also be broken mechanically more reliably.

5.7 Monitors

5.7.1 Portable Skid-Mounted Monitors (See Figure 5-5)

A classification of types of monitors is shown in Table 5-1. Data on skid-mounted monitors which have been developed are given in Data Sheets 5.7.1-1 through 5.7.1-23 (Vol.3) (Other types are discussed and Data Sheets included in Sections 5.7.2 and 5.7.3.) Monitors generally should have a barrel containing flow straightening vanes and a damping section to smooth flow disturbances caused by the bends in the feed system. The nozzles may be made of hard metal to minimize erosion by solids in recycled mine water.

In all practical applications, monitors have been supplied with high pressure water from fixed pump installations, usually on the surface, with distribution through pipes. However, higher pressures above 125 kg/cm^2 may be supplied by local pumps in a mine section.

5.7.2 Self-Propelled Monitors (Data Sheets 5.7.2-1 - 5.7.2-11)

Monitors can be mounted on mobile vehicles which obtain traction from caterpillar tracks or rubber tires, and are trammed by electric motors or open-cycle water turbines. Water must be supplied by flexible hoses or pipes with swivels. If low-pressure water were supplied, an electrically driven pump could be mounted on the vehicle to supply the monitor and an electric drive for tramping. If, as in most cases, high pressure water is supplied from the surface by a pipe range and high-pressure hose, the function of tramping

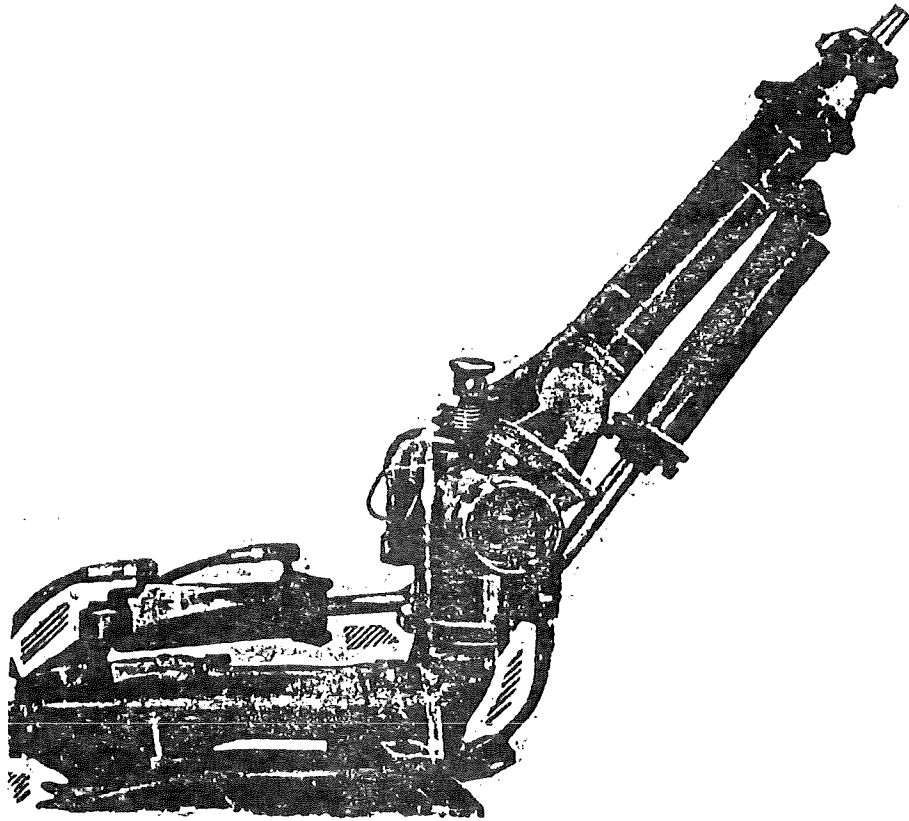


Figure 5-5
PORTABLE SKID-MOUNTED MONITOR

Table 5-1
SUMMARY OF MONITOR DEVELOPMENT

Country	Skid Mounted			Self-Propelled	Up-Raise Borehole Type (Jet Drill)	Hose-Suspended Type	Down-The-Borehole Type
	Manual Control	Water Hydraulic Control	Oil Hydraulic Control				
USSR (Donbass)	G-1R GMRTS-2A	GMDTS-2 GMDTS-2M G-1	IRMINETS GI-1 G-1	GP-1 (Caterpillar Track) GDP-2, GDP-2m (Telescoping Jacks) GD-2 (Caterpillar Tracks)	AGS-1 AGS-2 GVD-1 BU-1	DPG	
USSR (Kuzbass)	Gn-1 RGM-1 RGM-1m		PG-1u GDTS-3m GMDC-2 (GDC-3) GMDTS-3 GMDTS-3MA	GD-1T (Telescoping Jacks) PDG Type With Pressure Intensifier and Caterpillar Tracks GPS-1 (Caterpillar Track)			
German Federal Republic			Mod I (270 kg) Mod II (180 kg) Mod III (85 kg)		Steinkohlenbergbauverein		
Japan		Early Model (750 kg)	NIKKI Co. (For Kaiser)				
Czechoslovakia			DH-30 DH-40				

Table 5-1-
SUMMARY OF MONITOR DEVELOPMENT (Continued)

Country	Skid Mounted			Self-Propelled	Up-Raise Borehole Type (Jet Drill)	Hose-Suspended Type	Down-The-Borehole Type
	Manual Control	Water Hydraulic Control	Oil Hydraulic Control				
United Kingdom		Trelewis System (Initial Tests)	Trelewis System				
Poland	GIG-5						
United States	Roslyn # 9			Sugar Notch (Jacks) American Gilsonite (Tracked) Roslyn # 10 (Jacks) BuMines (Tracked) Thompson Creek (Jacks)			American Gilsonite Co. Hydro-Jet Services, Inc. Pacific Pumps Division, Dresser Industries (De-Coking) FMC Corp.

power can be accomplished using part of the water flow for a water turbine drive. It is also possible in this case to drive a pressure intensifier with open cycle water to raise the pressure of part of the water flow to a higher value. A pressure intensifier or pump may be mounted on the mobile vehicle or nearby, connected by high pressure hose.

The advantage of an all water hydraulic system is to avoid the need for electric cables near the face with their attendant hazards. Lighting and local ventilation can also be provided by water turbines.

In principle, Diesels with exhaust scrubbers could be used for traction. However, the use of Diesel-driven pumps on a mobile vehicle to supply the monitor would require high power levels (over 1000 hp) and large equipment.

Consideration of self-propelled monitor vehicles with pumps and an operator on the vehicle is under study by Ingersoll-Rand under Bureau of Mines contract H0155138 to study mining equipment for thick coal seams (over 12 ft). If water is to be supplied from outside the mine (e.g., recycled mine process water), the additional expense of designing the pipe range system for higher pressure may be warranted because the monitor vehicle can be more compact, less expensive and more adaptable for remote control to improve operator safety. Also the need for electrical power at the face can be reduced or eliminated and the servicing of pumps and motors can be accomplished more easily on the surface.

In the USSR, several types of self-propelled monitors have been developed. In all cases they are remotely controlled for operator safety. In some cases they are mounted on skids and advanced by jacks (see Data Sheets 5.7.2-1 through 5.7.2-6).

5.7.3 Borehole Monitors (Data Sheets 5.7.3-1 through 5.7.3-10)

As indicated in Table 5-1, specialized monitors have been developed for breaking coal in boreholes. The up-raise borehole type and jet drill types are mounted on a structure which can be extended up-raise in sections to raise the nozzle in a thin seam and bore a raise to an upper level. The nozzles can then be changed and the unit lowered back down the hole to break and flume coal from an extended area of the seam. They are useful in thin pitching seams subject to coal and gas outbursts.

The hose-suspended monitor is dropped down a drilled borehole and used to break coal as it is raised.

The down-the-borehole type is mounted on a rigid pipe structure (e.g., a drill string) and lowered into a borehole, then raised to break coal. It usually is operated remotely from the surface with hydraulic hoisting by jet pump. However, American Gilsonite has also used a system which washes gilsonite to a lower manway, from which it can be pumped by centrifugal pumps.

5.8 Mining Machines and Roadheaders (Excluding Monitor Types)

In addition to self-propelled monitors, a variety of mining machines have been developed for use in driving development headings and for production in hydromines (see Data Sheets 5.8-1 through 5.8-23). The trend in recent Soviet hydromine practice appears to make increasing use of mechanical coal cutting, in some cases using water jets to aid in cutting and to reduce dust generation.

Mining machines and roadheaders for use in hydromines may be classified into the categories shown in Table 5-2 denoting whether they use jet cutting, mechanical cutting, a combination, a pulsed water cannon, or drill-and-blast methods. The machines may be further classified with respect to the type of applications they may be used for (continuous miner or roadheader, longwall or shortwall) and their power source (electrical or water hydraulic). Where applicable, the type designation of Soviet equipment and the sources of other machines which have been developed or proposed are listed (standard continuous mining machines available in the U.S. have not been included). It is seen that Soviet practice makes extensive use in hydromines of mechanical cutter machines for driving headings. Seven types of Soviet machines are powered by water turbines instead of electric motors, which is the standard practice elsewhere. The absence of electrical requirements improves safety and the turbine exhaust water is used for fluming. The Soviet AP-2 roadheader is unique in that it combines hydrobreaking of coal with a capability for drilling and blasting rock, with crushing and hydraulic stowing of the broken rock.

5.9 Hydrotransport of Coal in Underground Mines

Hydrotransport (hydraulic haulage) of coal may use pressurized flow in pipes or open channel flow in flumes. The advantages of hydrotransport are a reduction in the number of service personnel, reduction of costs, elimination of the need for reloading material as in mechanical haulage, obtaining a continuous process with the possibility of automation,

Table 5-2
 CLASSIFICATION OF MINING MACHINES AND ROADHEADERS
 FOR USE IN HYDROMINES, SHOWING ACTUAL AND PROPOSED SYSTEMS

	Power Source	
	Electrical	Water Hydraulic
A. Jet Cutter		
1. Continuous Miner or Roadheader	Bendix* IITRI*	
2. Shortwall		ShGKV (using HSU Cutter)
3. Longwall		
B. Mechanical Cutter		
1. Continuous Miner or Roadheader	4PU, K-56M, K-56MG, PKG-4, PK-9	MGPP-3, MGPP-3A, LMGP-3, LMGP-5, Ural-38, MGP-2, KKG
2. Shortwall		
3. Longwall		
4. Tunnel Boring Machine	PBM	
C. Combined Jet and Mechanical Cutter		
1. Continuous Miner or Roadheader		ENUS-1
2. Shortwall		
3. Longwall	Skochinsky Type MVU and MVM, U. of Missouri, Pol. GIG-AG	
D. Water Cannon Roadheader	Terraspace TS-1	MPI-2, PI
E. Drill-and-Blast Roadheader		AP-2

* Denotes machines proposed but not developed

improved reliability, elimination of coal dust generated at reloading points, and improved health and safety for mine workers.

Hydrotransport occupies very little volume in a mine, permitting a reduction in the cross sectional area of headings and of shafts or inclines.

Utilization of hydrotransport requires the availability of water from inflow to the mine or from a nearby source. If water inflow is insufficient and recycling is required, the amount of water per ton of coal should be reduced to a minimum to reduce pumping power. The power required for hydrotransport is usually higher than with mechanical transport.

In horizontal coal seams or at pitch angles less than about 3° , hydrotransport requires pumps and pipes or hoses.

A discussion of slurry flow characteristics is given in Ref. 739. In brief summary, the following conclusions are reached.

Since pressure losses are proportional to the square of velocity, it is desirable to use low velocities (large pipes) to minimize pumping power. However, slurry velocity cannot be lowered below a critical velocity at which silting out of the slurry occurs which may plug a pipe or cause a flume to be blocked and overflow. Generally, slurry velocities of 2 to 2.5 m/sec (6.5 to 8 ft/sec) are used in slurry pipes.

For transporting coarse lumps, higher velocities are required, particularly for vertical hoisting, and pumping costs are greater than with fine particles.

The higher the density of solid particles, the higher the velocity required for suspension and the greater the power required. If a liquid of density greater than water were used as the carrier, the power required would be reduced. This effect can be obtained by using fine coal particles in suspension to increase the effective density of the liquid and transport coarse lumps more easily. As viscosity of the liquid increases, the power required for hydrotransport increases, but lump sizes can be increased.

The power required can be significantly reduced by increasing the slurry concentration to reduce the volume of water hoisted. Power can be reduced by using smooth pipes with low friction linings (glass, enamel, plastic, ceramic, etc.). Pressure losses due to flow turns, sudden expansions or contractions of flow area, misalignments of pipe joints, etc., are to be minimized. Bad flow patterns can also cause silting out and plugging of pipes and flumes.

Hydrotransport in turbulent flow causes grinding of lump coal. This effect can be reduced by using a highly concentrated suspension of fine coal (particles less than 0.06 mm, or 0.0024 inch) instead of water as the carrier. Slimes or residues from preparation plants, thickened by centrifuges, may be used. In some Russian mines (e.g., anthracite mines) lump coal is separately hoisted by skip to avoid size reduction by abrasion in pipelines and by passing through centrifugal pumps.

5.10 Fluming (Data Sheet 5.10-1)

Open channel gravity flow of slurry may occur in flumes (sluices or troughs), in unlined ditches, or in pipes. The presence of a free surface permits variation of the slurry flow cross section. An open flume can move larger lumps (by rolling) than a pressurized flow of the same liquid flow cross section. The seam floor should retain its strength when wetted.

The advantages of fluming are its simplicity, absence of mechanical equipment, safety, low cost of materials, and the ease in detecting and correcting obstructions to the flow.

The least economical method of fluming is when coarse lumps are not fully immersed in liquid, but roll and bounce. On the other hand, if the liquid depth is much larger than the largest lumps, the power of the flow is also not fully utilized because flow bypasses the lumps on the upper side. For optimum performance, the size of the largest lumps should be about equal to the depth of slurry flow, in order to use the dynamic pressure most effectively and minimize the specific water consumption (m^3/ton).

As the slope of a flume is increased, the water flowrate required to move the largest lumps decreases. When operating at optimum depth, the water flowrate required is proportional to the friction factor of the coal against the bottom of the flume. For transporting more dense materials like rock, the specific water consumption increases.

Removable flumes in mine sections are generally constructed of sheet steel at least 2 mm (0.079 inch) thick, bent into a trapezoidal shape (although an elliptical shape is most desirable) and mounted on wooden footings or laid directly on the ground. Flume lengths are usually 1.5 to 2 m (5 to 7 ft). A trapezoidal cross section requires less water flow than a circular or triangular shape. The width of the

flume should be about 1.5 to 2 times the size of the largest coal lump to be handled. For run-of-mine coals of 25 cm (10") maximum size, flumes should be at least 400 mm (16") wide at the base. For coal of 50 to 70 mm (2" to 3") size, the width should be 200 to 300 mm (8" to 12"). The depth should be adequate to prevent overflow (10" to 12"). For flumes at a slope of more than 0.10 to 0.15 (6° to 8.5°) the flumes usually should be covered up to prevent overflow, unless coal is pre-crushed (e.g., by a feeder-breaker as used in the Kaiser Hydraulic Mine No. 1). In some cases, main haulage flumes should be increased to 0.5 to 0.6 m² in area to prevent clogging (Ref. 1083).

For main haulage installations, the flumes may be lined with or made of abrasion-resistant materials to increase their life (ceramic, rubber, or wood). Wear is due mainly to rock and less to coal. Special steels like COR-TEN may be considered as well as ceramic-lined or enameled flumes. Enameled flumes last 5 to 6 times as long as steel alone and they have a lower friction coefficient, permitting a flume pitch as low as 4 to 5 percent (2.5° to 3°). Slurry flow is typically 300 to 500 m³/hr (1300 to 2200 gpm) (Ref. 711).

Methods for calculating the required slope and the water flow required for fluming as a function of flume material friction factors, and density of coal and rock are given in Ref. 739 (pp 53-60).

When fluming in ditches with rough walls, the specific water consumption can vary from 2 m³/metric ton at a slope of 0.20 (11.3°) to 7 or 8 m³/metric ton at a slope of 0.07 (4°). For moving coarse lumps up to 250 mm (10") size, at least 250 m³/hr (1100 gpm) water flow is required. Fluming in ditches is not advisable if the floor rock does not retain its strength when wet.

5.11 Coal Pumps (Centrifugal) (see Data Sheets 5.11-1 through 5.11-31)

Coal pumps are used to pump coal slurry up from one mine horizon to another or to the surface and also for horizontal transport, e.g. to a dewatering plant or preparation plant. Coal pumps in hydromines are almost always centrifugal pumps instead of piston or plunger pumps, which cannot handle lump coal and require fine crushing. The pump impeller inlet and passages of centrifugal pumps must be large enough to pass the largest lumps without wedging. A crusher must be used to reduce the size of larger lumps. The

number of centrifugal stages is normally not more than one or two to permit easy disassembly for replacement of rapidly wearing parts.

The pump is usually above the slurry level in the sump (up to 4 m or 13 ft) and must have provision for priming. If the volume of air drawn into the suction exceeds about 28 percent of the slurry flow, the pump may cavitate, lose suction and be damaged.

Coal pumps in the USSR are driven by electrical motors with a power of 320 to 1500 kw at 1450 to 1485 rpm. Their efficiency is about 50 to 55 percent. The maximum head produced by the 12UVG pump (2 stages with double suction) is 320 m (1050 ft of water) with a flowrate of 900 m³/hr (3950 gpm). The maximum flowrate produced by the 14U7 pump (1 stage single-suction) is 1400 m³/hr (6150 gpm) at a head of 175 m (575 ft of water). The internal parts are made of or faced with hard alloys. The pumps are usually designed to handle slurry with a ratio of water to coal of more than 5. The acidity of mine water should be maintained near neutral (pH of 6 to 8) to limit corrosion.

The head produced per stage by Russian coal pumps is quite high by comparison with American standards for slurry pumps, which use lower speeds to avoid wear and increase life when handling abrasive materials.

5.12 Hydraulic Hoisting

Hydraulic hoisting is used to hoist run-of-mine coal, crushed coal, and also waste rock from underground coal mines. The types of hydraulic hoist systems may be classified as shown in Table 5-3.

Hydraulic hoisting of coal most often utilizes centrifugal coal pumps with flow rates up to 1400 m³/hr (6150 gpm) with head up to 320 m of water (1050 ft or 455 psi). However, airlift and batch feeder systems are sometimes used.

5.12.1 Coal Pump Hydrohoist (Data Sheet 5.12.1-1)

Centrifugal coal pumps are used to pump slurry from a sump near the bottom of the mine shaft. A crusher must be used at the point where coal is fed to the slurry sump to reduce lump size to an acceptable value for the pump and pipeline (e.g., 75 to 90 mm or 3" to 3.5"). Generally, lump size should not exceed one third the pipe diameter. If the pumping height is excessive for a one or two stage pump,

Table 5-3
CLASSIFICATION OF HYDRAULIC HOIST SYSTEMS

A. Continuous Flow Systems

1. Coal Pumps
2. Airlift
3. Jet Pump
4. Mechanical Dry Coal Feeders
(Plunger, screw, rotor,
drum, etc.)

B. Batch Feeder Systems

1. Bin Feeders
2. Lock-Hopper Feeders
3. Pipe Feeders

sumps may be provided at intermediate horizons for collecting and repumping coal slurry. It is also possible to combine coal pumping with airlift.

Coal pumps have been built for lifting coal up to 200 meters (656 ft). By putting pumps in series or with intermediate pump levels, a total lift of 400 m (1312 ft) is possible.

5.12.2 Airlift Hydrohoist (Data Sheet 5.12.2-1)

An airlift is a relatively simple system for hoisting slurry from a mine. The shaft must be deepened to provide a deep sump (50 to 100 m or 165 to 330 ft deep) below the working level of the slurry surface to provide hydrostatic head. Compressed air is injected into a mixer near the bottom of the upflow pipeline to decrease the effective slurry density and permit flow by gravity. One air lift stage can lift up to 300 m (1000 ft) if the depth of the sump is 20 to 50 percent of the lift height. At greater heights of hoisting, a combination of coal pumps and airlift can be used, or multiple stages of airlift. With multi-stage airlifts, an air separator is installed at the end of each stage. Airlift may be used in vertical shafts or inclined shafts at a pitch greater than 55°. At lower angles, the air may separate and bypass the slurry.

The advantages of airlift are reliability and simplicity, and the small amount of equipment to be installed underground. The disadvantages are low operating efficiency, need for a larger cross-section and depth of shaft, and high operating costs for the air compressor.

Airlift has also been used in down-the-borehole mining of phosphates by Dresser Industries (Ref. 705 and 769) with small heights of hoisting.

5.12.3 Jet Pump (Data Sheet 5.12.3-1)

A jet pump can be used to hoist slurry, usually to a small height. A jet pump uses a high pressure jet of water directed into a venturi throat to produce a vacuum and aspirate slurry or air or both. The throat is followed by a mixing and diffuser section which recovers not more than about 20 to 40 percent of the hydraulic head of the jet.

An example of a jet pump system is the Dynajet made by the Marcona Corporation which is used for transport of phosphates, iron ore, and other slurries. Experiments are underway for transport of coal.

In the USSR, a jet pump system (a "hydraulic elevator") was developed to haul waste rock to a small height (4 m or 13 ft) and move it laterally into a heading for stowing while driving development headings (Ref. 739, p. 38).

A jet pump may be used alone or in combination with airlift to hoist slurry from a hydraulic borehole mining system. Hoisting height seldom exceeds 110 m (360 ft). A jet pump has been used by A.B. Fly (Ref. 531 and 707) in a borehole hydraulic mining system to hoist cuttings of sandstone, aluminum ore and uranium ore. Jet pumps have also been used in hydraulic borehole mining of phosphates (Ref. 770).

5.12.4 Mechanical Dry Coal Feeders (Data Sheet 5.12.4-1)

Dry coals can be injected continuously into a slurry pipeline or intermittently into the slurry hopper of a batch feeder system by means of mechanical feeders. When injecting dry coal into a pressurized slurry pipe, the main problems are to prevent leakage of water and to reduce the wear of mechanical parts which move in contact with solid particles.

The main types of mechanical feeders (Ref. 739) are the rotary pocket drum feeder, the rotary plug valve feeder, and the screw feeder. It is also possible to use a piston type or plunger feeder.

One of the most practical feeders is the screw feeder which depends on forming a plug of highly compressed coal which is pushed into a flowing water stream where it forms a slurry. The plug must have low permeability to prevent escape of water into the screw.

5.12.5 Bin Feeders (Data Sheets 5.12.5-1 and 5.12.5-2)

A bin feeder (Fig. 5-6) is a vertical or inclined chamber of large size (3 m or more diameter, and 20 to 30 m long). For continuity of operation, feeders are usually in pairs which alternate. The chamber is partially filled with water, then dry coal or rock is loaded, the system is closed and purged of air, then high pressure water is injected near the bottom to wash out slurry into the pipeline. A type BP-1 bin feeder was used in the Kapital'naya No. 6 mine in the USSR to hoist rock from a 320 m depth (1050 ft) and deliver it to a tailings area at a distance of 1.5 km (0.93 mile).

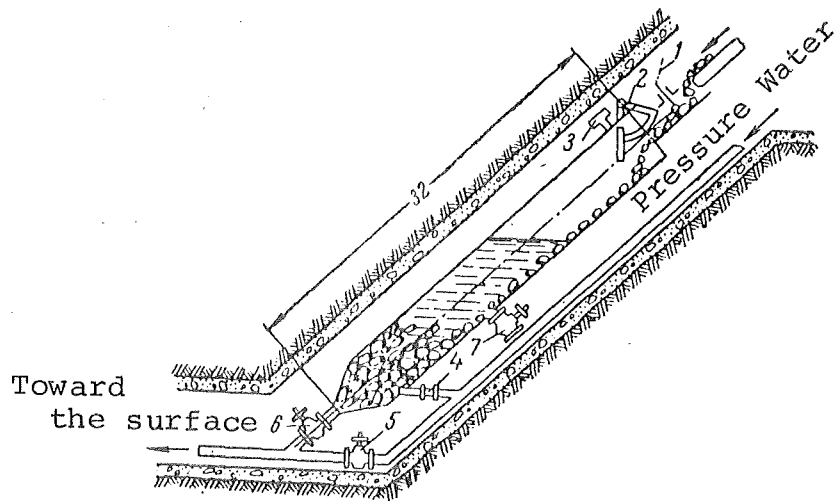


Figure 5-6

BIN-FEEDER

- 1) Gate Valve; 2) Valve; 3) Air Escape Valve or Vent;
- 4), 5), 6) Gates Regulating the Chamber Washout During Loading; 7) Drain Pipe Gate Valve

In order to hold high pressures, a bin feeder made of steel can be cemented into a rock cavity so that the rock aids in holding the pressure. The chamber pressure can be 45 kg/cm² (640 psi) with overload to 100 kg/cm² (1420 psi) if necessary to unplug a pipeline. However for deep mines, airlift or a combination of coal pumps and airlift is preferred.

5.12.6 Lock-Hopper Feeders (Data Sheets 5.12.6-1 - 5.12.6-9)

A lock-hopper feeder usually has two chambers which are alternately loaded with coal and water, then pressurized to force slurry into a pipeline. After a hoisting cycle, each chamber is left filled with mine water, which must overflow while loading dry coal. This water loss is a disadvantage of such systems. During loading, as gravity causes lump coal to settle to the bottom, fine coal may mix with the overflow and also be lost. Slurry valves for these systems tend to be unreliable. Systems of this type have been used in the USSR (Fig. 5-7) and in Poland (Fig. 5-8).

5.12.7 Pipe Feeders (Data Sheets 5.12.7-1 through 5.12.7-3)

Pipe feeders operate similarly to lock-hopper feeders except that each of two or more chambers consists of a pipe, usually along the mine floor, which is filled with high concentration slurry. Excess water is drained and then high pressure water is valved to force the high concentration slug of coal up the hoist pipeline like a piston. One pipe is being filled while a second is being discharged. Systems of this type are used in the USSR and in Germany. The Hitachi Corporation in Japan also sells pipe feeder systems of this general type called a Hydrohoist which are used for coal and other materials.

Soviet pipe feeders can operate with an operating pressure head up to 800 m (2620 ft) of water with slurry flow-rate up to 200 m³/hr (878 gpm).

The German pipe feeder in the Gneisenau mine uses two pipes, each 300 m long (1000 ft). The height of hoisting is 700 m (2300 ft) through a 200 mm (8") pipe. Two 9-stage centrifugal pumps supply water to the system with a total flow rate of 420 m³/hr (1840 gpm).

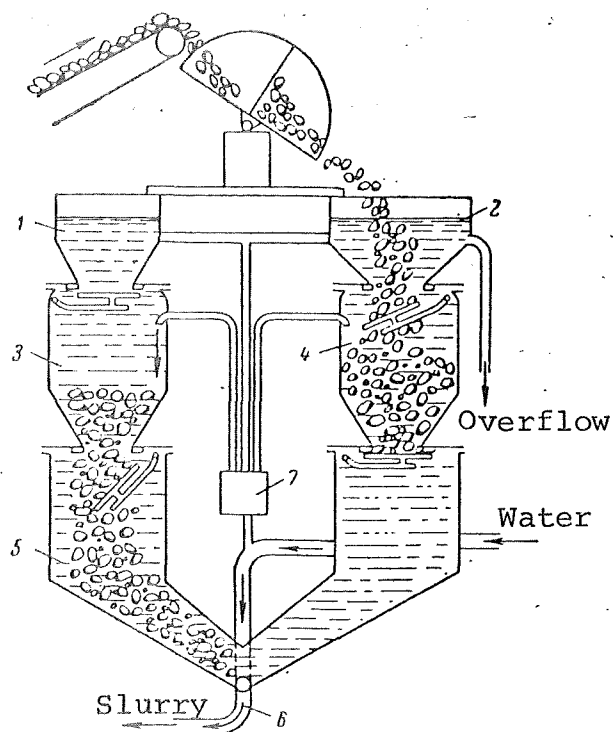


Figure 5-7
 RUSSIAN LOCK-HOPPER FEEDER
 1 & 2) hoppers; 3 & 4 pressure
 chambers; 5) unloading chamber;
 6) ring-shaped injector; 7) pump

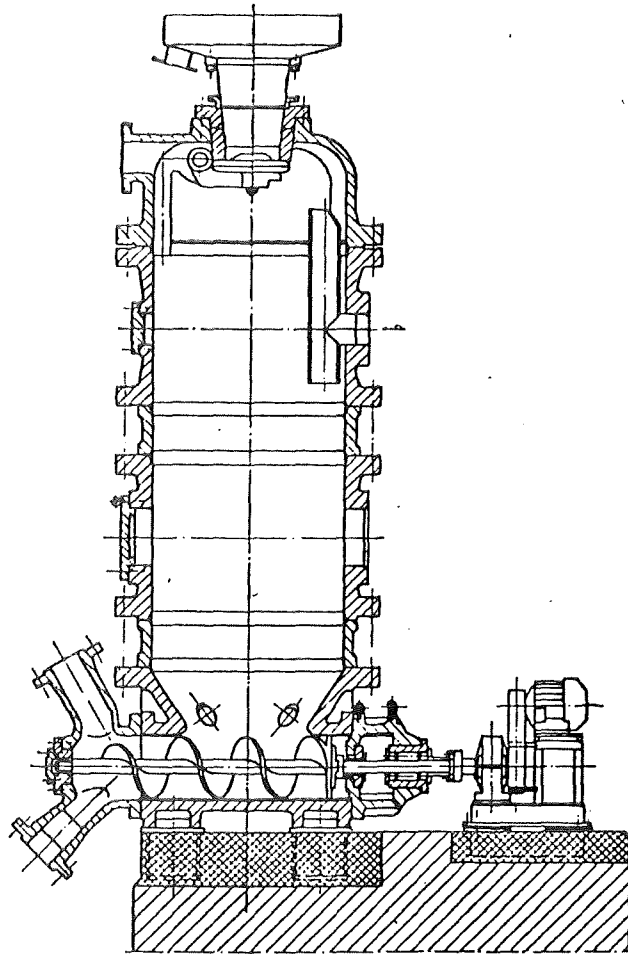


Figure 5-8
CROSS SECTION OF POLISH LOCK-HOPPER FEEDER

5.13 Slurry Pipes and Hoses (Data Sheets 5.13-1 and 5.13-2)

Slurry pipes and hoses for transport of lump coal, particularly with appreciable rock content, are subject to wear and abrasion. In the USSR more than 300 km of slurry pipelines are used in the coal industry and a 436 km pipeline is being constructed (Ref. 468).

In the German Carl Funke mine, a pipe wear of 1 mm was encountered after passing 200,000 tons of coal at a velocity of 2 m/sec. In the Gneisenau mine, a life of a million tons is expected with a 12 mm wall thickness at a velocity of 4 to 5 m/sec (Ref. 819).

In order to improve the wear resistance of pipes, the internal surface may be clad with a hard steel, with the outer shell providing strength and toughness. Soviet tests showed that the life of rolled and welded bimetallic pipes was 3 to 6.7 times longer than the usual low-carbon steel (Ref. 468). They are comparable in performance to bimetallic pipes made in East Germany and France by centrifugal or static casting, are available in lengths longer than 4 m (up to 12.5 m), and do not have to be tempered. They are now in production in the USSR.

In order to extend the life of pipes used in horizontal service, they are usually rotated periodically to achieve more uniform wear. The use of slip-on flanges is advantageous for this reason.

Hoses of 10 inch size made by Goodyear are used by Consolidation Coal for coal slurry haulage. Data on resistance to wear and abrasion is not available. Flexible water or slurry connections can also be provided to mining machines by the use of pipe sections connected by swivel joints (e.g., with pipe in a helical form, like a spring, with two rotary joints per turn).

5.14 Slurry Valves and Fittings (Data Sheets 5.14-1 through 5.14-10)

Slurry valves are used in connection with batch feeders of coal and a variety of types have been developed. Valves which have seats which must crush coal to close are unreliable and require high closing force. Valves with rotating or sliding closures are preferable. In some cases water may be used to purge the seat area during closure.

Another type of valve uses a cylindrical rubber sleeve which is collapsed to cut off flow by applying an external pressure. This type gives a very low obstruction to the flow when open.

5.15 Crushers, Feeder Breakers, Screens, and Sieves (Data Sheets 5.15-1 through 5.15-10)

Feeder breakers may be used to crush coal from a monitor and regulate its flowrate into flumes to avoid clogging (as in the Kaiser Hydraulic Mine No. 1).

Crushers are used at the point where run-of-mine coal from flumes is fed to a mine slurry sump. If the coal is to be hoisted by coal pumps, the slurry is dewatered on screens, the underflow going to the sump and the lumps reduced by a crusher to less than 75 to 90 mm (3" to 3.5") before entering the sump.

If hoisting is done by pipe feeders, larger lump sizes may be acceptable, up to about one-third the pipe diameter.

5.16 Water Pumps (Data Sheets 5.16-1 through 5.16-12 for centrifugal pumps and 5.16-13 through 5.16-14 for other types)

Water to operate monitors underground is usually supplied by pump stations located on the surface. Each monitor requires a flowrate of up to about 350 m³/hr (1530 gpm) at a pressure up to 120 kg/cm² (1700 psi). With more than one monitor, water use is scheduled to various mine sections.

The mine water pump station takes clarified water from settling basins on the surface and delivers it to the mine pipe range.

The high pressure pump stations of Soviet hydromines typically use multi-stage centrifugal water pumps (Fig. 5-9) having up to 10 stages, with spare units to meet repair and standby requirements. Data on Russian centrifugal water pumps is shown in Table 5-4 (Ref. 742, p. 6). The 6MS-7-10 pump has a flowrate of 173 m³/hr (767 gpm) at 430 m head (610 psi) and operates at 1500 rpm with a power input of 320 kw. The 12MS-7X8 has a flowrate of 800 m³/hr (3500 gpm) at 100 m head (1420 psi).

No.	Type of Pump	Output, m ³ /hr	Pressure Head (m. of Water)	Rotation Velocity, RPM	Power kw	Mass, kg
1	3MS-10-3	34	69	2950	10	213
2	3MS-10-10	34	230	2950	34	409
3	4MS-10-2	60	66	2950	17	220
4	4MS-10-10	60	330	2950	83	520
5	5MS-10-2	105	98	3000	55/50	480
6	5MS-10-10	105	490	3000	250/250	1086
7	6MS-7-2	175	86	1500	75/75	639
8	6MS-7-10	175	430	1500	320	1620
9	6MS-10-7	175	476	3000	320	1234
10	6MS-10-10	175	680	3000	500	1552
11	8MS-7×2	230	120	1500	160	—
12	8MS-7×10	230	600	1500	800	—
13	12MS-7×2	800	250	1500	—	—
14	12MS-7×8	800	1000	1500	—	—

Table 5-4
 TECHNICAL CHARACTERISTICS OF TYPE-MS PUMPS

Annotation. The first numeral denotes the rounded diameter of the inlet pipe in mm, reduced 25 times; MS denotes the types of pumps (Multistage, Sectional); the numeral 7 is the high-speed factor, decreased 10 times and rounded off;

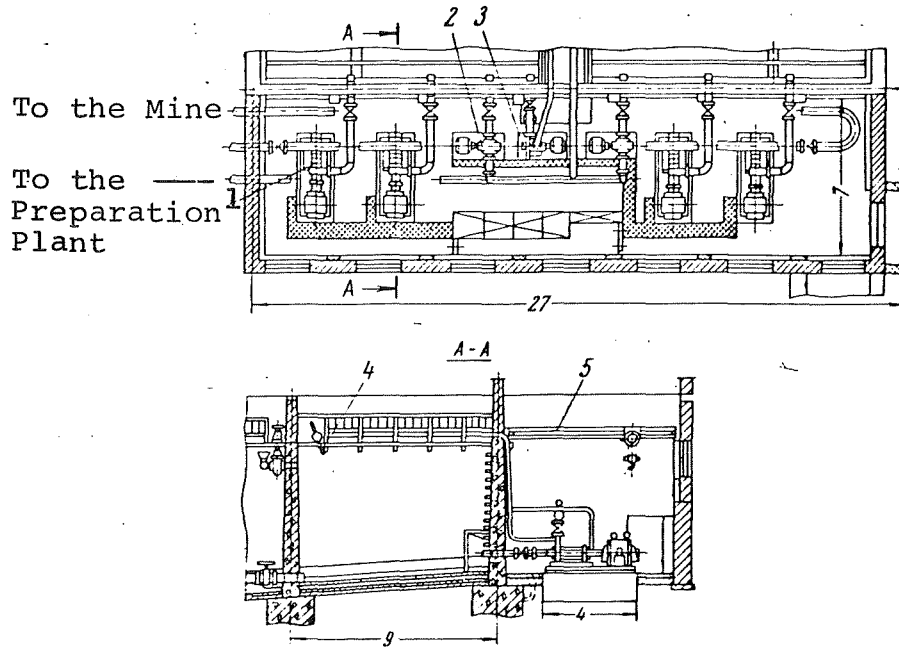


Figure 5-9
 HIGH PRESSURE PUMPING STATION
 1) main centrifugal pump; 2) 8NDV pump; 3) KSM-pump;
 4) monitor; 5) crane-girder of 3 t loading capacity

Piston pumps are also used extensively in the USSR for low flowrates e.g., 120 m³/hr (526 gpm) at a head of 950 m (1350 psi).

The USSR has also developed an axial flow water pump using multi-stages of blades and stators (Data Sheet 5.16-14). Its flowrate is 200 to 300 m³/hr (880 to 1320 gpm) at a head up to 1050 m (3600 ft or 1560 psi).

The water pump used in the Kaiser Hydraulic Mine No. 1 in British Columbia was made by Ebara in Japan. It is a 7-stage centrifugal pump with a flowrate of up to 1500 gpm at pressures up to 2000 psi and is driven by a 2500 hp motor (Ref. 1100).

Ingersoll-Rand, Wilson-Snyder, and Worthington in the U.S. make multi-stage centrifugal pumps which could be used to supply water for hydraulic mining. For example, the Ingersoll-Rand 4X9NH10 pump has a flowrate of 228 m³/hr (1100 gpm) at a head of 1410 m (4630 ft or 2000 psi). The estimated cost of such a pump with 2000 hp drive is about \$73,000 with stainless steel internal components for corrosion resistance.

5.17 Water Supply, Recycling, and Disposal

Hydromines are usually supplied with water from nearby rivers, lakes, or other reservoirs and the mine water is usually recycled. For mines with a large water inflow which must be pumped out, such as the German Gneisenau mine, part may be used for hydromining if adequate disposal facilities are provided for the slimes.

For a hydromine using monitors, water from a source goes in sequence to the water level maintenance pump station, the mine water reservoir, the high pressure pump station, the monitors, the feeder breakers (if used), the flumes, the crushers, the coal pump sump, the hydraulic hoist system, the settling basins and preparation plant (if any), then back to the mine water reservoir.

Mine water reservoirs are usually built in pairs under roof for all weather operation, one in operation while the second is being cleaned by a water jet with the slime sent to the coal settler.

Water to be supplied to monitors should normally contain less than 20 grams of solids per liter, and is usually clarified to 0.9 to 6 grams per liter. In some Soviet mines, slime containing 30 to 50 grams per liter is used (3 to 5 Percent) but this wastes power and causes more wear of equipment. Flocculating agents like polyacrylamides may be used to clarify to 0.5 to 1 gram per liter.

5.18 Electrical Equipment

Large hydromines require two or more water pump motors on the surface with total power required of 1000 to 5000 kw or more. Spare units are supplied for standby and repair requirements. In Soviet hydromines, electrical power is almost totally absent in underground production and development headings, but is supplied at 6 kv to drive the underground coal pumps and the main ventilation fans. Equipment in production sections is often powered by water turbines, e.g., for mining machines, fans and generators to provide lights. Turbine exhaust water from mining machines is used for fluming.

Soviet coal pumps are driven by asynchronous motors with phase rotor and surface high pressure water pumps with synchronous motors (3000 kw). Soviet hydromines as a rule have two separate electrical power transmission lines to supply reliable power to the mine.

5.19 Auxiliary Equipment (Data Sheets 5.19-1 through 5.19-21)

Some of the auxiliary equipment used in Soviet hydromines is listed below:

1. Manual and water hydraulic powered core drills
2. Diesel powered monorail units to transport timber, pipes, monitors, and other equipment in headings at pitch angles of 12° to 30°. Types DMV and DMV-5 use oil hydrostatic transmission of power to the drive wheels.
3. Cable transport systems using wire rope.
4. Flywheel-powered monorail transport vehicles. These use a flywheel driven by a water turbine to store energy which is later extracted to supply traction power.
5. Monorail tracks mounted on the high pressure pipe system or on separate supports.
6. Manual winches to move loads on monorails by cable

7. Hydro-illuminators which use a water turbine to drive a generator and supply light for use at the faces where hydro-breaking is done
8. Hydro-ventilators which are water turbine driven fans to provide local ventilation
9. Pneumatic fans for local ventilation
10. Water infusion test devices to measure specific water absorption of coal seams to determine the water pressure required to break coal and the need for pre-loosening by water infusion or blasting
11. Pumps for operational water infusion of coal seams
12. Hydraulic excavators (or dredges) to suck coal from sumps and feed it to the suction of coal pumps for hydraulic hoisting.

5.20 Coal Preparation and Dewatering (Data Sheets 5.20-1 through 5.20-2)

Although a survey of the field of coal preparation and dewatering was not within the scope of this study, some of the references which are relevant to preparation of coal from hydromines are included in the accessions (e.g., Ref. 422, 461, 467, 477, 506, 539, 567, 568, 627, 700, 741, 742, 811, 819, 830, 981, 1047, 1049, and 1127).

The ideal goal for a hydromine with or without a coal preparation plant should be to recycle all water with minimum makeup water and with no discharge of water from the system, in accordance with EPA requirements. This goal will be very difficult to achieve even for a typical preparation plant which requires a tailings pond to receive fine slimes. Such a pond requires a large area and may be subject to overflow of polluted water in case of a storm.

The economic feasibility of a suitable dam for refuse impoundment depends on the terrain, hydrology, and availability of local materials for dam construction. The midwestern U.S. provides generally better conditions than the Appalachian area in this regard.

There are a variety of approaches to dispose of coal slimes. They include:

1. Dewatering by various methods to recover useable coal as damp solid or slurry (for burning in boilers)
 - A. Mechanical dewatering by vacuum filters, centrifuges, or pressure filters
 - B. Thermal dewatering
 - C. Open pond evaporation
2. Dewatering to permit permanent impoundment (In situ or other dewatering to permit permanent stowage in refuse impoundments, with adequate dams for protection against runoff)
3. Chemical treatment, usually by use of solids, to form
 - A. Stable solid for permanent storage on surface
 - B. Useable or saleable product, e.g., aggregate
4. Underground disposal, e.g., by stowage in a mine.

The system used to dispose of slimes from slurry transport in the Black Mesa pipeline includes drying by cyclones, open pond evaporation, then combustion of the wet slurry as a secondary fuel by direct injection into power plant boilers. This system permits no discharge of polluted water from the system.

Since some of the major problems of hydromining relate to dewatering and drying of coal and to processing and disposal of slimes, these areas of technology should be surveyed more completely in the future.

5.21 Long Distance Hydrotransport by Slurry Pipeline

Hydrotransport of minerals, coal and overburden by pipeline is widely practised in many countries. It is not possible to review here the extensive literature which was outside the scope of this survey. However, some of the more significant references are included in proceedings of the conferences on hydraulic transport of solids in pipes sponsored by the British Hydromechanics Research Association (Ref. 756 and 622) held in 1970 and 1972. A paper on coal pipelines was published in 1969 (Ref. 301). Additional references on pipelines include Ref. 185, 468, 472, 536, 542, 543, 567, 585, 594, 639, 677, 696, 714, 718, 720, 721, 728, 729, 730, 731, 736, 737, 738, 739, 750, 753, 757, 758, 760, 761, 763, 764, 772, 773, 778, 779, 780, 823, 824, 835, 839, 841, 843, 844, 870, 898, 908, 865, 1027, 1030, 1031, 1037, 1038, 1048, 1050, 1056, 1057, 1059, 1172, 1173, 1174, 1175, 1176, 1177, 1178, 1179, and 1180.

5.22 Coal Slurry Pumps for Pipeline Service (Data Sheets 5.22-1 through 5.22-4)

Reciprocating pumps cannot handle lump coal and therefore are not used underground in hydromines.

However, reciprocating piston or plunger pumps are usually used for long distance slurry transport with finely ground particles. Large particles and particularly abrasive rock particles are not easily handled by the check valves which wear rapidly. By using a reciprocating pump with constant volume flowrate, the danger of silting out and plugging of a pipeline is less than with centrifugal pumps.

In the U.S., Wilson-Snyder plunger pumps (450 hp) were used on the Consolidation Coal slurry pipeline (108 miles) to Cleveland. Wilson-Snyder 1500 and 1750 hp piston pumps are used on the Consolidation Coal Black Mesa pipeline (273 miles). In both cases, particle sizes were limited to 14 mesh. Wilson-Snyder 300 hp reciprocating pumps were also used on the American Gilsonite Company pipeline (72 miles) to transport Gilsonite slurry of less than 4 mesh size.

A survey of slurry pumps for pipelines was published in 1972 (Ref. 758).

6.0 METHODS FOR OPENING COAL SEAMS

6.1 Geologic and Technical Factors

In underground hydraulic coal mining, the mine opening by shafts and inclines may be done by similar methods as in conventional mines. However, hydraulic fluming requires control of the pitch angle of all drifts and entries. The cross section of shafts and underground openings is generally determined by air ventilation requirements and not by transport requirements or size of equipment.

The main geologic factors affecting the method of mine opening are:

1. Angle of pitch, thickness, and number of minable seams
2. Distance between extreme seams to be mined
3. Thickness of overburden and maximum depth of mining
4. Presence of water-bearing soils in the overburden
5. Faulting of the seam
6. Methane content of the seams.

The technical factors affecting the method of opening are:

1. Production rate and coal reserves
2. Size of the mine field
3. Method of hoisting coal (coal pumps, airlift, or batch feeder)
4. Methods of face and main haulage and materials transport.

6.2 Production Rate and Coal Reserves

In the USSR, it is recommended that each hydromine or each block of a "hydromine complex" using hydraulic hoisting should have a production rate of 0.5 to 1.5 million metric tons per year with reserves of 12.5 to 75 million metric tons, permitting a life of 25 to 50 years. The life of each opened level in one mine may be 5 to 10 years.

For mines not requiring hydraulic hoisting, smaller reserves, and higher production rates may be feasible because of the lower capital investment.

6.3 Hoisting Requirements

The most significant factor affecting the method of development and the production costs of coal is whether the seam deposits and topography permit fluming coal out of the mine without the need for hoisting. The cases where this is possible are limited, but when it can be applied, the capital and operating costs for hydraulic hoisting can be eliminated and the time required to put the mine on production can be reduced. An example of such a case is the Kaiser Hydraulic Mine No. 1 at Sparwood, British Columbia. Many hydromines in New Zealand in the time period prior to the 1950's also flumed coal (which had been blasted) to the portal using relatively simple methods. Apparently all other existing hydromines require hoisting, which is done hydraulically.

The type of hydraulic hoist system to be used affects the selection of the depth of shaft and the need for intermediate hoisting horizons. The desired production rate affects the size of flumes and the pitch angle of drifts for fluming. For steam coal, the size of the lumps should be large, so in some mines, coarse lumps (which would be broken by pumping) are dewatered on screens at the shaft bottom and are separately hoisted by skip, with hydraulic hoisting of fines. This method has been adopted in the USSR for anthracite hydromines, and is used in China and Japan.

The choice of a hydraulic hoist system is primarily a question of economics. A batch-feeder system generally requires the highest costs for underground installation because of the large openings required and the heavy equipment to be brought to the shaft bottom. Coal slurry pumps are less expensive to install. An airlift system has the lowest capital investment but usually higher operating costs than coal pumps. In the USSR, coal pump systems are the most

highly developed and widely used, but are limited to shaft depths of 400 to 500 m (1310 to 1640 ft). For large depths over 1000 m (3290 ft) it is advisable to use multi-stage airlift or combined coal pump and airlift systems.

6.4 Underground Haulage Requirements

Main haulage of coal in hydromines may be accomplished by open flumes, gravity pressurized pipes, pumped flow in pipes or hoses, or by combined methods (e.g., coarse grades of partially dewatered coal may be hauled by conveyor or in mine cars, with fines hauled as slurry).

Fluming requires an inclination of 5 percent to 14 percent (3° to 8°) for all haulage openings. This is too steep for rail haulage. Materials are usually handled in Soviet hydromines on monorails or cableways. When main headings have a normal slope for rail transport (near 0.5 percent), slurry must be pumped through pipes.

In excavating a series of seams over a large vertical depth, it may be advisable to drop slurry from an upper seam to a lower seam by gravity pressurized flow. The liquid head due to vertical drop can then also move slurry through horizontal pipes.

Fluming is the most efficient method for small mine fields, roughly 2 to 4 km (6560 to 13,100 ft) on strike.

6.5 Methods for Opening Coal Seams by Shafts

A summary of the main methods for opening coal seams by vertical and inclined shafts (slopes) to permit hydraulic hoisting by coal pumps is given in Table 6-1.

6.6 Mine Development and Mining Plans

A mine is divided into parts called levels or panels. When divided down the dip into sections which extend on strike (Fig. 6-1) the sections are called levels, each with a lower haulage drift and upper ventilation drift.

When divided into parts on strike (Fig. 6-2) the sections extending up rise or down dip are called panels.

In the panel method, water pipes are installed only once in the drifts, whereas in the level method, pipes must be moved from one level to another.

Table 6-1
METHODS FOR OPENING COAL SEAMS FOR COAL PUMP HOISTING

1. Gently Pitching Seams (3° to 18°) And Pitching Seams (18° to 50°)
 - A. Thin Seams (0.6 to 3 m) with Mine Field Lengths On Dip Less than 1.5 to 2.5 km
 1. Two inclined shafts in seam, one for hydraulic haulage and exhaust air (lump coal may be hauled on conveyor)
 - B. A Single Gently Pitching or Pitching Seam - Two Vertical Shafts
 - C. A Series of Gently Pitching Seams
 1. Two vertical shafts with crosscuts at 5 per-cent slope
 2. Two vertical shafts with a main gravity slope and an exploring shaft
 - D. Large Area Mine Fields - Multiple Blocks, Each with a Coal Pump Station Forming a "Hydromine Complex"
2. Steep Seams (50° to 90°)
 - A. Vertical Shafts and Level Crossheadings
 - B. Inclined Shafts On-Dip with Crossheadings (For Mining 1 to 3 Seams at Small Depth)
 - C. Diagonal Inclined Shafts (At Pitch of 16° to 17°) For Large Production Rates
 - D. Two Central and Two Flank Vertical Shafts with Level Main Crossheadings for Locomotive Haulage with Monorails in Intermediate Drifts and Entries.

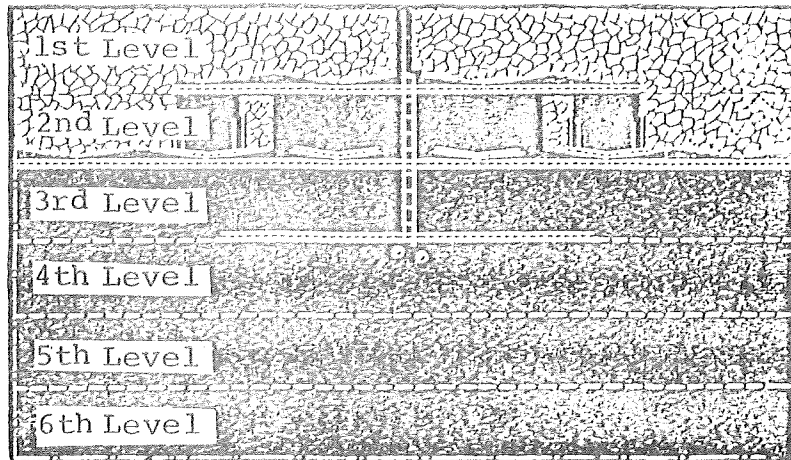


Fig. 6-1 Level Method of Development of a Mine

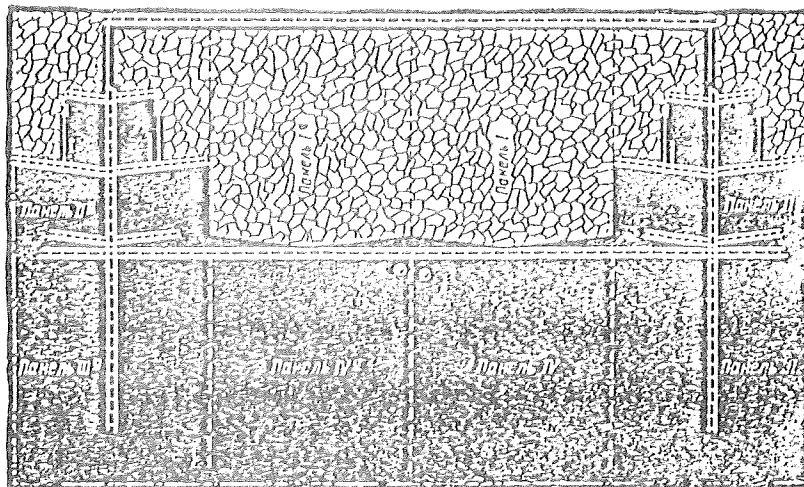


Fig. 6-2 Panel Method of Developing a Mine

The level method is applicable for small mines (less than 3 km on strike) with only one level. For larger mines it is preferable to use the panel method with pressurized pipe hydrotransport of coal to the shaft bottom.

6.7 Sequence of Mining Seams

Closely spaced seams should be mined so as not to undermine higher seams. Mining of seams may occur in groups to increase production rates with group drifts driven along the lowest coal seam which will avoid undermining higher seams (or driven in a layer of stable rock).

7.0 MINING PLANS AND MINING METHODS

Most hydromines use mining plans which are similar to shortwall or room and pillar methods. For steep seams, mining is by sublevel. A large amount of development driving is required using monitors or mechanical mining machines. Coal winning usually occurs in retreat, with controlled caving of the roof. A detailed discussion of Soviet mining plans and methods is given in Ref. 736. Table 7-1 lists the main types of hydraulic mining plans which have been used. A brief summary of the major characteristics of some of the most widely used plans is given below.

7.1 Long Pillars Up-Dip

One common mining plan for gently pitching seams is shown in Figure 7-1. From the bottom of the main incline, main (accumulating) drifts, and parallel cross drifts are given at an angle above strike to permit fluming. The lower accumulating drift is for slurry flow and the upper for movement of men and supply of materials. A parallel ventilation drift is driven to define the upper boundary of the panel. Stopping entries are driven up-dip to define long pillars to the rise of 12 to 18 m width. Cross-cuts are driven between adjacent stopping entries to provide ventilation and to define lifts to be mined by monitor. Stopping is done by two men operating a monitor remotely from near the upper end of the entry which has roof support. Stopping is done in retreat down dip, removing coal from half the pillar and allowing the roof to cave. The monitor may be used on both sides (bilateral) or on one side (unilateral) of the entry. Stopping is done in "lifts" of size determined by the range of effectiveness of the monitor jet.

Depending on roof rock conditions, open or closed lifts are used (Fig. 7-2). With open lifts, coal is stoped from the upper side adjacent to the goaf, without roof support. In closed lifts, the face is protected from premature caving by leaving a stump or coal pillar on the goaf side to be stoped last.

For hard coal, mining may be done with drilling and blasting of coal prior to washout with a monitor, which may be at a reduced pressure (50 kg/cm² or 710 psi). Preloosening of coal may also be accomplished by drilling the seam and infusing high pressure water which fractures the seam.

Table 7-1
SUMMARY OF HYDRAULIC MINING PLANS
FOR VARIOUS TYPES OF COAL SEAMS

1. Gently Pitching Seams (5° to 25°)
 - A. Long Pillars Up-Dip
 - B. Long Pillars On-Strike
 - C. Room and Pillar
2. Gently Pitching Seams (20° to 25°)
 - A. Long Diagonal Pillars
 1. Unilateral extraction in lifts down-dip
 2. Unilateral extraction in lifts up-dip
3. Gently Pitching Seams of Hard Coal Of Low And Medium Thickness (0.9 to 3 m) With Support Of The Face
 - A. Long Pillars Up-Dip - Shortwall in Retreat with Powered Roof Supports
 - B. Room and Pillar, Developed On-Strike - Polish Methods
4. Gently Pitching Thick Seams (Over 3.5 m)
 - A. Long Pillars On-Strike - Development by Mining Machines
 - B. Room and Pillar (3 to 12 m at 5° to 20°)
 - C. Long Pillars Up-Dip Using Monitors with Coal Face Inclined Toward Goaf
 - D. Long Pillars Up-Dip - Mining in Layers with Flexible Canopy
 - E. Diagonal Pillars with Flexible Canopy
5. Pitching And Steep Seams (40° to 90°) Of Small And Medium Thickness (Over 0.8 m)
 - A. Long Pillars Retreating On-Strike - Sub-level Hydrobreaking
 - B. Long Pillars Retreating On-Strike - Blasting and Fluming

Table 7-1 (Continued)

- C. Long Pillars Advancing On-Strike - Blasting and Fluming
 - D. Long Pillars On-Strike - Multi-jet Monitors Suspended on a Hose
 - E. Long Pillars Retreating On-Strike - Using Metal Arch Shields - Blasting and Fluming
 - F. Long Pillars Retreating On-Strike - Using Air Inflated Balloon Canopy - Blasting and Fluming
6. Pitching And Steep Seams Of Large Thickness (Over 3 m)
- A. Sublevel Mining of Long Pillars Retreating On-Strike - Sublevel Hydrobreaking in Ascending Order
 - B. Sublevel Mining of Long Pillars Retreating On-Strike - With Blasting and Fluming
 - C. Sublevel Mining of Long Pillars Retreating On-Strike - With Multi-Layer Development for Seams Over 8 m Thick
 - D. Sublevel Mining of Long Pillars Retreating On-Strike - With Crossheadings Across Seam to Improve Ventilation
 - E. Sublevel Mining of Long Pillars Retreating On-Strike - In Double Layers Under a Flexible Metal Canopy in Two Planes (for pitching seams up to 65°)
 - F. Sublevel Mining of Long Pillars Retreating On-Strike - But Canopy Only on Top Plane (for seams over 65°)
 - G. Sublevel Mining of Long Pillars Retreating On-Strike - Short Monitors Under Shield with Face Support Stull, with or without Blasting
 - H. Sublevel Mining of Long Pillars Retreating On-Strike - Jet Cutter Unit (HSU) to Undercut Coal
 - I. Shortwall Mining - Using Self-Advancing Roof Supports and Mechanical or Jet Cutting (e.g., Sh GKV Unit)

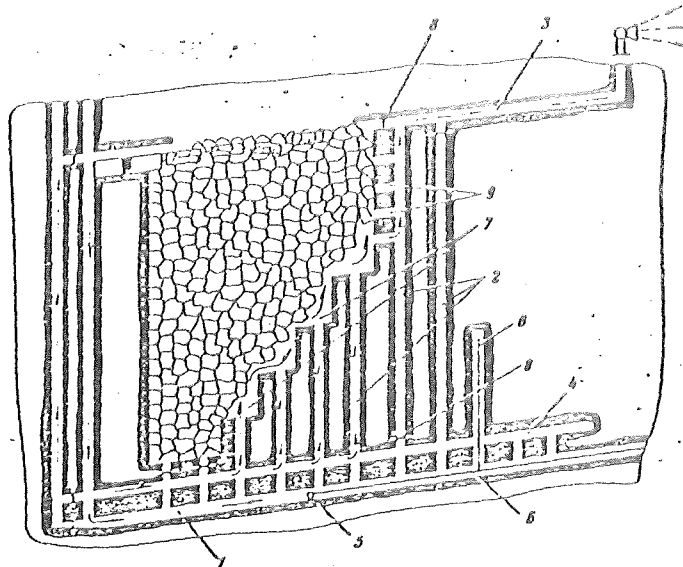


Figure 7-1

SYSTEM OF RETREAT MINING OF LONG PILLARS (TO THE RISE)
WITH EXCAVATION OF COAL IN DOWN-DIP "LIFTS"

- 1) Main (Accumulating) Drift
- 2) Stopping Entries
- 3) Ventilation Drift
- 4) Cross
- 5) Ventilator
- 6) Ventilation Pipes
- 7) Working Faces
- 8) Cofferdams (or Barriers)
- 9) Crosscuts

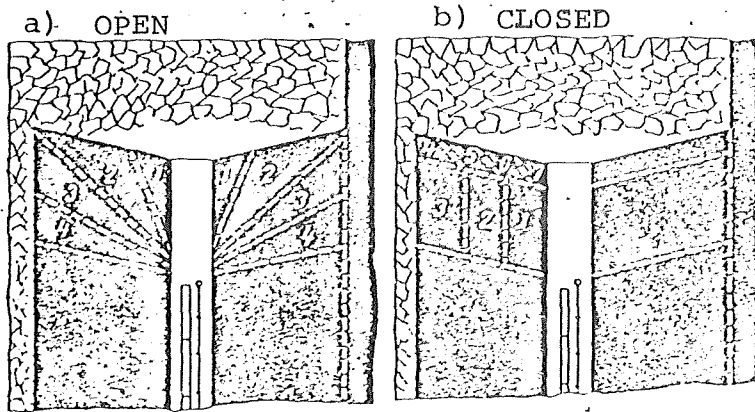


Figure 7-2

DEPLETING COLUMNS WITH OPEN AND CLOSED "LIFTS"
 1 - 7: SEQUENCE OF EXCAVATING COAL IN THE ADVANCE

With seam thickness over 0.8 m, mechanical cutting of coal may be considered with fluming. This is called mechanical-hydraulic mining (Fig. 7-3). This method was developed in 1960 in the Soviet "Zarechnaya" (previously called Polysayevskaya-Severnaya) mine, using the K-56 mg and PK-3 mechanical mining machines. The seam thickness is 2.3 m (7.5 ft) at a pitch of 6°.

7.2 Long Pillars On Strike

A second type of mining plan for gently pitching seams (6° to 25°) of 1 to 3.5 m thickness uses long pillars on strike (Fig. 7-4). The distance on strike between main entries may be 40 to 100 m. Small area cross drifts are driven from entries half way to the next entry (20 to 50 m). Mining is done in retreat using closed lifts. This system is desirable to take advantage of the higher production rate possible when aiming the monitor up-dip approximately parallel to the cleat plane of the coal. The system is applicable for roof rock of average or good stability.

7.3 Room and Pillar System

For gently pitching (5° to 20°) seams 0.8 to 1.3 meters thick with stable floor, mechanical cutting may be used with a room and pillar system (Fig. 7-5). The mine is developed in panels which are divided into stories on-dip by pairs of drifts. (The lower in each pair is for slurry accumulation and the upper for men, materials, and ventilation.) The mechanical mining machine can be a water turbine powered unit with the waste water used for fluming. The machine is remotely-controlled and rooms are cut in lifts or strips on dip. The main problem is adequate face ventilation, which is provided by water turbine powered fans (hydroventilators).

7.4 Sublevel Mining of Steep Seams

For steep seams generally over 45° to 50°, a variety of sublevel mining methods have been developed. Each sublevel is defined by subdrifts about 7 to 15 m apart on dip at the proper angle for fluming. The length of subdrifts may be 150 to 250 m (500 to 800 ft) or more. Monitors operate in each drift, aiming upward to wash down coal, then retreating after each lift with removal of roof supports for the next lift. The main block entries may be too steep for open channel slurry flow, in which case pipes or boreholes are provided to drop slurry. Subdrifts may be driven from only one side or from both sides of the main block entries.

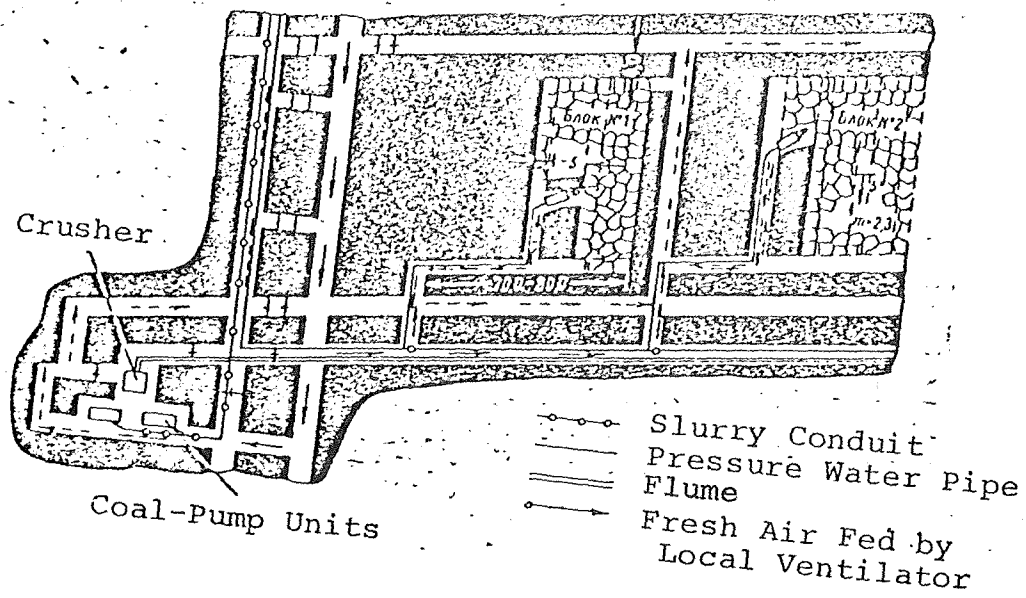


Figure 7-3

SYSTEM OF MINING WITH LONG PILLARS (TO THE RISE) USING
 MECHANICAL-HYDRAULIC EXCAVATION OF COAL DOWN THE DIP.

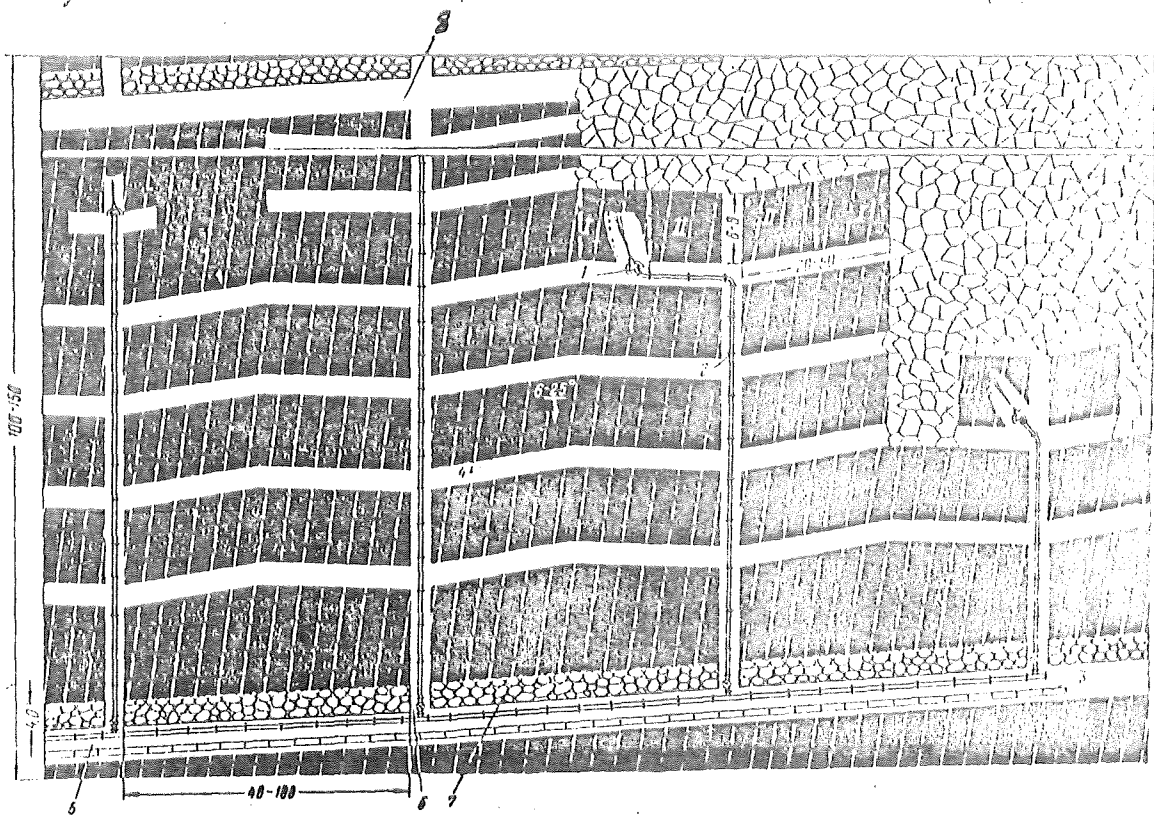


Figure 7-4

MINING SYSTEM WITH LONG CROSS-PITCH PILLARS USING BILATERAL
HYDRAULIC EXCAVATION OF COAL IN LIFTS ACROSS THE PITCH:

I AND II - ORDER OF EXCAVATION OF LIFTS;

1) monitor; 2) water pipe; 3) flume;

4) basic innate jointing; 5) main drift;

6) stoping entry; 7) cross; 8) airway drift

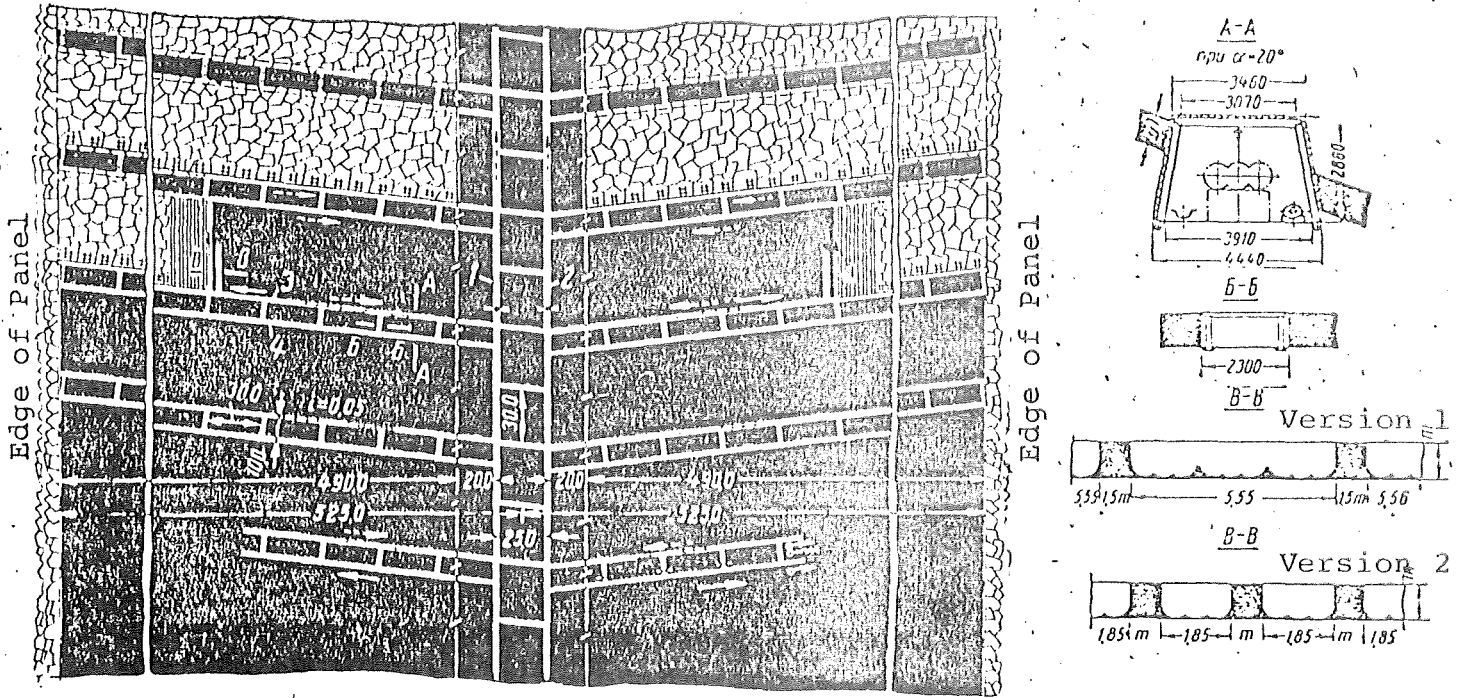


Figure 7-5

ROOM AND PILLAR SYSTEM WITH EXCAVATION OF ROOMS TO THE RISE
BY THE KG COMPLEX:

- 1) bremsberg (gravity slope) with rails;
- 2) slurry bremsberg (gravity slope;
- 3) story accumulating drift; 4) cross

- panel boundary
- ⊙ hydro-ventilators
- · - · boundary of protective pillars
- ← direction of slurry movement
- ⊕ hydromonitors
- ⊙ hydro-drill
- ≡ flume

A variation of this method and one of the most successful mines of this general type is the Kaiser Hydraulic Mine No. 1 at Sparwood, British Columbia (Ref. 1100). This mine uses flumes in the subdrifts and main roads at 7° pitch to flow coal all the way out of the mine without hoisting.

Methods have been developed in the USSR to mine steep seams of complex structure containing interlayers of rock which is abandoned in the mine (Ref. 815).

8.0 REVIEW OF WORLD HYDRAULIC COAL MINING EXPERIENCE
(Data Sheets in Appendix A, Vol. 2)

8.1 USSR

The first complete hydraulic coal mining system using high pressure water jets was designed by Prof. V.S. Muchnik in the USSR in 1935 and the first tests were conducted in the Kizel Basin in 1936-37 (Ref. 549). The first mine was constructed in the Donets Basin (Donbass) in 1939, but work was interrupted by World War II.

The Tyrganskies-Uklony hydromine was opened in the Kuznets Coal Basin (Kuzbass) in 1952, producing 500 tons per shift. The Polysayevskaya-Severnaya mine (now called Zarechnaya) in the Kuzbass was opened in 1953 and in 1956 produced 700 tons per day.

Professor Muchnik was active in promoting hydromine technology and directed the Hydraulic Coal Mining Institute (VNIIGidrougol) in Novokuznetsk, Siberia until he was replaced by G. Razgildeev in 1973 (who was replaced by A. Gontov in 1974). One of Muchnik's key associates at VNII was G.P. Chermenskiy, who had worked on water cannons with Professor B.V. Voitsekhovskiy at the Institute for Hydrodynamics near Novosibirsk in the early 1960's and later served as chief engineer at VNII until 1973, when he moved to the Khmel'nitskiy Technological Institute in the Ukraine. At VNII, Chermenskiy developed water cannons, pressure intensifiers and other equipment for hydraulic mining.

Extensive research on nozzles and jet cutting systems for coal has been conducted by G.P. Nikonov of the Skochinskiy Mining Institute near Moscow (Lhubertsy) since the early 1950's. In 1968, he published a book entitled "Investigation of Hydraulic Disintegration of Coal" (Refs. 663 thru 668).

Professor G.A. Nurok of the Moscow Mining Institute has published two books dealing with hydraulic mining technology (Refs. 670 and 673). Nurok's interests are primarily hydraulic transport of overburden, rather than underground hydraulic coal mining. However, his first book (Ref. 670) includes a chapter on hydraulic coal mining.

A special institute was established at Stalinsk (Donbass) to study the problems of underground hydraulic coal extraction, transportation, and mine development (Ref. 549). Later references refer to institutes in the Donbass known as DonUGI, UKrNIIGidrougol, and DONGIPROUGLEMASH.

Several hydromines were opened in the Donbass and Kuzbass in the period 1957 to 1968. Ambitious plans were made to increase production to 45 to 50 million metric tons per year by 1965 (Ref. 548), but actual production rates did not meet projections. Total production from nine hydromines was 8 million metric tons per year in 1967. Production in the Donbass increased from 0.2 million metric tons in 1959 to 2.9 million metric tons in 1968, and was projected to reach 4.8 million metric tons in 1970 (Ref. 277). A broad experiment was conducted at ten Soviet mines to decide on the optimum mining plans. By 1972, production had increased, new mines were under construction, and the total annual production was 10.3 million metric tons from nine hydromines and from five hydraulic sections within regular mines in the Kuzbass, Donbass, and Karagandin basins.

In 1973, the temporary director of VNII, G. Razgil'deev, stated (Ref. 613) that the Ministry of Coal in the USSR made a decision in May 1973 to expand the applications of hydromechanization of underground mining. He states that under complex mining and geologic conditions, hydraulic technology permits obtaining high economic efficiency and labor productivity 1.5 to 2 times higher than with the regular method of extraction. Pneumoconiosis (black lung) is virtually eliminated and mining accidents are much less in hydromines than in other coal mines.

In 1973 plans were being made to expand hydraulic coal production in the Central Donbass, Prokopi-Kiselev and Anzhero-Sudzhen regions of the Kuzbass, and in Primorye and on Sakhalin Island, where complex mining and geologic conditions exist. Also plans were made for conversion of some mines to hydromines, and for installation of hydraulic sections to recover remaining reserves. In 1973, research on the major problems of hydromining were being worked on by the VNIIGidrougol Institute, the UKrNIIGidrougol Institute, the Laboratory of Hydraulic Disintegration of Coal and Rock of the A.A. Skochinsky Mining Institute, and the Donets Polytech and Leningrad Mining Institutes. Some of the major remaining problems are the high temperature and humidity at the face, the desire to increase coal recovery, dewatering and drying of coal, and instruments for measuring coal flow rates in slurry (Ref. 613).

In 1974 a mining engineering textbook was published in Moscow entitled "Underground Hydraulic Coal Mining," by V.A. Okrimenko, A.I. Kuprin, and I.G. Ishchuk (Ref. 733 thru 746). It presents very extensive coverage of all Soviet developments in this field, and has been an important reference in conducting this survey.

Mining conditions in the USSR are generally difficult, particularly in the Donbass where seams are in most cases gassy and thin (0.6 to 1.2 m) with only a few seams reaching 2-2.5 m thickness. Anthracite seams in the Donbass are mined for energy production and generally require blasting. Many seams are pitching at 5° to 85°. These difficult conditions have provided the incentive to develop hydraulic mining technology.

8.2 Japan

The Hitachi Company in Japan has developed hydraulic hoisting systems for slurries including alumina and coal. In 1965 to 1968 a Hitachi Hydrohoist system was tested in the Mitsui Mining Company's Sunagawa Mine in Hokkaido, which is now operating. The Japanese were active in research and testing of high pressure water jets for coal mining prior to 1965 (Ref. 715 and 717). Mitsui engineers also visited the Soviet Union hydraulic mines in the Kuzbass and carried out further development of Soviet technology for mining steeply pitching seams.

Some of the technology developed by Mitsui was later introduced into Canada by Kaiser Resources Ltd. for use in their Hydraulic Mine No. 1 (Crows Nest Mine) at Sparwood, British Columbia. Kaiser has conducted hydromining with Japanese pumps and Japanese-made monitors since opening the mine in 1970.

8.3 Canada

The major hydraulic mining activity in Canada is conducted by Kaiser Resources Ltd. In 1974, Kaiser signed an agreement with the Mitsui Mining Company of Japan and the Coal Mining Ministry of the USSR regarding exchange of technology and export of technology to Canada, the United States, and other countries.

The Kaiser Hydraulic Mine No. 1 (Ref. 1100) is probably the most successful hydromine in the world, having set a shift production record of 3485 tons of coal in one shift by one monitor crew in June 1974. Productivity is reported to average 25 to 30 short tons per man shift (overall for all 150 men at the mine).

Installation began in 1970 and total monitor production reached 802,399 short tons in 1974 plus 111,215 from development. The coal is soft and friable and easily broken by a hydromonitor jet. The mine geology has permitted fluming coal directly from the mine without hydraulic hoisting, which results in a substantial reduction of capital investment and operating costs and a decrease in the time required to develop the mine. Future development below drainage level will require hoisting. The price of the coking coal for shipment to Japan was increased to \$47 per long ton in 1975 (Ref. 1069).

Kaiser Resources is making plans for a second hydraulic mine 10 miles south of Sparwood, British Columbia which will also flume to the portal. Planned production will be 1.7 to 2.2 million clean tons per year. Kaiser will also assist Fording Coal Ltd. in engineering a mine 40 miles north of Sparwood, which will be a hydraulic mine with fluming to the portal.

8.4 Poland

Hydraulic coal mining was conducted in Poland in the period of the 1950's. Thirteen mines in the Upper Silesian coal field (Czeladz and Sierza) used these methods in 1958 (Ref. 543). The monitor technology was similar to the Russian developments. Considerable work was conducted on hydraulic hoisting by means of lock hopper feeders. Hydraulic mining was discontinued in the 1960's, but consideration is now being given to reviving the method.

Polish engineers also assisted the Chinese in establishing a hydraulic mining capability, including design of the Lu-Cja-To hydromine in 1958.

8.5 Germany

Hydraulic coal mining experiments were conducted in Germany in about 1958 in a steep pitching seam (Ref. 549). Tests were conducted in the Carl Funke mine prior to 1965 (Ref. 782). Since 1962, hydraulic mining and hydraulic hoisting methods have been developed in the Ruhr District of Germany (Ref. 387) by Ruhrkohle AG. A series of three models of monitors of successively lower weight were developed. The monitors and nozzles were improved to increase the range of action from 8 m (26 ft) to more than 25 m (82 ft).

Large scale tests have been conducted in the Carl Funke and Gneisenau mines (Ref. 819) but the Carl Funke mine has been shut down. In 1974 only one hydraulic section was operating in the Gneisenau mine, with hydraulic hoisting by a pipe-feeder system from a depth of 700 m (2300 ft).

A jet drill type monitor has been developed for use in up-raise borehole mining of thin seams (similar to the Soviet systems used in the Donbass).

A new all-hydraulic mine, the Hasner mine, is now under construction in the Ruhr to be opened in 1975. It is planned to have a 17 year life at a production rate over one million tons per year. It will use the up-raise borehole monitor method (or jet drill) for thin seams and conventional monitors for the thicker seams (over 1.2 to 1.4 m).

8.6 United Kingdom

The hydraulic mining of coal using jets was first seriously considered by the National Coal Board in England after a technical mission visited Russia in 1956 (Ref. 677). Three sites were considered for field trials and the Trelewis drift mine was chosen. Installation started in 1958 and hydraulic mining trials were carried out from June 1959 to September 1960 when the work was stopped (Ref. 542).

The system included a surface plant for water clarification and high pressure pumping, a monitor system for cutting and loading coal into an open flume, and an underground pumphouse. The large coal was separated and hoisted by conveyor and the small coal was hoisted by centrifugal coal pumps with a lift of 52 m (170 ft).

Satisfactory operation was obtained with a monitor pressure of 1000-1200 psi, but a solid stone band in the coal seam reduced the productivity to a fraction of its potential.

It was concluded that the method, as tried, might have limited application in the United Kingdom owing to the scarcity of suitable mining conditions and possible objection to the working conditions.

It may be noted that the monitor system used at Trelewis was complex and heavy by comparison with more recent Russian, German, and Japanese developments.

Hydraulic hoisting of coal was developed in England at the Markham Colliery and the Woodend Colliery in the period 1952 to 1960. The most promising design was a horizontal lock-hopper feeder which was developed, manufactured, and tested at Woodend Colliery in 1959-1960, when investigation of hydraulic transport was stopped.

8.7 United States

A literature survey on hydraulic mining and transporting coal underground was made by W.T. Boyd in 1959 (Ref. 549). The application of hydraulic mining and slurry transport of gilsonite was conducted by the American Gilsonite Company in Bonanza, Utah in the period 1949 to 1974 (Refs. 301, 536, 595, 897, 989, 990, 1037, and 1038). Although hydrobreaking of gilsonite was terminated and the 72 mile pipeline to the refinery was closed down in 1974, hydraulic haulage is now used over several miles distance from mines to the preparation plant.

A review of "Hydraulic Mining in the U.S.A." was presented by J.N. Frank, et al (Ref. 662) at the First International Symposium on Jet Cutting Technology in 1972. (also see Ref. 153). Hydraulic mining experiments have been conducted by the Bureau of Mines at the following locations:

1. West Lebanon Drift Mine, Western Pennsylvania
2. Roslyn No. 9 Mine, Washington
3. Roslyn No. 10 Mine, Washington
4. Thompson Creek Mine, Carbondale, Colorado
5. Sugar Notch Mine, Pennsylvania (Anthracite, Concrete, and Frozen Gravel)
6. Army Cold Regions Research and Engineering Lab Tunnel, Fox, Alaska (Frozen Gravel)
7. Badger Hill, California (Gravel)
8. White Pine Copper Company, Michigan (Copper Ore)
9. IIT Research Institute, Chicago, Illinois (Open Pit Coal).

In addition, the Bureau of Mines has supported design studies on jet cutter coal mining machines by Bendix Research Labs (Ref. 1033), IIT Research Institute (Ref. 54), and the University of Missouri at Rolla (Ref. 1102). A National Science Foundation contract with Flow Research, Inc., partly supported by the Bureau of Mines, will develop

a pressure intensifier which will be tested for jet cutting in a tunnel boring machine. Contract J0155036 with FMC Corporation in San Jose, California will design a jet cutter head for a shortwall mining machine. The Twin Cities Mining Research Center of the Bureau of Mines has conducted laboratory experiments on borehole mining and a contract program to conduct borehole mining of coal from a steep seam is underway (Flow Research Inc.) in the Carbon River field in Washington (Contract HO252007).

Development of hydraulic techniques for excavation of coal, rocks, and other minerals was performed by Brown Engineering of Huntsville, Alabama on contract HO232062 for the Bureau of Mines and completed in 1974. A contract for "Development of Percussive Jets" (Contract No. HO242008) was initiated with Scientific Associates, Inc., Santa Monica, California in January 1975. A contract on hydraulic haulage of coal in mines has been conducted by the Colorado School of Mines Research Institute, but the report has not been released (Ref. 24). A design study by Ingersoll-Rand Research, Inc. was initiated in April 1975 to investigate hydraulic methods and equipment for mining thick coal seams, over 12 ft thick.

Bureau of Mines contract activities on hydraulic coal mining are expected to expand during the fiscal year beginning July 1, 1975.

Other U.S. government agencies have supported work on continuous jets and pulsed water cannons for excavation and mining as follows:

1. Under-Reaming of Boreholes
Fenix and Scisson, Inc.
Reno, Nevada
2. Pulsed Jet Augmentation
Bowles Engineering Company
Silver Spring, Maryland
3. Pulsed Water Cannons
Terraspace, Inc.
Rockville, Maryland
4. Pulsed (Quasi-Steady) Jets
IIT Research Institute
Chicago, Illinois

5. Continuous Jet Cutting
Oak Ridge National Laboratory
Oak Ridge, Tennessee
6. Continuous and Pulsed Jets and
Design of Jet Longwall Machine
University of Missouri
Rolla, Missouri
7. Cutting of Permafrost and Ice
U.S. Army Cold Regions
Research and Engineering Lab
Hanover, New Hampshire
8. Cavitation Erosion
Hydronautics, Inc.
Laurel, Maryland.

Private corporate development has also occurred in the U.S. including:

1. Borehole Mining
Hydro-Jet Services, Inc.
Amarillo, Texas
2. Jet Drilling
Exxon Production Research
Houston, Texas
3. Water Cannons
Exotech, Inc.
Gaithersburg, Maryland
4. Jet Drilling (with Abrasives)
Gulf Research and Development Co.
Pittsburgh, Pennsylvania
5. Jet Cutting and Hydraulic Haulage
of Coal
Continental Oil Company
Ponca City, Oklahoma
and
Consolidation Coal Company
McMurry, Pennsylvania
6. Borehole Mining of Gilsonite
American Gilsonite Company
Bonanza, Utah
7. Jet Cutting and Drilling of Rock
Ingersoll-Rand Research, Inc.
Princeton, New Jersey.

The most extensive work in the U.S. on underground hydraulic haulage of coal is being conducted by Consolidation Coal Company and Continental Oil Company. Underground trials of equipment for accepting coal from a continuous mining machine and hydraulically hoisting it to a preparation plant are being conducted in the Robinson Run Mine in West Virginia (Ref. 550).

Slurry transport tests have been conducted by the Colorado School of Mines Research Institute in Golden, Colorado. However, much of the work has not been publicly reported. Slurry test loops are planned by the U.S. Bureau of Mines at their experimental mine in Bruceton, Pennsylvania.

8.8 Czechoslovakia

Hydraulic coal mining was conducted in Czechoslovakia, prior to 1958 (Refs. 543 and 549). Productivity per face worker was reported to be 10 tons per man-shift prior to 1958.

Hydraulic mining was conducted at the Czech Army Mine No. 1 in Karvina, the Hlubina Pit in Ostravo-Karvina and hydraulic haulage was used in the Stalin II Pit. Technology was similar to that in the USSR and Poland, using monitors for both development and production. Problems were encountered in dewatering coal. Centrifuges similar to the Soviet and West Germany designs were tested. Prof. Alois Riman wrote a summary on hydraulic mining (Ref. 492 in Czech). It was reported that a "long-face" mining method was used in Czechoslovakia instead of shortwall to reduce the amount of development drivage (Ref. 711).

It was reported in 1974 (Ref. 725) that hydromechanization is not to be used in Czechoslovakia.

8.9 New Zealand

Fluming of coal was started as early as 1891 in New Zealand (Ref. 549). Numerous small hydraulic coal mines were operated in New Zealand in the period 1920 to the 1950's. In 1956 there were thirty mines using hydraulic methods "but the method was merely being played with" (Ref. 628). In most cases, the coal was blasted from pillars and then flumed with low pressure water directly from the mine. Two small mines installed a hydraulic lift (Ref. 849). The technology was crude and generally small scale, making no major advancement of the state-of-the-art as compared to the Soviet developments. Conferences on the subject were held at the University of

Otago in 1953 (Refs. 568, 620, and 621) and in 1956 (Refs. 566, 567, 624, 625, 627, 628, 630, and 631) at which a review paper was presented of developments in the USSR (Ref. 627).

In 1974 it was reported that hydraulic mining persists on a small scale in New Zealand but consideration is being given to a revival of hydraulic methods.

8.10 China

Some of the larger underground coal mines in China are hydromechanized using water to aid both in winning and transporting coal. One such mine (Ref. 699) is Lu-Cja-To (in the Tang-Shan province of North China), which has a capacity of 10,000 metric tons per day, of which 4000 is hoisted by a slurry pumping system and 6000 by skip hoist.

A shortwall retreating-to-dip system of mining is used as in Poland and the USSR. The mine and plant were designed by a group of Polish mining engineers in 1958. Construction started in 1960 and by 1968 it was at about two-thirds of planned capacity.

Mining uses blasting and monitors at 30 to 50 kg/cm² (425 to 710 psi) pressure, with steel-lined flumes. Coal of greater than 1mm size is transported in mine cars and hoisted by skip. The fine coal is hoisted by coal pumps from a 425 m (1400 ft) depth, using three pumps from each of three panels.

8.11 Evaluation of Hydromine Experience

In this section a brief evaluation is presented of data on hydromines which have been selected as relatively successful and which represent generally good practise at the time they operated. Mines in New Zealand have not been included. Some basic data for each mine is included in Appendix A. It may be noted that all the mines used fluming of coal in open flumes and therefore required a large flow-rate of water at the face. In most cases, monitors were used to break coal or to wash hard coals from the face after blasting or water infusion. In some of the more recent mines in the USSR, water-turbine powered or electrically powered machines are used to cut coal. In these cases, low pressure monitors are used to wash coal into flumes. This approach appears to be gaining favor in the USSR.

Soviet experience has shown that hydraulic mining using flumes is possible in seams pitching over 3° , but 5 to 8° is preferable. However, development of thin seams by long pillars up the pitch requires pitch angles less than 18 to 20° , because at greater angles, delivery of materials through the steep entries is difficult and also the mounting of equipment at the face, the movement of men in the drifts and the erection of supports is more difficult. The use of sublevel mining is most effective for pitch angles of 50 to 90° . Therefore the most favorable seams for hydromining are those with pitch of 8 to 18° or 50 to 90° . (Ref. 736, p. 4) However, intermediate pitch angles are possible in thick seams, using diagonal entries as in the Kaiser Hydraulic Mine No. 1 (Ref. 1100).

Mining of anthracite is usually done by blasting and fluming, with underground separation of lump coal which is hauled separately in mine cars and hoisted by skip.

The most successful mines are those where the geology and topography permit fluming all the way to the mine portal.

9.0 DATA ON U.S. COAL SEAMS APPLICABLE FOR HYDRAULIC MINING

9.1 COLLECTION OF DATA

Data on U.S. coal seams was obtained by visits to the U.S. Geological Survey at Reston, Virginia and Denver, Colorado and by collection of relevant GQ (Geological Quadrangle) and coal maps. Data were also obtained by correspondence and telephone communications with various coal mining organizations. Attention was directed to locating seams more than four feet thick with pitch angles over 3°. A summary of data on pitching coal deposits in the U.S. is given in Table 9-1.

9.2 APPALACHIAN REGION COAL SEAMS

9.21 General Summary

Most of the Appalachian region has nearly horizontal bedding of coal seams, except at the extreme eastern edge where the seams generally pitch upward and outcrop. There are also pitching seams in Kentucky, in the anthracite fields of Pennsylvania, and in Somerset County, Pennsylvania.

A study by the U.S. Geological Survey (Ref. 638) indicates the existence of coal seams dipping 15° or more in parts of Alabama, Kentucky, Maryland, Pennsylvania, Tennessee, Virginia, and West Virginia. Surface mining is reported in these regions in Alabama, Maryland, Virginia, and West Virginia.

Pitching and in some cases nearly vertical seams of coal exist in the Pennington Gap Quadrangle of Lee County, Virginia and Harlan County, Kentucky (Ref. 847), but in most cases are relatively thin (2 to 4 feet). The thicker seams often have a rock parting layer.

In the Bromwell Quadrangle of West Virginia and Virginia (Ref. 845), the Pocahontas No. 3 seam outcrops at a steep pitch near Pocahontas but is reported to have been almost completely depleted by extensive underground and strip mining. A few small mines were in operation in 1965 and in 1966 in coal from 7 to 12 ft. thick.

There is pitching coal in the Cahaba Basin about 20 to 30 miles southwest of Birmingham, Alabama. The property is held by U.S. Steel and has not yet been adequately explored. The coal is not now being mined but held for future development.

Table 9-1 DATA ON PITCHING COAL DEPOSITS FOR POTENTIAL HYDRAULIC MINING

RESERVES (Million Tons)	STATE	LOCATION	TYPE OF COAL	SEAM THICKNESSES	PITCH ANGLE	FLOOR ROCK	ROOF ROCK	WATER SOURCE	POSSIBLE MINING SYSTEM	PROBLEMS	OVERBURDEN DEPTH
Over 100 (885 in whole field)	Colo.	near Silt (Grand Hogback Field)	Bituminous	6', 9', 7', 40' (5 seams)	55°-59°			Near Reservoir & Colorado River	Sublevel mining: Monitors, flume & Hydraulic Hoist	Spontaneous com- bustion in gob, & burning from the outcrop above drainage	0 to 2500 ft.
	Colo.	Thompson Creek near Coal Basin (Anschutz Oil Co)	Met. Coal	Anderson -10' A-seam - 6.5'	26°-32°	Hard Sand- stone	Fair Shale	Creek	Sublevel mining: Monitors & flume	Methane, high altitude, low temperature, water disposal	1000 to 3000 ft.
	Colo.	Carbondale (Mid-Continent Coal & Coke)	Coking	4'-16' (3 seams)	13°	Sand- stone	Fair	Crystal River	Long pillars, flume & hoist	Methane, high altitude, low temperature, water supply & disposal	1000 to 3000 ft.
Very large	Wyoming	Kemmerer (Ada- ville Formation)	Sub-bitum.	16 seams 4' to 93'	20° (18°-25°)	Varies	Varies	Hams Fork River	Long pillars, flume & hoist	Water availability	0 to ~ 2000 ft.
20-25	Wyoming	Hanna (Energy Dev. Corp.)	Sub-bitum.	14'-16'	14°-16°	Good		20 miles Medicine Bow River	Long pillars, flume & hoist	Water availability	0 to 1500 ft.
	Wash.	Roslyn-Cle Elum Field	Bituminous	5:4.5'-5.5' (11 seams)	10°-54° Syncline	Sandy Shale (Good)	Sand- stone		Monitors flume & hoist		
~50 +	Wash.	Carbon River (Hume & Associates)	Coking	6'-12' (7 seams)	45°-90° (Anti- clines)	Fair	Fair (Top 2 seams sand- stone)	Creek	Sublevel mining: Monitors & flume	Water disposal, possible roof problems, methane	0 to 2000 ft.
	Penna.	Coaldale	Anthracite	many seams up to 42'	0°-60° (Syn- cline)	Shale	Shale	Mine inflow	Conti- nuous Miners flume & hoist	Roof support, for shortwall: Mine being pumped out	600 to 1600 ft.
~5	Va.	Pine Mountain	Coking	30" to 50" Raven seam	~8°	Shale	Poor	Russell Fork River	Up-raise borehole monitors	Bad roof, under Jefferson Nat'l Forest	0 to 300 ft.
Large	Alabama	Cahaba Basin (SW of Birmingham) U. S. Steel	Coking		Pitching			Creeks		Not explored yet	?

A discussion of three possible locations in Appalachia for hydraulic mining is given in the following three sections.

9.22 Fetterolf Coal Co., Somerset County, Pennsylvania

The Fetterolf Coal Co., part of Cerro Mining Company, is developing a pitching coal mine in the southern half of Somerset County, Pennsylvania. The single seam is 3 to 7 ft. thick with a rock parting of 6" to 48". The pitch angle is 11 to 18% (6 to 10°) near the surface, dropping to 4 to 5% (2.5 to 3°) near the base of the syncline. Depth of development is now 600 to 700 ft., with ultimate depth of 800 to 900 ft. Continuous miners are used with shuttle cars and belts. The floor is a hard limey shale. The metallurgical coal has low sulfur and a grindability index of 100 and is sold to customers in the U.S. and Japan.

9.23 Pine Mountain, Virginia

A deposit of pitching coal exists in the Elkhorn City Quadrangle of Kentucky and Virginia (USGS geological quadrangle map GQ-951). It underlies the Jefferson National Forest, south of the Pine Mountain Fault, east of the Russell Fork Fault and bounded on the east and south by Russell Fork River. The Raven coal seam outcrops on the boundaries of the block which is about 7000 ft. on strike and 6000 ft. on dip. It pitches upward to the northwest with an average pitch near 8°. The Raven coal has never been mined extensively, apparently owing largely to its roof (usually a few inches to several feet of soft clay shale irregularly overlain by resistant sandstone) which is difficult to hold.

The seam thickness varies from about 30" to 50", averaging about 36". One coal sample assayed 3.1% moisture, 29.5% volatile matter, 64.6% fixed carbon, 2.8% ash, 1.1% sulfur, 14,520 BTU and had a Free-swelling Index No. 8 1/2.

The deposit could be mined hydraulically from one or more entries on the south-eastern boundary extending up dip with gravity fluming of coal to the portal. Experiments would be required to determine what type of hydraulic mining plan to use to mine lifts in retreat without mixing excessive caved roof rock with the coal. The use of up-raise borehole monitors for remote mining of lifts by back reaming at ranges up to 500 ft. or more appears to be possible for this deposit. Water is presumably available from the Russell Fork River, or from the Laurel Branch or Little Laurel Branch which cross the area.

The thickness of overburden varies up to a maximum of about 300 ft. near the center of the deposit. Small surface subsidence can be expected over the entire area mined, depending on the coal recovery and stability of any pillars that are left in the seam.

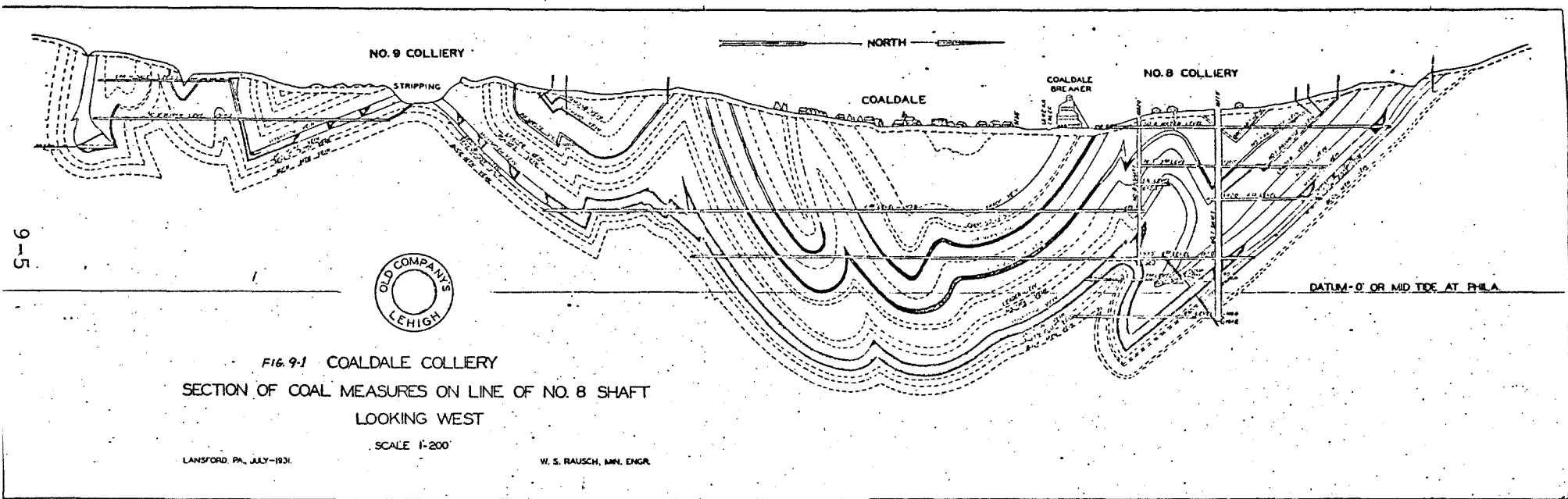
9.24 Bethlehem Anthracite Mine, Coaldale, Pennsylvania

Data was supplied by Mr. L. B. Gray, Jr., Vice President of Bethlehem Mines Corp., Bethlehem, Pa. (Ref.1256) on an anthracite property recently acquired by Bethlehem. Fig. 9-1 shows the seam cross section. The deposit has multiple seams up to about 42 ft. thick forming a large syncline with outcrops over more than one mile north to south and over 10 miles east to west. Underground mining is contemplated from about 600 ft. depth to about 1500 or 1600 ft. depth.

The old mine workings are now being pumped out. The remaining coal is mainly at the lower levels of the syncline where pitch varies from flat to about 60°. The coal seams have variations of hardness and various shale partings. The floor and roof rocks are generally thinly laminated fissile shale or in some cases sandstone. In 1975, old drilling records were being reviewed to aid in planning mine development.

This appears to be a deposit quite well suited to development of hydraulic mining methods using fluming to a hydraulic hoist station at the bottom of the syncline. This would require sinking a 1600 ft. shaft.

Coal breaking would probably require pre-loosening by water infusion or blasting to permit washing out by monitors. As an alternative, continuous miners could be used, possibly powered by water turbines with the turbine exhaust water used for fluming. Following the Russian practice in anthracite hydraulic mines, the large lump coal could be separated underground and hoisted by skip, with hydraulic hoisting of the fine coal.



9.3 MIDWESTERN REGION COAL SEAMS

The coal seams in the midwestern U.S. as in Illinois and Indiana are generally flat and not adaptable to hydraulic fluming. However, the use of hydraulic transport in hoses and pipes should be considered with continuous miners, longwall or shortwall equipment.

Arkansas is reported to have pitching coal seams, but relevant coal maps have not yet been reviewed.

9.4 WESTERN U.S. COAL SEAMS

9.41 Uinta Region

Data on coal seams in the Uinta Region of Colorado and Utah were extracted from Ref. 809. Coal seams with pitch of more than 3.5° exist in many coalfields as shown in Table 9-2 and Figure 9-2.

In Colorado, pitching seams outcrop along the eastern edge of the Uinta Region in the Crested Butte, Carbondale, Grand Hogback, and Danforth Hills fields. In the southern part of the Carbondale field there is excellent coking coal in seams from 4 to 16 ft. thick.

In the Mid-Continent Coal Company mines near Carbondale, the seams outcrop on the east near 10,000 ft. altitude and dip at about 13° to the west under several hundred feet of cover. Truck transport from the portal is hindered by snow and avalanches in the winter. Underground mining is now done by continuous miners but longwalling is planned. It is possible that opening the deep seams could also be gained by sinking shafts or slopes from the western side of the mountains to intersect two or three seams at the deepest point, with hydraulic mining development to permit fluming to the shaft bottom. Problems requiring investigation include:

1. Access to the western slope by truck or rail to permit shipment of coking coal to steel mills in Utah or California
2. Availability of water from streams (mainly snow run-off) from the western slopes of from mine inflow
3. Disposal of slimes.

Table 9-2
 PITCHING COAL SEAMS IN COLORADO AND UTAH (UINTA REGION)

Coalfield	Pitch Angle	Seam Thickness	Water Inflow	Availability Of Water Nearby	Problems	Suitability for Large Mine
Colorado:						
1. Book Cliffs A. Between Palisade and Utah Border)	5-20°	3-7 ft			Too Steep Slopes for Mining Machinery	
B. Near Cameo (4.5 mi N of Palisade)	<10°	6-10 ft			Sandstone Dikes	
2. Carbondale (Marble to 4 mi SW of Glenwood Springs)	13° (10-45°)	In Southern Part Excellent Coking Coal 4-16 ft, 8.5 ft in Thompson Creek Mine (@ 26°) (Sandstone Floor)	Occasional Water Inflow Problem		High Methane, High Altitude (near 10,000 ft) Occasional Water Problem, Heavy Snow	Yes
3. Crested Butte		Anthracite, Semi-anthracite & Coking Coal 5-25 ft			Folded, Faulted, Igneous Intrusions	No
4. Danforth Hills (NE Part of Uinta) S to Meeker & W to Coyote Basin	Up to 68° (Near Meeker) Moderate to Flat Elsewhere	Thick and Consistent		Lack of Water Nearby	Good Top, Low Methane, No Water Problems	

Table 9-2 (Continued)
 PITCHING COAL SEAMS IN COLORADO AND UTAH (UINTA REGION)

Coalfield	Pitch Angle	Seam Thickness	Water Inflow	Availability of Water Nearby	Problems	Suitability for Large Mine
5. Grand Hogback (4 mi SW of Glenwood Springs to Hogback Escarpment near Meeker)	30-60°	6-47 ft Sub-bituminous	Small	Yes Near Silt Colorado	Steep Dip, burning of outcrop and spontaneous combustion in the gob	Yes
6. Grand Mesa (4 mi S of Palisade to 4 mi NW of Paonia)	Small Dip	Sub-bituminous			High Moisture in Coal, Fair Roof, Moderate Water, Little Methane, Dikes and Seam Undulations	No
7. Somerset (W Elk Mountains to 4 mi NW of Paonia)	Small Dip 3.5° (6%)	Coking Coal 11-23 ft, 6-9 ft. 6-25 ft, 21 ft ave. B. seam, 7 ft ave. C seam	High Water Inflow in Some Mines		Favorable, Bumps at Depth, Water Problem in Some Mines, Spontaneous Combustion in B Seam	Yes
8. Lower White River Coyote Basin to Utah line	Small Dip			White River Nearby	Burning of Outcrop, but Ideal Conditions	
Utah:						
1. Book Cliffs	Nearly Level	2-6 ft High, Shale Content			Fair Roof, Little Methane, Shale Bands in Coal	
2. Castlegate A. Around Price	5-7°	Good Stoker Coal 10-30 ft Seams Nine Seams			Weak Roof, High Methane, Seam Undulations, Bumps at Depth	

Table 9-2 (Continued)
 PITCHING COAL SEAMS IN COLORADO AND UTAH (UINTA REGION)

Coalfield	Pitch Angle	Seam Thickness	Water Inflow	Availability of Water Nearby	Problems	Suitability for Large Mine
B. Gordon Creek	Nearly Horizontal				Faults	No
C. Hiawatha		Thick	2,000,000 gal/day into Mine		Excellent, Good Roof	Yes
D. Pleasant Valley			Low Water Inflow		Most Seams Partially Mined, Fault Zone, Fair to Good Mining, Fair Roof, Moderate Methane	No
E. Spring Canyon					Most Seams Partially Mined, Good Roof, Little Methane, Just Enough Water for Conventional Mining, Few Bumps, but Undulations of Seam (10% in 15 ft)	Yes, but From Several Seams
F. Upper Huntington		Several Seams			Faults	
G. Wellington	3.5° (6%)				10-15 mi to Railroad, High Productivity	Yes 10 ⁸ T in One Block
3. Emery (S of Carbon County)	>3.5° (6%)	10-20 ft	200 gpm in Browning Mine		Favorable, No Methane, Faults Near Mouth of Huntington Canyon	Yes (W of Huntington Canyon)
A. NE of Orangeville		13-15 ft			Excellent	Yes

Table 9-2 (Continued)
 PITCHING COAL SEAMS IN COLORADO AND UTAH (UINTA REGION)

Coalfield	Pitch Angle	Seam Thickness	Water Inflow	Availability of Water Nearby	Problems	Suitability for Large Mine
B. Semir County	<1.7° (3%)					
C. Salina Canyon		Thin Seams (<3 ft)	Water Inflow Problem		Faults, Poor Conditions	No
D. Near Sterling	15-20°	4.5 ft in North Horn Formation	Large Water Inflow		Little Commercial Value	No
E. Mt Pleasant		5 Seams Each < 5 ft			No Value	No
F. Wales	23°	5 ft 2 in.	Large Water Inflow		Difficult Mining	No (Small Reserves)
4. Sunnyside (N of Carbon-Emery County Line & S of Pace Canyon)		Coking Coal			Bumps, Faults, Poor Roof, High Methane, Poor Conditions, but Extensively Mined, Can be Longwalled	
5. Vernal (Uintah County)	<37°	67 in. seam with 3 rock bands totaling 15 in.			Extremely Poor Conditions, Thick Rock Bands, Thin Seams, Small Deposits	No

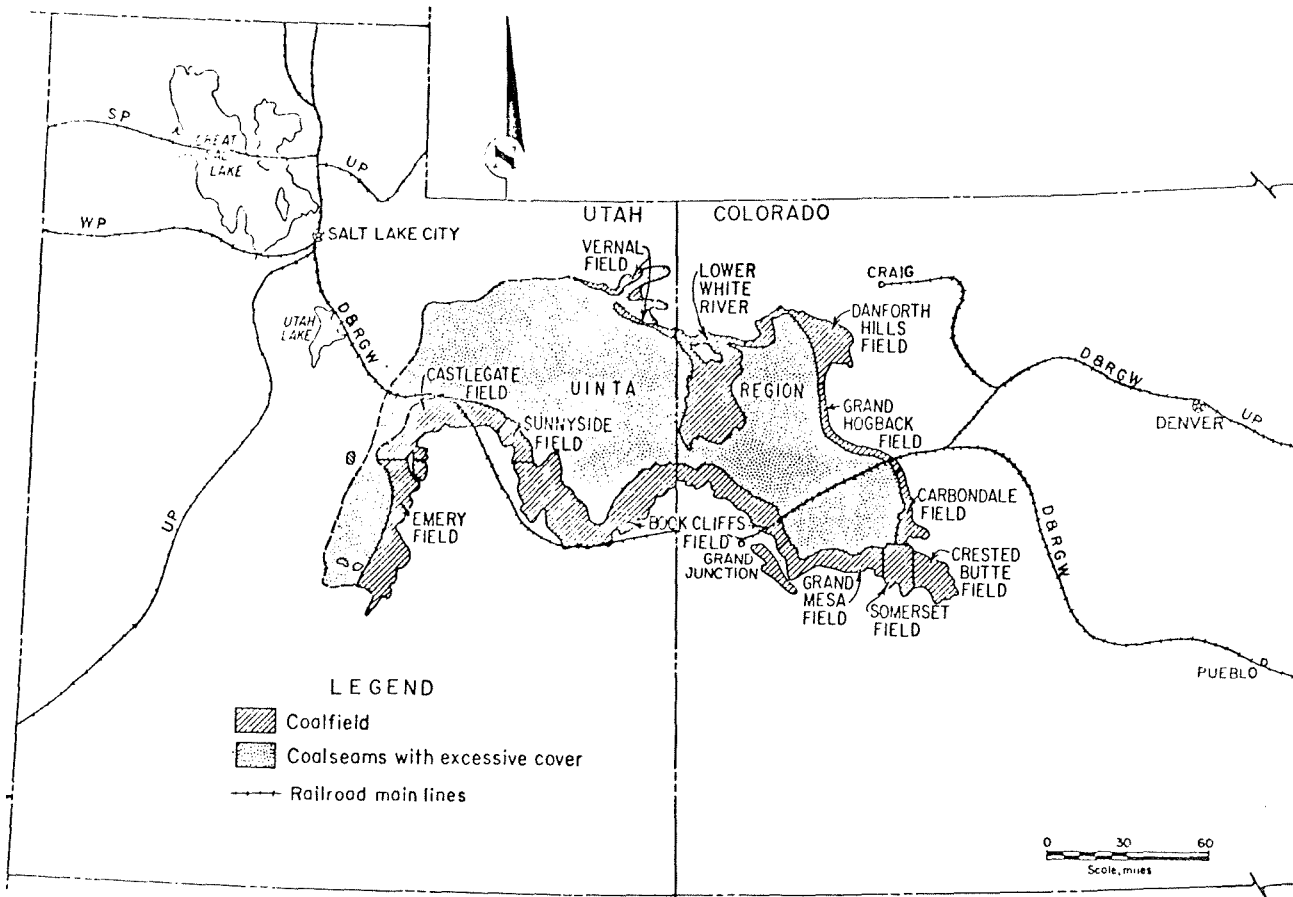


Figure 9-2
 COALFIELDS OF THE UINTA REGION

The seam pitch angle (13°), seam thickness (near 8 ft.), floor rock conditions (sandstone), and quality of the coking coal all indicate favorable conditions for mining by monitors, with fluming and hydraulic hoisting. Reserves exist between adjacent mines and are inferred at depth down-dip beyond present planned development.

The Anschutz Oil Co. is planning to conduct longwall mining of pitching seams of metallurgical coal in the area about 10 miles west of Coal Basin, Colorado. This includes the Thompson Creek mine. The A-bed is 6.5 ft. thick, pitching at 30° with a bank of rock near the bottom. The Anderson seam is 800 ft. above the A-bed and is 10 ft. thick and relatively free of rock bands. Mining will be done with a depth of cover from 1000 to 3000 ft. The old mine workings are being repaired and the mine drained. Coal transport will be by rail. It will take 1 1/2 years before starting to mine. There is water available from a creek on the property. The coal can be broken well by a monitor jet as shown by earlier experiments.

One section of the mine has a 32° pitch and 6.5 to 7 ft. seam height which can be reached through old entries about 1 1/2 miles long on strike. Hydraulic mining might be done in this location without interference with the rest of the mine. Hydraulic transport by fluming is being considered for use with longwall mining with the longwall on a 30° pitch moving on strike.

The coal seams in the Somerset field are also coking coal in thick seams with large reserves, but with generally small pitch (3.5°). There is high water inflow in some mines. More investigation is needed to determine whether hydraulic mining is feasible.

Other fields with pitch over 3.5° and with large reserves include the Wellington area of the Castlegate field and the Emery field in Utah.

The Grand Hogback coalfield of Colorado, extending from a point southwest of Glenwood Springs to Meeker, contains estimated reserves of 885 million tons of bituminous steam coal in seams with pitch angles of 30° to 80° (Ref. 809). Seam thicknesses are from 6 to 40 feet and at least 5 seams are present near Silt. These cannot be mined economically by non-hydraulic methods, but could be mined underground by sub-level hydraulic mining, using monitors and flumes. Due to burning from the outcrop, it is suspected that much of the coal in some seams above drainage level may have been destroyed. Therefore, hydraulic hoisting may generally be required through shafts or slopes at least in later stages of mine development. One seam is now burning in Burning Mountain. The coal is susceptible to spontaneous combustion in the gob.

Water is available from the Colorado River and from at least one reservoir near Silt. Water inflow to the seams is very low. Water should be recycled and water requirements will be low, mainly to make up for evaporation from reservoirs and flumes. Water requirements for startup are estimated to be about 20 acre-feet per million TPY production rate.

Potential markets for the steam coal include a power-plant near Cameo. An additional power plant could be considered on the Colorado between Glenwood Springs and the Utah border. Water flow of the Colorado in this region averages between 2 and 4.3 million acre-feet per year. Coal could also be shipped by rail east or west from Rifle, Silt or New Castle.

The water flow of the White River at Meeker is less than 25% of the flow of the Colorado near Silt, making the northern end of the Grand Hogback less favorable for hydraulic mining or for supplying local power plants. Also, strip mining in the Danforth Hills field to the north may provide competition.

9.5 COAL SEAMS IN WASHINGTON STATE

9.51 The Carbon River coal deposit contains several seams of coking coal from 6 to 12 ft. thick in a highly folded configuration with steep pitch angles up to nearly 90°. Plans for development of the mine are being made by Donald B. Hume and Associates of Mercer Island, Washington. Consideration is being given to the use of monitors and fluming to a long tunnel which would intersect all the seams. Coal could be hauled hydraulically several miles to the coast for preparation and shipment.

A program is underway by the U. S. Bureau of Mines to conduct borehole mining experiments from the surface in one of the seams.

9.52 Roslyn-Cle Elum Deposit, Washington

Hydraulic mining experiments have been conducted in the Roslyn #9 and #10 mines which are now closed (Ref. 153 and 487). The coal deposit is a syncline with eleven seams at pitch angles from 10° to 54°. The No. 5 seam is from 4.5 to 5.5 ft. thick. This deposit could be mined by monitor jets with fluming and hydraulic hoisting.

9.6 COAL SEAMS IN WYOMING

9.61 Kemmerer Coal Field, Wyoming

In the vicinity of Kemmerer, Wyoming, extensive deposits of steam coal are present in thick seams which outcrop and dip to the west at an angle of 18° to 25°. Approximately 16 seams with thicknesses up to 93 feet (Ref. 1098)

could be surface-mined by an open-pit with a depth of 1770 ft. Ten seams could be mined if the depth were limited to 1005 ft. (Fig. 9-2 and 9-3). The area is near the Union Pacific Railroad and the Hams Fork River. A Utah Power and Light Company power plant now exists and another is planned.

The seam deposits could potentially be opened by vertical shafts or slopes for underground mining. The pitch is generally excessive for development by continuous miners using long pillars directly up the pitch. However diagonal headings could be driven. Self-propelled monitors, possibly equipped with floor and roof traction, could be considered for driving development headings up-dip, with fluming and coal pump or air-lift hoisting (or a combination). The availability of water poses a problem which needs investigation. The large thickness of the seams also presents difficult problems of roof control and subsidence.

9.62 Hanna, Wyoming

The Energy Development Corp. is developing a mine in a pitching seam of steam coal in Hanna, Wyoming using continuous miners, shuttle cars and Diesel supply vehicles. The mine has no wash plant. The seam pitch is 14° to 16° and seam thickness is up to 14 to 16 ft., but about 2 ft. of lower quality coal is left at the roof of the seam. Entries are driven at an angle to the dip, at a true pitch of about 8° .

Total reserves are 20 to 25 million tons, extending to depths of 1500 ft. Development has proceeded only to a depth of 400 to 450 ft.

The coal is easily broken, porous and permeable and has a grindability index of 52.

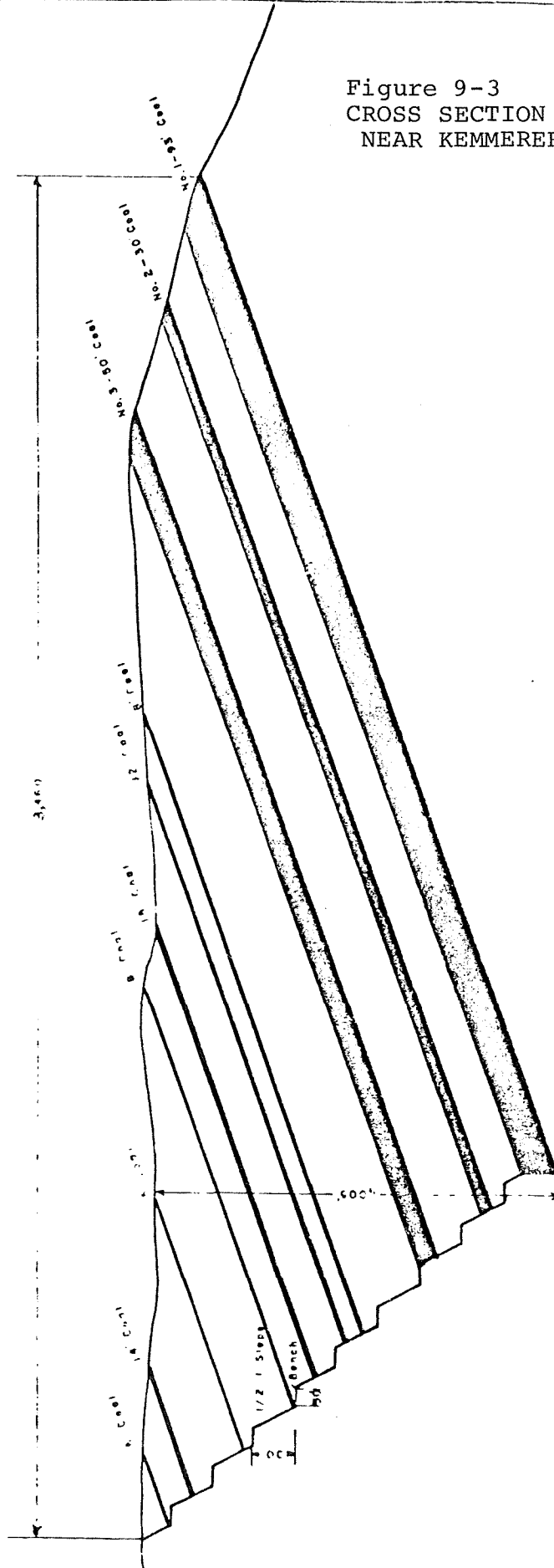
The water inflow to the mine is only about 30 gpm. The nearest supply of water is 20 miles.

This seam could utilize fluming and hydraulic hoisting. It would also be possible to pull pillars by monitor jet.

9.63 Rock Springs, Wyoming

The underground Stansbury mine is being developed near Rock Springs, Wyoming in pitching coal seams (Ref.1322). There are five seams at a pitch of 25% (14°) near the outcrop. The two upper seams are from 6 to 14 ft. thick and are 100 ft. apart. Total reserves are 80 to 100 million tons. The steam coal will not be washed and production is expected to be 1 to 1.5 million TPY. Hydraulic mining could be considered for the three lower seams after 1980.

Figure 9-3
CROSS SECTION OF COAL SEAMS
NEAR KEMMERER, WYOMING



CROSS SECTION BIG PIT
KEMMERER COAL COMPANY

SCALE: 1" = 400'

PLATE 3

9.7 BELUGA COAL FIELD, ALASKA

The Beluga coal fields, about 50 miles west of Anchorage, include two large deposits (Capps and Chuitna) (Ref. 1081). Reserves are estimated at 1.5 billion tons at a stripping ratio of 10:1. The coal is in two or three nearly horizontal seams, each of which vary in thickness from 6 to 40 feet. The coal has low sulfur (0.2%) high water content (24.9%), and 9.9% ash.

Attention should be given to the use of pipes and hoses for hydraulic haulage and hoisting in case underground mining is considered. More details on the geology are required to study the feasibility of hydraulic mining. It may be possible to strip the overburden by large monitor jets with hydraulic transport.

10.0 BASIS FOR SELECTION OF HYDRAULIC MINING SYSTEMS

10.1 HYDRAULIC MINING WITH GRAVITY FLUMING

The primary potential advantages of hydraulic mining systems which utilize monitors and gravity fluming are:

1. Relatively high productivity in working thin and pitching seams, particularly under difficult mining conditions, bad roof, complex geology, high methane content, or the possibility of gas and coal outbursts
2. Very high productivity in pitching thick seams, particularly when fluming can occur all the way to the portal, without the necessity for hoisting
3. Improved safety due to removal of men from the face area, simplification and automation of coal haulage, and additional dilution of methane at the face by air entrained in the monitor jet
4. Improved health by reduction of coal dust generation, reducing the hazard of pneumoconiosis (black lung)
5. Lower capital investment than alternate methods under many mining conditions

10.2 DESIRABLE CONDITIONS FOR HYDRAULIC MINING

The favorable conditions which are most desirable for hydraulic mining include:

1. Seam pitch angles above 5° to 8°
2. Thick seams (6 to 50 ft. or more)
3. Fairly uniform pitch angle of seams without major undulations or faults which would interfere with maintenance of proper slope for flumes (usually 4° - 7°), preferably permitting fluming to portal.
4. High value coal (e.g., coking coal), not hampered by competition from lower cost strip mined coal in the region

5. Hard floor rock, not attacked by water
6. Soft friable coal, easily broken by a monitor jet
7. Less than 2000 ft. of overburden and relatively stable roof rock which will cave in a predictable way, without major seismic bumps.
8. A deposit in an area without surface installations or waterways which would be affected by subsidence
9. Availability of water and electric power nearby
10. Low sulfur content of the coal and not excessive water inflow to the deposit which could cause a problem of disposal of acid mine water
11. Location near customers for coal transport by rail, truck or slurry pipeline
12. Local terrain and hydrology favorable for refuse disposal by lagooning without causing water pollution

10.3 LIMITATIONS OF HYDRAULIC MINING

The primary problems and limitations of hydraulic mining are the following:

1. Open flumes are not applicable to flat seams less than 3° pitch or to gently pitching seams where the floor rock is to be exposed to water for an appreciable length of time, because of mud formation. In these cases, hydraulic haulage in pressurized pipes or hoses is required. This limitation exists in most of the mid-western and Appalachian coal regions of the U.S. with the possible exception of some pitching deposits (e.g., in the anthracite beds and at the eastern fringe of the Appalachians) where further investigation may show that hydraulic mining is applicable. Possibilities may also exist in Arkansas.

2. Hydraulic mining requires a water supply adequate for initial start-up as well as make-up water to replace losses. This is a severe problem in many western U.S. locations, requiring detailed hydrological investigation to determine available water quantities from mine inflow and nearby sources. In many western U.S. locations, the use of surface waters from streams has been over-committed for agricultural, mining, and other uses and is the subject of considerable litigation. Future water requirements for coal gasification and liquefaction, for oil shale processing, for power plant cooling, for coal slurry pipelining, and for other mining needs should be considered when evaluating the feasibility of hydraulic coal mining in particular western locations.
3. Hydraulic mining produces quantities of fine coal slimes which pose a difficult problem of dewatering or disposal in some areas unless they can be dried sufficiently by lagooning or other methods to be burned directly in a power plant (e.g., as is done to dispose of all water from the Black Mesa pipeline). Slime disposal at present limits the hydraulic production from the German Gneisenau mine, which has a water inflow in excess of mining requirements. Dewatering and drying are major problems for Russian hydromines.
4. Hydraulic hoisting requires more electrical power than hoisting by skip or conveyor.
5. Hydraulic mining by monitors requires special clothing and face protection for men working near the face. Humidity, high temperature, and visibility at the face are problems requiring special attention.

6. Hydraulic mining with controlled caving of the roof often leads to incomplete recovery and quantities of crushed coal in the goaf. If the coal is prone to spontaneous ignition, fires may occur, requiring sealing off the mine block. This problem can be minimized by improving coal recovery (80 to 85 percent is often obtained) and by planning extraction schedules to limit the time of operation in one section to less than 6 months. However, Soviet experience over 15 years shows that the probability of fires in thick seams which are prone to spontaneous combustion is lower with hydraulic mining than with standard drill-and-blast methods of mining. The ratio of burned out sections to the total worked out was 0.67 for standard and 0.3 for hydraulic methods (Ref. 461).

10.4 JET CUTTING OF COAL

The use of high pressure water jets combined with mechanical cutters to cut coal can potentially be accomplished using high water pressures (over 350 kg/cm² or 5000 psi) with low enough water consumption to permit haulage by conventional means (shuttle cars, conveyors, and mine cars). The primary advantages of such systems would be to reduce dust, to avoid ignition hazard, and to increase the size of coal produced by continuous miners, by longwall or shortwall machines. It is not expected that major gains in productivity, reductions in cost, or improvements in mechanical reliability will be introduced by these coal cutting methods. However, they could improve the health and safety in many existing or planned mines, and would be generally applicable in a large number of coal mines in all areas of the U.S. They are therefore worthy of considerable development effort.

10.5 WATER CANNONS

The usefulness of pulsed water cannons similar to the MPI-2 type developed by G.P. Chermenskiy or the Voitsekhovskiy type for breaking coal or for driving development headings in coal and rock has not been properly evaluated in the United States. The potential advantages are to break either coal or rock without spark ignition hazard or dust generation and without breaking or wearing out mechanical picks. Efficiency of breakage is comparable to present continuous miners, with potentially better health, safety and

reliability. The problems to be overcome are the control of noise and the ability to control smoothness of the roof and rib contour for adequate roof support. Peak jet pressures of 40,000 to 100,000 psi are applicable to medium hard rocks. Higher pressures are possible for hard rock, using either piston impact extrusion or the Voitsekhovskiy exponential nozzle, which requires nozzle purging between shots. However, the latter may introduce an ignition hazard unless nozzle purging is done with inert gas. The water cannon has good potential for use in a small roadheader to drive entries in thin coal seams, particularly in anthracite or where roof or floor rock must be ripped. Russian developments are continuing (Ref. 1110).

10.6 MECHANICAL OR JET CUTTING WITH HYDRAULIC HAULAGE

The system under development by Consolidation Coal Company permits collection of dry coal from a continuous miner and injection into a slurry pipeline through a flexible hose. This type of system is not seriously limited by coal seam pitch angle or floor rock conditions. Therefore it is in principle applicable to all coal seams in the U.S. which can be mined by a continuous miner at pitch angles of zero to about 15°. (By improving traction, higher angles would be possible). It is also adaptable for use with longwall or shortwall systems. The present Consol system is too high and too bulky for use in many thin seams, but development of a coal injector is planned by the Bureau of Mines to permit use in a four foot seam and also to accept coal from a longwall or shortwall machine (Ref. 1088). Such a development could have broad application in coal seams in the Appalachian and mid-western areas.

The advantages of these hydrotransport systems are the increased utilization of the mining machine, as well as improving reliability and safety of the face and main haulage systems. Dust levels can be reduced.

10.7 VERTICAL BOREHOLE MINING

A preliminary review of hydraulic mining through approximately vertical boreholes from the surface indicates that it will have very limited application in the U.S. coal deposits. Deposits should be steeply pitching and preferably thick for best productivity. Steeply pitching seams of small or medium thickness may also be applicable for borehole mining, particularly for coking coal deposits which command a premium price (e.g., the Carbon River deposit in Washington state).

11.0 AVAILABILITY OF HYDRAULIC MINING EQUIPMENT

Detailed data on hydraulic mining equipment and components is included in Volume 3 (Appendix B) of this report. Much of the equipment required for hydraulic mining is commercially available in the United States, including multi-stage centrifugal high pressure water pumps, water pipes and valves, and single stage centrifugal slurry pumps which could be used for hydraulic hoisting from small depths.

High pressure pumps and monitors have been obtained from Japan by Kaiser Resources Ltd. for use in their first hydraulic mine.

Hydraulic monitors and borehole monitors may also be available from Germany or from the USSR, since no suitable monitors are yet manufactured in the U.S.

Steel flumes with low friction linings can be custom made in the U.S. without difficulty. Abrasion resistant steel pipe and valves are also available for coal slurry. Appropriate pipe couplings to permit quick-disconnection and reconnection of high pressure water pipes may require modification of existing designs.

If hydraulic hoisting is required for shaft depths more than a few hundred feet, it would be desirable to use two-stage centrifugal coal pumps, although none are available in the U. S. Soviet developments in this field are extensive and their pumps develop higher head per stage than the usual rating of U.S. slurry pumps. It is believed that U.S. slurry pumps could be operated at higher rated tip speeds and develop higher head per stage without serious wear if the rock content of coal is kept low. Also, if necessary, two-stage pumps with large capacities could be developed without major difficulty. It is important that multi-stage slurry pumps be designed for ease of disassembly and repair because of abrasive wear and failure of seals and bearings.

The effective use of hydraulic mining with fluming requires rapid development of entries, often in thin seams (4 to 6 ft.) pitching at 20° or more. No American road-headers or continuous miners are well-suited to this application except where the seams are thick enough (e.g., in the Kaiser mine), to permit driving sublevel drifts entirely in the coal. The problems of roof support and material supply are closely related to the type of roadheader used. Since many western coal seams are only 6 to 8 feet thick or less

and pitch at 20° to 90°, serious consideration should be given to develop an improved entry driving system, including suitable roof support and material supply systems which are compatible with gravity fluming. Unless the entry driving equipment is quite small, roof and floor rocks may have to be ripped. Also, if the sublevel drifts cannot safely be driven with local air ventilation, parallel ventilation drifts may be required with periodic cross cuts to provide for air return. This requires a small maneuverable roadheader. These problems must be solved to permit mining the thin seams which often overlay much thicker coal seams, as in the Grand Hogback and Kemmerer coalfields and the Pennsylvania anthracite fields.

The problems in mining anthracite hydraulically are even more difficult because the coal may be so hard and impermeable that a monitor jet will not break the coal effectively unless pressure is increased beyond 2000 psi, or pre-loosening is accomplished by blasting or water infusion. Consideration may also be given to mechanical cutting (e.g., a Dosco machine) or water cannons for driving entries and mining of anthracite. Preferably the machines should be powered by water hydraulic power to avoid electrical hazards at the face and to permit the use of waste water for fluming.

Water cannon roadheaders have been tested in the USSR by Chermenskiy (Ref. 1191 and 1192) and by Stepanov (Ref. 1110) but none are commercially available in the U.S. Water cannon experiments have been conducted in the U.S. by Terraspace Inc. (Ref. 347).

No equipment is available in the U.S. which uses high pressure low flow jets for cutting coal. However a jet cutter longwall device is under development by the Missouri School of Mines at Rolla, and a shortwall machine is being developed by FMC Corporation with support from the Bureau of Mines. Design studies of continuous mining machines using small water jets alone for cutting coal have shown that power requirements are much higher than for mechanical cutters.

12.0 ECONOMIC COMPARISON OF HYDRAULIC AND CONVENTIONAL MINING SYSTEMS

12.1 GENERAL DISCUSSION

The types of coal deposits where hydraulic mining and/or hydraulic transport methods may have economic advantages may be classified as follows:

- A. Pitching seams at 20° to 90°
- B. Pitching seams at 3° to 20°
- C. Flat seams (less than 3°).

The two categories of pitching seams may also be divided into those which permit fluming to the portal and those which require development by shafts or slopes driven down-dip.

In the case of steeply pitching seams, over about 20°, hydraulic methods can make significant improvement in costs, particularly where water supply is adequate, the roof quality and depth of cover permit roof caving under controlled conditions, and the floor rock is not seriously affected by water. In fact, when these factors combine with a thick seam of soft friable coal and with a deposit which permits fluming to the portal, the use of monitor jets and fluming can provide one of the most economical underground mining systems possible. An example is the Kaiser hydraulic mine at Sparwood, British Columbia.

For pitching coal seams at 3° to 20° pitch, coal transport by open flumes is possible, which can reduce the costs of face, secondary and main haulage systems substantially as compared to the use of shuttle cars, belts or mine cars. Fluming is also much less expensive than the use of pipe hydraulic transport. The steeper pitch angles of 10 to 20° provide the best opportunity for competition of hydraulic fluming with conventional room-and-pillar mining because the steeper pitches are more difficult for the operation of shuttle cars and continuous miners. The hydraulic mine only requires material supply haulage which may be accomplished with diesel powered vehicles, diesel mono-rails, or cableways.

For flat horizontal seams (less than 3° pitch) gravity fluming is not possible. Hydraulic transport must use hoses and/or pipes. An example is the system under development by Conoco and Consolidation Coal at the Robinson Run Mine. Coal cutting is now done with continuous miners because no system has been developed yet using a monitor jet and crusher to make coal slurry at the face and feed it into a pipeline from a horizontal

floor. For such a development to be successful, it should permit a reduction in the size of face equipment, reduction of entry width and roof bolting requirements and the attainment of a high utilization factor for the coal cutting monitor jet. A primary limitation is the present size of coal crushing equipment needed at the face to reduce coal to less than 2 inch size for slurry transport. A goal should be to develop a monitor jet, crusher, slurrifier and slurry injector system which can all operate by remote control through small entries.

12.2 EFFECT ON COST OF COAL DISINTEGRATION EQUIPMENT

For bituminous coal the capital cost of a monitor jet device is much less than that of a continuous miner per unit of coal cutting capacity. Depending on the coal properties, one, two, or more monitors may be needed to equal the production rate of a continuous miner. Therefore a hydraulic mining section often uses two or more monitors with the water supply alternated to the operating monitor. The major cost items for a monitor mining system are the surface pump station which has motors, pumps, settling basins, etc. and the piping system to bring recycled mine water under pressure to monitors at the face. The piping system is movable from one section to another. The length of pipe varies approximately inversely as the square root of the coal seam thickness for a given production rate and mine life. The pumps should have standby and spare units to assure continuous operation, much as some mines provide a spare continuous miner section on standby.

The operation of a water pump station and monitor system can have greater reliability than a typical continuous miner. The basic reason is that a continuous miner is complex, its picks are subject to breakage by operation, the electrical supply system is subject to damage, and the face environment is not conducive to easy maintenance or repair. By contrast, a monitor and pipe range are simple and reliable, and the water pumping equipment is stationary and on the surface where maintenance and repair are convenient and effective.

An overall comparison of the relative economics requires consideration of maintenance and the effect on costs of the down time. A major parameter affecting the comparison is the ease of disintegration of coal by a monitor jet which determines the jet pressure and flowrate required for a given production rate. For example, a hard impermeable coal like anthracite will require high jet pressure and high pumping power, whereas soft bituminous coal such as in the Balmer seam of British Columbia is broken very easily. Therefore no accurate comparison of

costs can be made unless data exists on the attainable monitor production rate for a particular type of coal as a function of jet pressure, flowrate and the dimensions of the coal "lift".

If the specific water absorption of the coal seam is known, the method of Nikonov (Eq. 5.5-1) may be used to predict cutting rates. If the coal hardness is known, the methods presented by Okhrimenko et al. (Ref. 738, p.7) may be used for prediction. However, the effect of coal properties is so important that experimental data on monitor cutting rates in the actual coal deposit being considered is highly desirable to permit accurate cost comparisons.

12.3 COST OF UNDERGROUND HAULAGE EQUIPMENT

For pitching coal seams above 3 to 5° pitch, the cost of installing steel flumes to haul coal slurry from the face in sublevels and entries is considerably less than the cost of a belt system. Also, no shuttle cars are needed. The cost of a typical steel flume including installation on the floor is estimated to be about \$15.00 to \$20.00 per foot, whereas the cost of a belt conveyor system is around \$60.00 per foot. The cost of the piping and pump system to extend main entries for a pipe haulage system may be as much as \$140 per foot for a system capacity near 400 tons per shift.

Gravity flumes have the advantage of low capital investment and no power costs for operation. Maintenance costs are also low unless the coal has appreciable abrasive rock content or the coal lumps are large, leading to frequent blockage and manual labor to clear the flumes. In the latter case, it is expedient to install a feeder-breaker near the face.

12.4 REDUCED CROSS-SECTION OF ENTRIES

In most hydraulic mines, there is usually a deliberate effort to reduce the size of entries and sublevels to the minimum size possible as limited by ventilation requirements or by the size of mining and transport equipment. By this means, development costs can be reduced and the fraction of the coal won economically by monitor mining of lifts is much larger than the coal won during development. On the other hand, American room-and-pillar operations with continuous miners use wide and multiple entries, so there is early production of coal during development and a smaller fraction of the total coal is won during retreat by pulling of pillars. The American practice is obviously influenced by legal

requirements for multiple entries, by safety problems if pillars are pulled, and also by the desire to develop early cash flow by increasing coal production during development.

By contrast, hydraulic mines are most efficient when mining lifts in retreat with roof caving. Therefore, there is an incentive to minimize the volume of development coal. It is therefore desirable to use small cross-section entries and to drive them rapidly at low cost in order to expose coal for retreat mining. Cash flow is therefore delayed, unless the development time can be reduced.

The size of entries in a typical Soviet hydraulic mine may be about 3 m by 3 m or less. Main accumulation roadways are of similar size and with only one parallel ventilation drift. There is no hazard from dust or fire as in a belt conveyor entry which in the U. S. requires a separate entry.

Sublevel entries in foreign hydromines often are driven using small size monitor jets, sometimes self-propelled units under remote control. In most cases, coal is washed directly into flumes which can handle large lumps. In recent years, compact water turbine powered continuous miners have been used more extensively for development. In these cases, a crusher is not used at the face.

In the Kaiser Sparwood mine, the coal seam is thick (50 ft.), large lumps are encountered, and it was decided to use large 16 ft. diameter sublevel drifts supported by steel arch supports which permit a feeder-breaker to be installed at the face to assure uniform flow to the flumes. Appreciable savings in development costs can potentially be attained by reducing the size of the feeder-breaker which would permit also reducing the size of the drifts to the limit set by ventilation requirements for a blind entry. (This method of development required special approval in Canada).

Further improvements in economy and safety could be attained by further reducing the entry cross-section and using remote control of smaller roadheaders and more compact monitor and crusher equipment and to reduce or eliminate the need for human access to the hazardous face region.

12.5 EFFECT ON COSTS OF SHAFTS OR SLOPES AND HOISTING SYSTEM

For underground hydraulic mines in which coal cannot be flumed to the portal, coal is usually hoisted by a hydraulic hoist system. In many cases, only the fine coal is hoisted hydraulically and the lump coal by skip or belt conveyor. The use of pipes to hoist all or part of the coal permits a reduction of the cross-section area of the shafts or slopes required and reduces the capacity of the production hoist and headframe building. This cost reduction may be more than balanced by increased costs for installation of a crusher, slurry sump and hydraulic hoist pumping station as well as sump cleaning and recovery equipment at the shaft bottom. The use of hydraulic hoisting generally increases the capital investment, and increases the electrical power requirements, but reduces the manpower required and greatly improves the safety and reliability of the hoisting system. The most unreliable components of a typical hydraulic hoist are the coal pumps, which require frequent maintenance. This problem is alleviated by using a pipe feeder (e.g., the Hitachi Hydrohoist) in which the pumps handle mine water instead of lump coal.

If coal is to be delivered from the mine mouth to a preparation plant, the cost of hydraulic transport by the hoist system all the way to the preparation plant may be less than alternate haulage methods, such as a belt.

It is often desirable to separate lump coal underground and hoist it on a belt or skip, using coal pumps to hoist the fines. This reduces the pumping power and reduces the vertical slurry velocity needed to suspend the finer coal. For coal mined by a monitor, the coarse coal above 13 mm size is about 52% of the total (Ref. 461, p. 3). The optimum economic solution is usually to hoist only the fine coal (below 3 to 20 mm) hydraulically. This practice is used in China, Japan, and all Soviet anthracite hydraulic mines and is planned for extension of the Kaiser mine below drainage level.

12.6 VENTILATION REQUIREMENTS

The use of monitor jets to break coal provides added face ventilation due to air entrained by the jet. Also the water droplets at the face reduce the hazard of methane and dust. Therefore, the amount of air required to be supplied to the face is reduced. It is important to operate monitor jets in the proper direction to aid the air flow provided by the mine ventilation system.

12.7 EFFECT ON ELECTRICAL POWER CONSUMPTION

In most hydraulic mines, the major consumption of electrical power is for operation of the surface pumping station and for operation of pumps underground for the hydraulic hoist system.

The power required to supply high pressure water to monitors exceeds the electrical power to operate mechanical mining machinery at the face for equal production rates. Also, the power consumed in hydraulic hoisting may be several times larger than for mechanical hoisting or belts. This is basically because about 3 to 5 tons of water are hoisted with each ton of coal for a coal pump system. With a batch feeder, the ratio of water to coal is still at least 2 or 3 to 1. The result is that hydraulic mines consume more electrical power than a conventional mine. This is true, even when gravity fluming is used instead of shuttle cars and belts for face, secondary and main haulage.

In Soviet hydromines, no electricity is distributed to the faces and water turbines are used to drive light-generators, ventilation fans, and in some cases to recharge compressed gas batteries for monorail delivery vehicles. The primary advantages are the avoidance of electrical hazards in the mine and elimination of the electrical installation costs underground, except to the hydraulic hoist station.

12.8 EFFECT ON COAL PREPARATION

With a hydraulic mine for coal which does not require coal washing, additional costs are usually incurred for dewatering the coal to meet customer requirements. If the coal requires washing, dewatering of raw coal slurry using settling basins (thickeners) and screens is usually adequate to provide wash plant feed slurry. This equipment and flocculation equipment are often required in any case to clarify mine water adequately for recycling through high pressure pumps to monitors in the mine.

Since hydraulic mining and transport produce a higher content of fine coal than mechanical mining, the problem of dewatering of slimes can pose a more severe problem than usually encountered in a preparation plant. Centrifuges, cyclones, vacuum filters or thermal drying may be required, depending on particular coal characteristics and transportation or customer requirements.

12.9 EFFECT ON WATER SUPPLY

A hydraulic mine requires a larger water supply than for a conventional mine and therefore a nearby stream is usually used as a source. However, in some mines (e.g., the German Gneisenau mine) water inflow to the mine exceeds the requirements for hydraulic mining and in fact may present a disposal problem. Therefore no general statements can be made about higher water costs for hydraulic mining except in dry regions such as the Rocky Mountain area where water is generally in short supply.

After original mine start-up, requiring about 20 acre-feet of water per million TPY capacity, the continuing water supply required for make-up due to losses in the moist coal product, refuse disposal and evaporation are generally small (of the order of 50 acre-feet per year per million TPY production rate).

12.10 PRODUCTIVITY AND COST ESTIMATES

Approximate estimates were made of the productivity and costs of various hydraulic mining methods in comparison with continuous mining by the room and pillar method. Fig. 12-1 summarizes the productivity results as a function of seam thickness. Fig. 12-2 summarizes the cost estimates as a function of shaft depth. All costs in this study are derived for comparison with a study by the Colorado School of Mines Research Institute (Ref. 24). The costs do not include a profit or depreciation of capitalized development costs. All cost estimates are based on costs as of January, 1974 to provide relative comparisons, although all costs have increased substantially in 1974 and 1975.

The reference curve A in each figure is for continuous miners by room and pillar with shuttle car and belt haulage to a shaft. This is based on analysis (Ref. 24) for a horizontal 5.5 ft. coal seam and a 300 ft. shaft depth with skip-hoist and two-mile main haulage. The mine includes a preparation plant. The variation of overall mine productivity with seam thickness from 3.5 to 8.5 ft. is estimated from statistical data on similar mines presented by Woodruff (Methods of Working Coal and Metal Mines, Vol. 3, Pergamon Press, p. 230).

The data points marked B & C in Figures 12-1 and 12-2 are the results of analysis by CSMRI for mines with hose and pipe hydraulic transport and hydraulic hoisting by coal pumps. Point B is for a direct feed system and Point C is for a surge feed system behind continuous miners.

Point D is for a mine using continuous miners with gravity fluming for face and secondary haulage to sumps in the main entry with a two mile pipe transport system to the hydraulic hoist.

This case, D, is analyzed as a perturbation from the design of the mine using continuous miners with a direct feed hydraulic transport system as estimated in Ref. 24. The seam thickness is 5.5 ft. and the mining operation is assumed identical except that the mine is assumed to be in a pitching seam at an angle of 5° to 15°. The coal is transported by gravity in open flumes from the face to the horizontal main entries where it is transported in horizontal pipes to the shaft sump for hoisting. The installation of feeders, pumps, hoses and pipes for face and secondary haulage is replaced by an installation of flumes leading to the main entry. Water is brought to each face through one

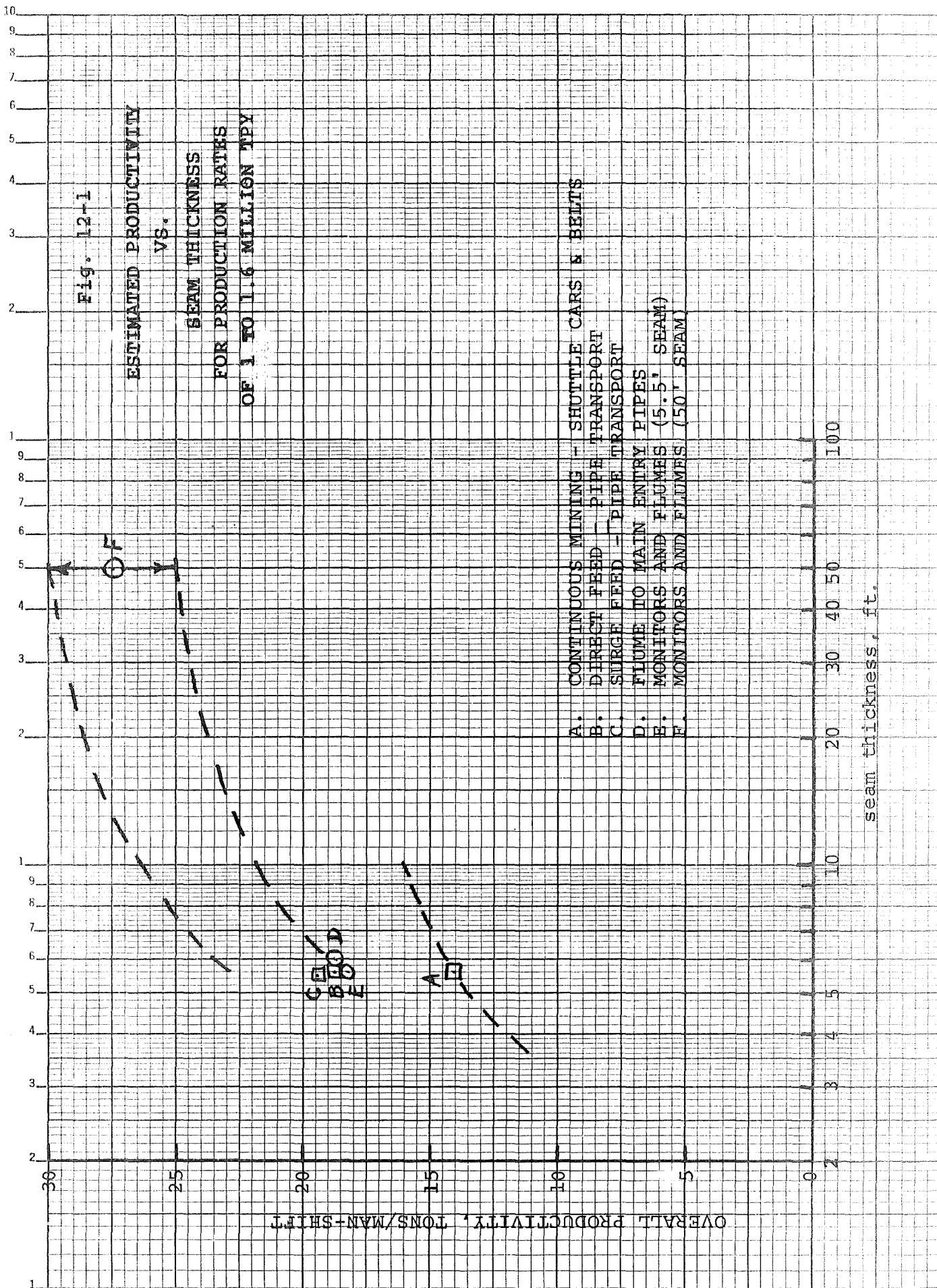
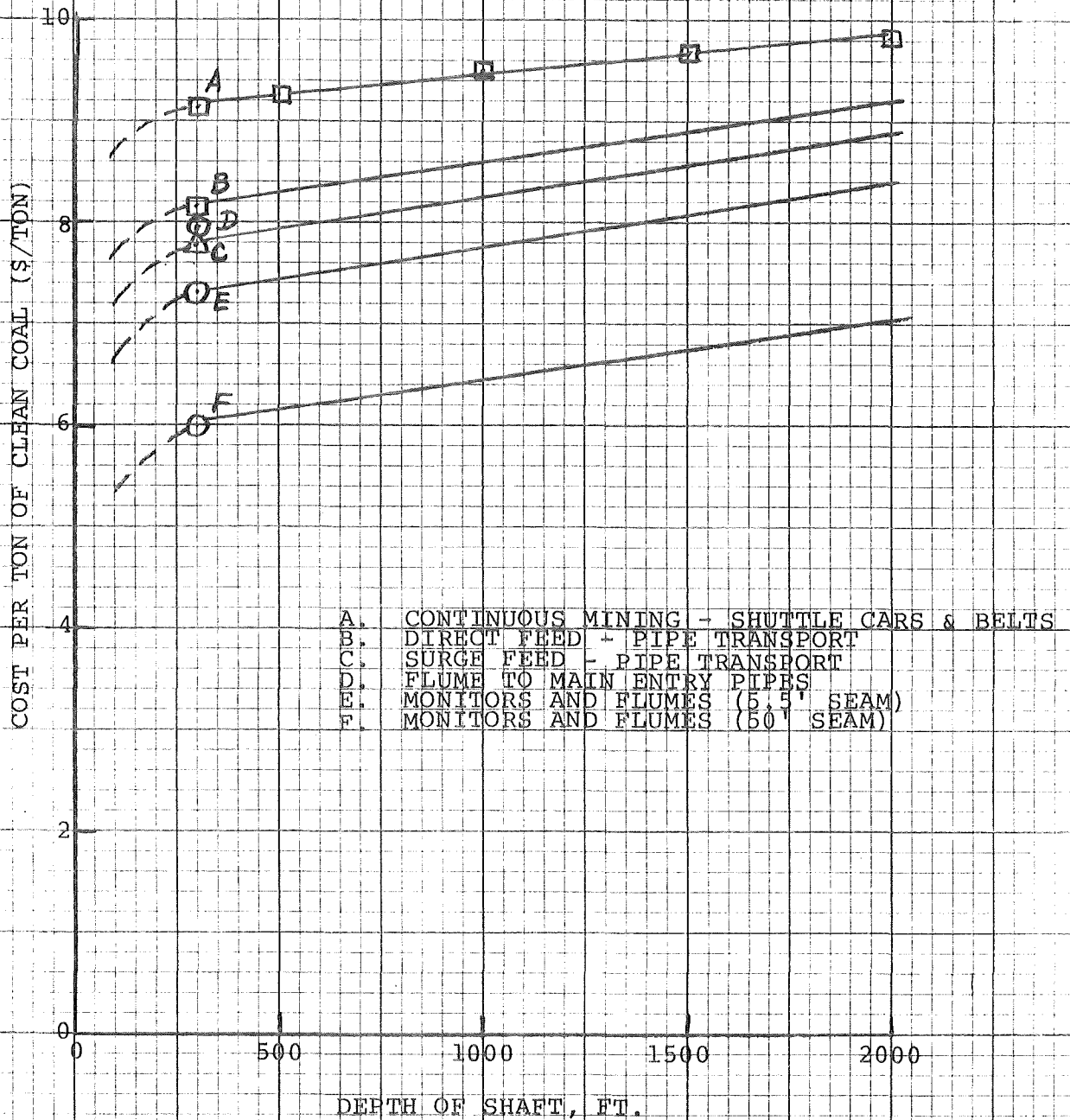


Fig. 12-2

ESTIMATED COST PER TON OF COAL
 BY VARIOUS MINING METHODS
 VS.
 SHAFT DEPTH
 (2 mile - main entry)



10 inch pipe and a low pressure monitor is used to wash coal into the flume behind a continuous miner. As in the reference case, the continuous miner is assumed to be equipped with a built-in breaker to reduce lump size below 2 inches to assure good flow in the flumes.

The manpower is assumed to be unchanged from the reference Case B, so productivity is the same. However, there is a cost saving by reduced capital and repair costs for face and secondary haulage equipment. The reference system had face area capital costs of \$4,413,800 for a mine producing 1,484,000 tons of clean coal per year. By replacing the hose and pipe slurry system at the face with flumes, the face area capital investment is estimated to be reduced by 27%, to \$3,220,000. This includes 7700 ft. of 10" pipe and 2800 ft. of 10" hose to bring fluming water to the 7 faces. Sumps are assumed to collect slurry to feed into the main entry hydraulic transport system at several locations.

The cost of the secondary haulage system is reduced by eliminating slurry pump, slurry feeder, a transformer, cables, a 4 inch drainline and one half of the 10" pipe from each panel. The cost is increased by installing 3000 ft. of flume in each panel, which is moveable as mining progresses.

The cost of the face and secondary haulage system is reduced from \$4,385,000 by 16% to \$3,680,000, although the cost of the main haulage system stays the same.

A comparison of the total initial capital investments is shown in Table 12-1. The use of fluming for face and secondary haulage reduces total initial investment by 8.7% to \$20,183,400. It is assumed that labor and all other operating costs remain the same as for the reference pipe transport mine. The reduction of electrical power costs for slurry transport from the faces is neglected.

By computing the depreciation on all facilities and equipment, the annual depreciation for the fluming mine is reduced to \$1,352,000 per year from the reference \$1,690,739 (Table 8-3 of Ref. 24). The net effect on the cost of coal production is to reduce it from \$8.15 per ton by 2.8% to \$7.92 per ton, neglecting electrical power savings. This makes the costs of Case D about the same as Case C, the surge feed pipe transport case.

TABLE 12-1

Total Initial Capital Investment

(Two mile main haulage & 300 ft. depth)
(Thousands of Dollars)

	Pipe Transport (Horizontal Seam)	Flume to Main Entries (Pitching Seam)
Face Haulage	4,413.8	3,222.0
Secondary & Main Haulage	4,385.0	3,680.0
Shaft and Surface	9,806.0	9,806.0
Miscellaneous	<u>3,475.4</u>	<u>3,475.4</u>
Total Initial Investment	22,080.2	20,183.4

Case E is a mine using continuous miners for development but monitor jets for mining pillars in retreat with roof caving. Transport is by gravity fluming all the way to the shaft sump.

This case is also analyzed as a perturbation of the design of a mine using continuous miners with a direct feed hydraulic transport system (Ref. 24). The seam thickness is assumed to be 5.5 ft., but is pitching at an angle of about 15° so all main entries and sub-level drifts are driven with a true pitch of 4° to permit fluming in plastic-lined steel troughs, all the way to the shaft sump. A feeder-breaker is assumed to reduce lumps to 2 inches at the face to avoid flume blockage (as used in the Kaiser Sparwood mine). Water is supplied from a high pressure pumping station on the surface through pipes to monitors at the face.

The coal disintegration rate from each 2500 h.p. monitor is assumed to be only 100 tons per hour while operating because the seam thickness of 5.5 ft. is much less than the 50 ft. of the Kaiser mine which attains 330 tons per hour. This estimate is conservatively based on the method of Okhrimenko (Ref. 738, p. 7) for estimating coal disintegration rates.

It is assumed that pillars are pulled in retreat by the monitors with roof caving. Entries are 16 ft. wide on 66 ft. centers, leaving 50 ft. by 50 ft. pillars to be pulled by monitor. Therefore, 57.5% of the coal is available to be broken by monitor (75% recovery) while 42.5% is mined by continuous miners on development, with the development coal flumed to the sump.

At full production it is assumed that there are 2 continuous miners operating 3 shifts on development at a production of 582 tons per miner per shift, yielding 700,000 tons of clean coal per year. There are 3 monitor sections operating 4 hours per shift for 3 shifts, each producing 400 tons/shift or a total of $400(3)(3)(200) = 720,000$ tons of clean coal per year. Total production is 1,420,000 TPY, of which 49% is development coal. A third continuous miner section and a fourth monitor section are equipped for standby use.

The labor estimated for the direct feed pipe transport case is reduced by 9% because of reduced labor for operation and movement of flumes as compared to the pipe & pump system. The production rate drops from 1,484,100 TPY to 1,420,000 TPY. The productivity improves from 17.34 tons/man-shift by 5% to 18.3 tons/man-shift.

The costs for this Case E were estimated in detail by dropping out costs for the pipe system, adding costs of monitors, flumes, high pressure pipes to the face, and adding five high pressure water pumps to the surface installation. The total depreciation charges are reduced from \$1,690,739 per year to \$945,300 per year. The labor costs are estimated to be reduced by 9%. The repair and supply costs decrease in proportion to the depreciation. The total mine costs are reduced from \$12,096,589 per year to \$10,343,000 per year. The cost per ton is reduced from \$8.15 per ton to \$7.30 per ton.

The Case F is based on the Kaiser Sparwood hydraulic mine in a 50 ft. steeply pitching seam with fluming to the portal. The productivity is reported to be 25 to 30 tons raw coal per man-shift (Ref. 1100). The lower limit of the band for Case F is drawn through point E on Fig. 10-1. The upper band is 20% higher.

Very approximate cost estimates were made for the thick seam hydraulic mine. It is roughly estimated that costs, excluding profit or amortization of capitalized development costs, should be of the order of \$6 per ton for a mine with hydraulic hoisting from 300 ft. depth and a production rate of one million TPY. The assumptions are again consistent with those of Ref. 24. The shape of the cost curve is sketched in Fig. 12-2 as a function of shaft depth using the point F as reference. It should be noted that the productivity and costs for Case F are derived from limited data available on the Kaiser mine. The driving of long blind entries is assumed, which required special approval in Canada. The safety record of the Kaiser mine indicates that such methods should be considered in the U. S. The cost estimates otherwise are based on U. S. practice in early 1974 and do not reflect the different taxes or other differences existing in Canada, nor the increases in cost since January, 1974.

13.0 APPLICABILITY OF HYDRAULIC MINING IN THE U.S.

The most likely locations for early commercial use of hydraulic monitor mining with fluming in the U.S. are in metallurgical coal deposits in pitching seams above 20° pitch with seam thickness of 6 ft. or greater. Examples are the Thompson Creek Mines of Anschutz Oil Co. near Coal Basin, Colorado, and the Carbon River field in Washington.

Assuming successful demonstration of an economic mining system, it may also be applied to pitching coal deposits in the Grand Hogback coalfield of Colorado, and the Adaville formation near Kemmerer, Wyoming. Timing for this development will depend on the relative costs and environmental impacts for strip mining of coal in the Colorado and Wyoming area, as well as the locations of future large consumers of coal relative to these coal deposits. A power plant on the Colorado river between Greenwood Springs and Rifle, Colorado could make use of coal from the southern part of the Grand Hogback coalfield.

The use of pipe and hose transport of coal with continuous miners is expected to be used more widely in the Appalachian area, particularly if developments are completed to apply it in thinner seams (4 ft.) than presently possible with the Consol system (6.5 ft.).

The use of fluming and hydraulic hoisting of fine coal appears promising for application to the anthracite mine of Bethlehem Mines Corp. at Coaldale, Pennsylvania. Applications in other anthracite mines should be investigated. The method for coal disintegration and for driving entries should be optimized.

If remote-controlled hydraulic monitor mining can be developed for use through small (3 to 5 ft.) raise holes or horizontal boreholes in coal seams, it could be widely applied throughout the U.S. and have a major impact in improving productivity, safety and economy of underground mining.

14.0 NEEDS FOR RESEARCH AND DEVELOPMENT

14.1 PRESENT TRENDS AND POTENTIAL APPLICATIONS

The trends of world development in hydraulic mining are to use monitor jets and gravity fluming to mine pitching seams of bituminous coal with pitch angles above about 5° which cannot be mined as economically or safely by other methods. The most economical applications are those mining metallurgical coal in thick pitching seam deposits above drainage level which can use gravity fluming to the portal. When mining must proceed below drainage, hoisting is usually done by hydraulically hoisting the fine coal with coal pumps and hoisting larger coal by skip or belt.

Advantageous geological conditions for hydraulic mining exist in the Canadian Rocky Mountains and at least two additional hydraulic mines are being planned by Kaiser Resources, Ltd.

Development of hydraulic mining in the U. S. has been delayed because of a lack of knowledge and experience with hydraulic methods by the U. S. mining industry and because many coal deposits can be mined very economically by present methods, including strip mining. However, strip mining has encountered great resistance because of environmental impacts. The development of underground hydraulic mining in the U. S. will proceed when coal deposits with an advantageous combination of characteristics can be identified and feasibility and comparative economic studies be conducted.

The major competition for hydraulic mining in underground mining of pitching western coal seams (above 15° pitch) will be longwall mining, particularly under large depths of overburden where roof control is a problem. With longwall mining of pitching seams, the possibility exists for using gravity fluming down the face and either flumes or pipes for secondary and main haulage, combined with hydraulic hoisting. This system is under consideration by Anschutz Oil Co. for reopening the Thompson Creek mine near Coal Basin, Colorado, using a longwall on a 30° pitch. Even in flat seams, hose and pipe haulage should be considered with longwall methods.

The use of hydraulic transport in hoses and pipes with continuous miners is under development by Consolidation Coal. The Bureau of Mines is supporting development of feeders to extend the technology to thinner seams (4 ft.) for application to continuous mining, longwall or shortwall. This technology is potentially applicable to flat seams throughout Appalachia and the mid-western U. S., and could also be used in western and Alaskan coal deposits. Its broad applicability and high

potential for improving productivity, safety, health, and economy makes it desirable to advance the development of pipe haulage with high priority and to encourage its application by the coal mining industry for use with continuous miners, shortwall and longwall methods.

The next step in development of pipe haulage for continuous miners will be to install a complete hydraulic transport system with 3 to 5 mining faces (Ref. 550). Many practical technical problems must be solved to make the system economical. This work is proceeding with private financial support by Continental Oil Co. and Consolidation Coal. The Bureau of Mines should encourage this development and the licensing of this technology to other mining companies when it can be proven to be practical and economical.

The use of monitor jets and gravity fluming should be advanced for application in pitching coal seams, particularly in Colorado, Wyoming and Washington.

The most likely locations which have been identified for early development include the Carbondale, Somerset and Grand Hogback coalfields of the Uinta Basin in Colorado, the deposits near Kemmerer, Rock Springs and Hanna, Wyoming, and the Carbon River and the Roslyn-Cle Elum fields in Washington state.

These deposits include coal seams of thickness 6 to 93 feet, with pitch angles of 3.5° to vertical. Detailed studies are required to evaluate the merits of hydraulic mining methods in specific deposits in comparison with alternate underground mining methods.

The steeply pitching seams of the Grand Hogback field in Colorado (30° to 80°) and the Carbon River mine in Washington (up to 90°) appear clearly to be minable most effectively and perhaps only by hydraulic methods. One of these steeply pitching deposits could be selected to demonstrate and advance the technology of monitor jet mining and fluming by the sublevel method with caving. The upper seams in both deposits are of small to medium thickness (6 ft.). Therefore, development should emphasize the use of smaller entries and more remote control technology as compared to the present technology in the Kaiser hydraulic mine which uses 16 ft. drifts. The methods demonstrated should be broadly applicable for multiple coal seams above 20° to 30° pitch and with thickness as small as 6 ft. or less in Colorado, Wyoming and Washington.

14.2 KEY PROBLEMS AND RESEARCH NEEDS

14.21 Mining Multiple Pitching Seams (20° - 90°) in the Western U. S.

The primary factor which has delayed the application of monitor jet mining and fluming in the U. S. has been the lack of detailed knowledge of foreign developments by the U. S. coal mining industry. Kaiser Resources, Ltd. of Canada is prepared to license U. S. companies to practice hydraulic mining. However, Kaiser has released publicly only very limited information concerning their mine in British Columbia. Obviously, Kaiser has expertise relating to mining a single thick pitching seam. This technology should also be applicable to mining the thick lower seams (40 ft.) in the Grand Hogback coalfield of Colorado and in the Adaville formation (12 to 93 ft.) near Kemmerer, Wyoming. However, in both locations, the thickest seam is overlain by thinner seams which should preferably be mined first. No major research or development is needed for mining the thick seams (over 12 ft.), although improvements now being conducted by Kaiser (Ref. 1100) should make the systems more economical. The main problem will be to select a method for developing the thinner seams which is feasible and economically attractive for application in mining multiple seams.

The major problems are:

1. Rapid excavation techniques for small sublevel drifts driven in the coal or by ripping rock, and for driving crosscut drifts through rock between seams.
2. Roof support methods, permitting recovery and reuse of support materials or a reliable and low cost method to make the entries self-supporting (like shotcrete). The difficulty of entry roof support increases with mining depth.
3. Adequate face ventilation, protection against outbursts of gas or coal, and avoiding ignition of methane.
4. Remote control methods for operating heading excavation equipment to provide greater safety for the operators.

A key problem in mining relatively thin (4 to 6 ft.) and multiple seams above 20° pitch is the lack of suitable small and safe equipment for driving entries where ripping of roof or floor rock may be required and where maneuverability is desirable to also drive crosscut drifts through rock between adjacent seams. Small machines like the Dosco, or similar small roadheading machines may be adaptable if the rock is not too hard, although they introduce spark and electrical hazards. Impact hammer roadheaders may also be considered.

A circular tunnel boring machine (TBM) is suitable for use entirely in coal, but is not desirable if the seam thickness is less than the diameter of the machine, resulting in mixing of rock with the coal. The smallest TBM presently available (Robbins) is about 7 feet in diameter and is not easily maneuverable to drive crosscuts between seams.

A self-propelled monitor jet is ideal for driving small entries entirely in coal, but cannot make cross drifts in rock, unless the jet pressure were increased to about 600 kg/cm² (8500 psi) or more.

A pulsed water cannon of the type under development in the USSR (Ref. 1110), if proven reliable, appears to meet the requirements for safe driving of small entries in either coal or rock of compressive strength up to 1200 kg/cm² (17,000 psi). It should be relatively maneuverable, with a weight of 12 to 15 metric tons which includes a loader. The machine is powered by high pressure mine water (50 kg/cm², 720 psi) either with an open or closed cycle. The open cycle is preferred for fluming of coal, whereas a closed cycle permits mechanical loading of rock, using only a small amount of water through the pulsed jet at peak pressures up to 8000 to 10,000 kg/cm² (114,000 to 142,000 psi). It is believed that it will not pose a hazard of methane ignition, which is a problem with pick cutters and impact hammers operating in rock or in coal having rock, pyrite or sulfur ball inclusions. The efficiency of the pulsed jet in breaking coal or rock is comparable to mechanical cutting machines. Therefore, it is believed that a water cannon roadheader would prove to be a desirable machine for development of thin pitching coal seams and multiple seams of the type found in the Grand Hogback coalfield and the Adaville formation near Kemmerer, Wyoming, as well as in thin (4 to 6 ft.) pitching seams of bituminous or anthracite coal in other locations.

The technology for developing and mining these thinner seams could be proven out in locations such as the Carbon River field in Washington, which has seam thicknesses from 6 ft. to 12 ft. and pitch angles up to vertical, or the Thompson Creek mine in Colorado, which has 6.5 ft. and 10 ft. seams at about 30° pitch. Alternate test locations could be in the Roslyn-Cle Elum, Grand Hogback or Adaville formations. Evaluation of the relative difficulty of roof support in various deposits depends on further data on the quality of roof rocks, strength of the coal, and the mining depth.

14.22 Mining Gently Pitching Seams (3° to 15°)

Coal seams at pitch angles up to 15° and thickness of 3.5 to 10 ft. can be developed using continuous mining machines by the room and pillar method, followed by the use of monitor jets to pull pillars. Flumes can be used for transport in mines with pitch angles of 3° to 15°, both during development and also to transport coal mined from pillars by monitor jet. The mining plan may use long pillars, diagonal entries or other variations similar to those developed in the USSR.

Possible locations where this mining method could be used are in the Carbondale and Somerset coalfields of Colorado, Rock Springs and Hanna, Wyoming and in Somerset County, Pennsylvania. The problems to be solved include:

1. Develop an optimum mining plan to minimize costs by optimizing the ratio of coal cut by continuous miner to coal broken by monitor jet.
2. Devise methods to wash development coal from behind a continuous miner into flumes, which is compatible with providing roof bolting or other roof support. Shortwall mining methods may be considered. The methods used in the USSR in the Yubileinoe mine should be evaluated for use in gently pitching seams (Ref. 736, pp. 28-31).

14.23 Mining Flat Seams (up to 3°)

Flat seams are typical in Appalachia, the mid-western U.S. and parts of the western U.S. Mining may be done with continuous miners, shortwall, or longwall, with hydraulic transport in hoses and pipes.

Research and development is needed to use smaller area entries, and remote control monitor jets to mine flat seams with roof caving and to feed raw coal slurry into pipes or hoses. This will require development of horizontal boring technology, entry roof support, methods for reducing lump sizes at the face, methods to feed slurry from a flat floor into pipes, as well as instrumentation and remote control methods to permit unmanned mining at the face.

In Appalachia, small entries may be driven from an outcrop, similar to auger mining. In other cases, underground workings will generally be required from which remote controlled mining can be conducted.

14.3 POSSIBLE USERS OF HYDRAULIC MINING TECHNOLOGY

The potential applications for hydraulic mining and transport in the U. S. are so extensive and diverse that it will be necessary to determine priorities and to establish a plan for research, development and demonstrations which will make significant early improvements for the coal mining industry, yet not neglect the long range goal of developing completely remote-controlled and automated mining systems.

It is necessary for one or more capable mining companies to participate in the development and demonstration program. Since the interest of U. S. coal mining companies is to assure profits with minimum risk, it is most likely that a company will adopt hydraulic technology for coal mining if several of the following criteria are applicable:

1. The unit value of their coal is high (preferably coking or metallurgical coal).
2. The selected mining methods do not depart greatly from methods which have been proven successful elsewhere (e.g., the Kaiser hydraulic mine).
3. The company has access to, or control of, appreciable reserves of coal which could be mined economically by the hydraulic method to be demonstrated.
4. The company has adequate capital, a competent research and development organization, and a willingness to invest in development of new technology.
5. The company is not now irrevocably committed to an alternate technological approach for their advanced mining systems.
6. The company also has an interest in adapting the new technology for the mining of other minerals (e.g., uranium).
7. The company has an interest in licensing the technology, in designing or constructing hydraulic mines, and/or manufacturing and selling hydraulic mining equipment to be used by other mining companies.

A company will be less likely to cooperate with the U. S. Bureau of Mines in a publicly open R & D program if it is primarily motivated by item 7 above, in which case their interest will be in acquiring and maintaining a proprietary position with patent protection. Companies which already have patents or a proprietary position are even less likely to participate in Bureau of Mines programs.

Based on the above criteria, several U. S. companies can be identified which meet one or more of the seven criteria and may therefore be interested in hydraulic mining. They can be broken into two groups, depending on the type of their coal reserves, namely pitching 20° or greater, or pitching from 3° to 20°. The companies and location of their coal reserves are given below.

- | | |
|--|------------------------------|
| A. Pitching 20° or Greater | |
| Kerr-McGee | Colorado |
| C F & I Steel Co. | Colorado |
| Anschutz Oil Co. | Colorado |
| Kemmerer Coal Co. | Wyoming |
| Rocky Mountain Energy Co. | Wyoming |
| Donald B. Hume & Associates | Washington |
| Roslyn-Cle Elum Mine
(owner not identified) | Washington |
| Bethlehem Mines Corp. | Pennsylvania
(anthracite) |
| B. Pitching 3° to 20°: | |
| Rocky Mountain Energy Co. | Wyoming |
| Mid-Continent Coal & Coke Co. | Colorado |
| Energy Development Co. | Wyoming |
| Fetterolf Coal Co. (Cerro) | Pennsylvania |
| U. S. Steel Co. | Colorado
and Alabama |

In addition, the Kerr-McGee company is interested in hydraulic mining of uranium, but its coal reserves now are mainly in flat deposits, except for property in the Grand Hogback.

14.4 PLANS FOR DEVELOPMENT AND DEMONSTRATION

It appears that a demonstration of hydraulic mining in steeply pitching seams (20° or more) should be conducted in bituminous coal seams in Colorado, Wyoming or Washington. The goal should be to develop technology applicable to multiple seams in the thickness range of 6 to 93 ft. at pitch angles of 20° or more. The methods should be applicable for mining steam coal in Colorado or Wyoming at a price range below \$10 per ton

to permit competition within 5 to 10 years with strip mined coal in that area. If the methods are applied to coking coal at Thompson Creek, Colorado or in the Carbon River coalfield in Washington, mining costs may exceed \$10 per ton and still be very competitive in the next few years.

The companies having coal deposits at pitch angles of 5° to 20° are generally mining the seams by continuous mining methods. Longwall methods are also planned by Mid-Continent Coal and Coke Co. The seams are generally not over about 8 ft. thick and therefore the economic gains to be obtained by converting to hydraulic monitors and fluming are not major. For this reason, it appears unjustifiable to conduct a substantial government-funded program to improve the technology specifically for these gently-pitching seams. The demonstration of monitor jets and fluming in steeply-pitching seams will provide data which should also be applicable for the gently-pitching seams.

In addition to demonstration of monitor jet mining in pitching seams through manned entries, research should be conducted leading to remote controlled monitor jet mining and fluming through small up-raise borehole entries at ranges greater than 250 feet, (the approximate present limit for coal augers). This technology would permit reducing the volume of development workings in a mine and removing men farther from hazards near the mining faces.

Further study is needed to optimize a hydraulic mining system for the pitching anthracite seams in Pennsylvania.

15.0 CONCLUSIONS

1. Hydraulic mining technology using gravity fluming is now being successfully applied in pitching coal seams in the USSR, the Peoples Republic of China, Japan, Canada and Germany. Additional hydraulic mines are being planned for pitching seams in Canada, Germany and the USSR.
2. Hydraulic mining using monitor jets and flumes can be used in coal seams with pitch angles greater than 3° to 5°. It is the safest method of underground mining because of the reduction of hazards associated with methane and coal dust explosions, electrical equipment, roof falls and transport system failures. This is achieved by water suppression and dilution of methane and coal dust, elimination of electrical equipment near the face, removal of workmen from the hazardous face area, and improving the reliability of the coal transport and hoisting systems.
3. Hydraulic mining can reduce the dust pollution in a mine by a factor of 5 to 10, reducing ventilation air requirements and resulting in virtual elimination of pneumoconiosis (black lung) as a health hazard.
4. The Kaiser hydraulic mine in British Columbia has achieved the highest productivity reported for any underground coal mine in the world (25 to 30 tons per man-shift) and has established safety records for coal mines in Canada. It appears that the production costs have been relatively low because of a combination of favorable factors, including the fact that fluming to the portal was possible. The mine is now being equipped to hoist coal from below drainage level.
5. For thick (12 to 50 ft.) pitching seams of soft bituminous coal, overall productivity can be in the range from 20 to 30 tons per man-shift. Production costs, excluding profit and amortization of development excavation costs, are estimated to be in the range from \$5 to \$7 per ton of clean coal for mine depths up to 2000 feet, based on January, 1974 costs. The costs are lower than by other known underground mining methods, particularly when raw coal can be flumed to the portal without installing a hoist system.

6. For most pitching coal deposits (particularly deep gassy seams) at pitch angles above 8° , hydraulic mining with gravity fluming and hydraulic hoisting permits higher productivity, better health and safety, and lower production costs than alternate mining methods. The economics is improved as the seam thickness increases.
7. The most favorable conditions for hydraulic mining in the U.S. are generally in pitching coal seams in the states of Colorado, Wyoming and Washington. One of the uncertainties which may place limitations on the use of hydraulic mining in Colorado and Wyoming is the availability of water. However, the water requirements for hydraulic mining are much less than those contemplated for coal gasification, liquefaction, pipeline transport or oil shale processing in these regions. In several locations in Colorado and Wyoming, pitching coal deposits exist within reasonably short distances from major rivers and other streams. Recycling of water and proper treatment of refuse can prevent water pollution.
8. The Grand Hogback coalfield represents a major resource of steam coal in steeply pitching seams which can probably be mined most economically by hydraulic methods. One seam is 40 ft. thick. Total reserves are estimated to be 885 million tons. Further investigations of the geology and hydrology of the Grand Hogback field are warranted, and tests to verify the feasibility of sublevel hydraulic mining with monitors and flumes should be conducted. Economic studies should be made to determine whether steam coal from underground hydraulic mining in this area can compete with coal from other sources, including strip mines, within the near future.
9. Since the profitability of underground mining depends on the value of the coal, early exploitation of underground hydraulic mining is more likely to occur in deposits of metallurgical coal, which commands a higher price than steam coal. For this reason, the deposits of high quality coking coal in the southern part of the Carbondale coal field of Colorado are likely to be of commercial interest for hydraulic mining at an early date if it can be shown that hydraulic mining is more economical than the present methods. In particular, the coal seams near Coal Basin at pitch angles above 15 to 20° cannot be mined economically by continuous miners. Longwall mining at 30° pitch is being planned by Anschutz Oil Co. for the Thompson Creek mine, possibly with gravity fluming. Seam thicknesses are 6.5 and 10 ft. Further feasibility studies of hydraulic mining using monitors and flumes in the pitching seams of coking coal near Coal Basin, Colorado are warranted to determine whether monitor jet systems can make significant improvements.

10. The thick pitching (20°) deposits of steam coal of the Adaville Formation near Kemmerer, Wyoming provide a major energy reserve with good potential for underground hydraulic mining. The deposit is now being mined by open pit methods. Proper exploitation to mine the coal at depths greater than about 1000 ft. would require a major capital investment to establish a complex of one or more underground hydraulic mines with hydraulic hoisting (at least of the fine coal). The timing for development depends on the relative costs for strip-mined coal in the future from this and other deposits in the area.
11. Pitching steam coal deposits near Rock Springs and Hanna, Wyoming appear to meet requirements for hydraulic mining, although further investigation is necessary.
12. Pitching coal deposits in the state of Washington include the Carbon River and the Roslyn-Cle Elum fields, both of which are potentially minable by monitor jets and fluming. Plans are being made to reopen the Carbon River field to mine the steeply pitching seams hydraulically. The coal is applicable for export as coking coal, or for local industrial use. The Roslyn-Cle Elum mine is also well located to ship steam coal to the west coast.
13. Pitching coal deposits which may be mined by hydraulic methods also exist in Alabama, Arkansas, Virginia, Somerset County, Pennsylvania and in the Anthracite fields of Pennsylvania. However, further investigation is required to define the geological and hydrological conditions and to evaluate the desirability of particular hydraulic mining methods.
14. The use of small borehole monitor jets to drive ventilation raises in coal seams, to permit methane drainage, to prevent coal and gas outbursts, or to provide small entries for remote mining of lifts with a monitor jet has high potential for improving productivity and safety in underground hydraulic coal mines. The Russian and German developments in this field provide a basis for further development. A primary advantage of an up-raise borehole monitor is that the hole is larger than the monitor device and with large water flow there is less likelihood of squeezing of coal and trapping the device than with a mechanical drill or raise borer.
15. Further study is needed to optimize entry driving systems, roof support and material haulage for medium thickness (6 to 12 ft.) seams which pitch at 20° to 90°.

16. The development of hose and pipe transport of coal in underground coal mines has potential for improving the economics and safety in mining flat seams.
17. The use of high pressure (over 5000 psi) small diameter jets for cutting coal is primarily useful in combination with mechanical breakage of coal for longwall machines or continuous miners. The primary advantage would be dust reduction and the production of larger lump sizes.
18. Pulsed water cannons with peak jet pressures up to 100,000 to 150,000 psi show potential for use in small maneuverable roadheaders for driving small entries in hydraulic mines.
19. The major characteristics of hydraulic mining machinery, namely small size monitors and small cross sections for water pipes and slurry conduits, are well adapted to permit mining by remote control through small entries. The potentialities for greatly improving safety, productivity, and reducing costs warrant a major effort to develop remote controlled hydraulic mining technology for use in small unmanned entries. Potentially large increases in coal production could be obtained without the need for proportional increases in underground manpower and the associated hazards.

If remote controlled mining with hydraulic transport in pipes can be developed for flat seams, the methods are likely to be of most immediate value in mining seams less than 6 ft. thick in the Appalachian and mid-western regions, where productivity is generally lower than in thick deposits of the western U.S. Within the next few decades, it is expected that ever increasing development will occur to apply remote control to underground mining of coal and uranium using hydraulic transport. The technology of underground coal and uranium mining may come to resemble more closely the production of oil and gas. The various types of hydraulic technology for exploiting deposits of fossil fuels and of uranium will be mutually beneficial. The methods for remotely mining coal and uranium may also be adapted for underground mining of tar sands, phosphates or other soft minerals. Extension of the technology to hard ores will require higher liquid jet pressures or other rock disintegration methods.

16.0 RECOMMENDATIONS

1. A portable monitor jet test system should be developed and a series of short duration (e.g., one minute) hydraulic breaking tests conducted in various U.S. coal deposits to measure breakage rates as a function of pressure, nozzle diameter and range. The test data should be taken with a modern high quality monitor and will permit determination of the feasibility of monitor jet mining of specific coal seams and optimization of jet parameters. Tests should be conducted in potentially favorable seams of bituminous and also anthracite coal, in accessible locations on the surface or in underground mines.
2. A demonstration of hydraulic mining with monitors and flumes should be conducted in a pitching seam (20° or more) in Colorado, Washington or Wyoming. The Thompson Creek or Carbon River deposits appear favorable for an early demonstration. More detailed geological and hydrological study of the most favorable coal deposits should be conducted to permit optimization of the hydraulic mining demonstration system.
3. Design studies should be conducted to optimize systems for driving manned entries, and for roof support and material supply in 6 to 12 ft. seams of bituminous coal, pitching at 20° or more. Consideration should be given to possible modifications of existing mine safety regulations to permit use of new mining techniques and to assure safety.
4. Design studies should be conducted to optimize a hydraulic mining system for pitching anthracite seams.
5. Research and development should be conducted to demonstrate the feasibility of remote-controlled monitor mining of bituminous coal through small (2 to 5 ft. diameter) unmanned entries, both in pitching and flat seams.