copy 1

APPLICATION STUDY OF PORTABLE UNDERGROUND HARDROCK CRUSHERS

Prepared for:

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by:

RAPIDEX, INCORPORATED
P.O. BOX 520
18 SARGENT STREET
GLOUCESTER, MASSACHUSETTS 01930

RAPIDEX, INC.

FINAL REPORT

on

USBM Contract No. J0265006
Application Study of Portable Underground Crusher

DECEMBER, 1976

DISCLAIMER NOTICE

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

OFR 93-77

(this page replaces old Title Page)

REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Application Study of Portable Underground Hard Rock Crushers		5. Report Date August 1976
		6.
7. Author(s) Carl R. Peterson Allan T. Fisk Richard E. Brooks		8. Performing Organization Report No.
9. Performing Organization Name and Address Rapidex, Inc. P.O. Box 520 Gloucester, MA 01930		10. Project/Task/Work Unit No.
		11. Contract or Grant No. J0265006
12. Sponsoring Organization Name and Address Office of the Assistant Director--Mining Bureau of Mines Department of the Interior Washington, D.C. 20241		13. Type of Report Final
		14.

15. Supplementary Notes

16. Abstract

In many underground mining operations the highest cost is the loading and haulage of run-of-mine ore. Ore hauling costs can be reduced significantly with the use of belt conveyors, a common practice in coal and other soft mineral mines, if oversize ore can be eliminated prior to conveying, hence the demand for crushers close to production areas. Portable feeder-breakers are used extensively in conveyorized coal mines, but no such equipment is available to extend the benefits of belt conveyor haulage into hard rock mines of low to medium headroom. A hard rock crusher that could be easily moved would permit the use of lower cost haulage means, and would improve the safety and productivity of all elements in the underground ore handling system.

This report describes a study to determine the optimum design parameters, and provide a concept, for the design of a low profile, hard rock, portable underground crusher in order to insure that future development will lead to maximum utilization by the industry. The recommended design is a rotary jaw concept.

17. Originator's Key Words

Crushers
Portable Crushers
Jaw Crushers
Roll Crushers
Underground Mining:
Metal & Nonmetal Mines
Room and Pillar Mining
Belt Feeders
Feeder Breakers

18. Availability Statement

19. U. S. Security Classif. of the Report	20. U. S. Security Classif. of This Page	21. No. of Pages	22. Price
Unclassified	Unclassified	123	

-FOREWORD-

This report was prepared by RAPIDEX, INC., Gloucester, Mass. under USBM Contract Number J0265006. The contract was initiated under the Advancing Metal and Nonmetal Mining Technology Program.

It was administered under the technical direction of Twin Cities Mining Research Center, with Mr. Sam G. Demou acting as the Technical Project Officer. Mr. George A. Honold 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 May 18, 1976 to August 7, 1976. This report was submitted by the authors on August 30, 1976.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION ONE

INTRODUCTION

1.1 Background and Purpose

A study by Dravo Corporation (1) points out that in many mining operations the highest cost operation is the loading and hauling of ore (32 percent of operating cost for medium and large scale room-and-pillar mines). This report indicates that significant improvements could be expected in ore handling if smaller portable crushing units, for use relatively close to production areas, were available for the harder materials in underground mining.

Another study of five underground mines (2) using five different mining methods in quite different rock types, indicated that oversize ore is the single most important problem in reducing the productivity of the ore handling system , with oversize ore handling accounting for 15 to 25% of the total man hours spent in ore handling. Furthermore, this study showed a correlation between exposure to handling oversize ore and percent of total ore handling accidents.

Ore hauling costs in room and pillar mines can be reduced significantly with the introduction of conveyor haulage systems, a common practice in coal and other soft mineral mines of generally horizontal configuration. In fact, the ton-mile cost of conveyor systems can be as low as one-tenth that of rubber tired haulage. Conveyor systems in turn can be made less costly and much more reliable if oversize ore can be eliminated prior to conveying--hence the demand for crushers close to production areas in such mines. These savings are already enjoyed in mines handling soft materials and in at least one large room-and-pillar copper mine handling medium strength ore, but no suitable portable crushers are available to extend these benefits to room-and-pillar mines handling strong ores.

Other mine types, handling massive or vertically extending orebodies, such as block caving, sub level caving, open and shrinkage stoping, and cut and fill, frequently employ a variety of ore handling means, on multiple levels, with considerable vertical, as well as horizontal, motion between the "production" site (for example, a draw point) and the shaft or portal. As indicated in reference (2), oversize ore handling also adds significantly to ore haulage costs in these mines, and for a variety of reasons, none of which need involve belt conveying. This is particularly true in multi-level operations where ore is transferred repeatedly from one system to another.

Again, then, it would be advantageous to crush the ore close to the production site to ease all downstream ore handling problems.

1.2 Summary and Major Conclusions

This report describes a study to determine the optimum design parameters of a low profile hard-rock, underground, portable rock crusher for maximum utility by the mining industry, and to provide concepts for the design of such a machine.

The study included a survey of available literature and contacts with 44 mines and 30 manufacturers. Both hard and soft rock mines were contacted, the latter in an attempt to establish some background in the use of portable crushers where suitable machinery is available. In brief summary, the following major conclusions can be stated:

> The use of portable crushers close to production sites would provide significant haulage cost reductions in both room and pillar and non-room and pillar mines.
>
> Where machine dimensions are the principle deterrent to portability (low head room room and pillar mines and most non room and pillar mines where typical drift dimensions are small), maximum crusher dimensions should be about 7-9 feet high by 8 feet wide. Within reason, length is not critical. Throughput should be 100-300 total tons per hour in most cases.
>
> Where installed size is not a deterrent (high head room room and pillar mines like limestone and perhaps oil shale mines), substantially new crusher concepts are not required and adequate equipment, though large, is already available. However, improvements in portability can be made by proper design of modular assemblies, operating savings can be achieved if lower loading heights are provided, and new low profile concepts would be applicable.
>
> For belt conveying of crusher discharge (probably a desirable goal in any case), product size should be about minus 8 inches or less for very dense ores.
>
> Critical feed opening size for low profile machines should be about 30 to 36 inches.

Where possible, scalping of feed to avoid unnecessary crushing of beltable material should be provided.

Portability particularly of low profile machines, can be enhanced by employing separate units such as hopper-feeder, or hopper-feeder-scalper and crusher. Separating functions also eases maintenance problems.

For medium and hard rock, jaw crushers, or units using similar principles are preferred. Three novel low head room concepts are presented, although only one of these is recommended for immediate development.

Separate means, such as hydraulically powered hammers, should be provided to break occasional very oversize feed, thus permitting reasonably sized crushers to handle all of the throughput.

Such separate means, if successful, could have significant application in non-room and pillar mines independent of the existance or use of portable crushers.

The following report includes both quantitative and qualitative justification of these conclusions, and detailed descriptions of recommended new crusher concepts. Section 2 presents general requirements in brief form, thus providing a proper perspective for what follows. Section 3 then discusses present crusher types in terms of appropriate parameters for comparison to the requirements of portable underground crushers. Section 4 discusses various types of mines in general terms, to outline where portable crushers might advantageously be used. Section 5 expands upon this discussion with selected examples of how portable crushers are being used, or could be used if available, in specific mines. Section 6 contains a compilation of the data gathered from the mining operations while Section 7 presents an example of the economic gains that can be expected from the application of portable crushers. Conclusions are presented in Section 8. Three novel low profile crusher concepts are presented in detail in Section 9, although only one is recommended for immediate development in Section 10.

SECTION TWO

TYPICAL PORTABLE UNDERGROUND HARD ROCK CRUSHER REQUIREMENTS

The basic concept under investigation here might better be described by the phrase "decentralized crushing to allow automated ore haulage". Clearly this means more and smaller crushers exhibiting some degree of mobility, and automated ore haulage (usually) means belt conveyors. The tradeoff is a necessarily more costly crushing system against a more efficient and productive ore handling system. From the crusher manufacturer's point of view the challenge is to achieve small size and portability without sacrificing too much in the important areas of feed opening, throughput, system availability, and capital and operation costs.

In order to better understand that which follows and to establish a common basis for discussion within the purposes of this study, a few definitions are in order:

"Portable" simply means that the crusher is moved periodically in order to be close to production, thus minimizing costly haulage of run of mine material. Within this simplified definition however, portability has quite different meanings in mines of widely varying ore bodies and mining plans. We shall further assume that a portable crusher is one that can be moved through standard mine passageways with minimal dismantling, and can be set up with little or no site excavation.

"Underground" is obvious, and when taken with "portable" brings to mind such terms as low, narrow, horizontal, light, serviceable, and mobile. This study may define a machine that is also applicable to some above ground installations but no attempt will be made to enhance such applicability at the expense of underground performance.

"Hard-rock" is sometimes taken to mean "non-coal", but this broad definition would include many weaker mineral mines not in need of the fundamentally new equipment that is the subject of this study. Many of these non-coal mines have, however, developed highly efficient and mechanized coal-like mining methods that would be applicable to hard-rock mines if suitable equipment (crushers) were available. We have therefore gained valuable information by studying these mines, but the intended beneficiary of this investigation is the underground "hard-rock" industry, defined as those mines that cannot economically make use of presently available portable underground crushers.

To begin, let us attempt to define approximate requirements in order to establish a background for further specification of performance parameters, and to form the basis for a critical examination of existing crusher designs. In fact, it seems clear that no single "optimum" set of parameters can ever be sharply defined. However, with adequate documentation and an appreciation of likely individual case variations, such an approximate set of parameters can serve as the basis for new concept generation and further development work.

2.1 Portable Crusher Applications

Before defining what a portable crusher is, we need to know how it will be used. Fortunately for the purposes of this study, portable underground crusher applications may be divided into two rather distinct categories, and one of these, though worthy of further thoughts and development, does not require fundamentally new hardware development. The distinction, perhaps predictably, is primarily one of physical machine size, although, to a lesser degree, distinctions can also be made in the desired degree of portability within a given size category.

The first category, which we shall dismiss for the moment, is one in which machine size, per se, is not limiting. Applications in this category are high head-room room and pillar mines, such as large limestone mines having 35 foot backs , and, in the future, oil shale mines having even higher backs. While significant portability improvements can be made in assembly methods and general layout, as discussed in Section 9, this category of applications can in general be satisfied by existing manufacturers through modification of essentially standard machine components.

The second category is that in which machine size is very much a limiting factor--so much so that today's standard hard rock primaries are simply not applicable. The two general mine types falling in this category include, obviously, low head room room and pillar mines and, perhaps not so obviously, most mines with vertically oriented ore bodies. The latter include caving mines, whatever the caving mechanism (block caving, sub-level caving, etc.), and other generally vertical mine plans such as open stope, shrinkage stoping, cut and fill, etc.. For purposes of this study, these mines are collectively characterized by gravity delivery of ore to a stationary, or nearly stationary, draw point or chute from which the ore is handled (and often rehandled) by a variety of means in both the horizontal and vertical directions. Even though massive ore bodies may be involved, typical drift dimensions in such mines are not large, on the order of 8 to 12 feet high by not much greater widths.*

Both mine types in this category of "small" applications suggest maximum installed crusher sizes of 7 to 9 feet high, 8-10 feet wide, and any reasonable length (the latter determined by transport conditions rather than installed dimensions). It is important to note that this height includes whatever overhead feed components (and dump space) may be required by vertical feed crushers--thus standard top fed jaw crushers, which would normally be selected for hard rock, are much too tall.

Portable crushers will receive run of mine material from the "face" regardless of the mining method or the primary haulage system used, and then crush this ore and feed it into a more continuous and efficient ore haulage system. Within these applications it appears that for a decentralized crusher arrangement a throughput of 100 to 300 tons per hour will suffice. Although there is no clearcut limit, this throughput is obviously a function of the size of the mining unit it services, and the ability, within the stated drift dimensions, of the primary haulage system to deliver material to the crusher. Thus it is not surprising that a limited range of throughputs will serve a wide variety of mining operations.

2.2 The Input to the System

Just like the very large central crusher located (probably) at the shaft, the proposed decentralized portable crusher system must handle ROM (run of mine) ore. This fact, when taken with the low headroom restrictions, will continually challenge the would-be portable crusher designer.

A study (3) by the U.S. Bureau of Mines in five underground mines, utilizing five different mining methods, in extremely different types of rocks, showed a striking similarity of "oversize ore", not only in mean size but in shape as well. Table I presents these results. The indicated size uniformity is considered misleading, particularly in view of the fact that the study did not attempt to

*See, for example, reference 5 and Section 6 of this report.

TABLE I

Oversize Ore Characteristics

Mine (3)	Mining Method	Oversize Dimensions -ft.
Quartz Fissure Vein	Shrinkage Stoping	2.7 x 1.9 x 1.1
Magnetic Iron Ore	Sublevel Stoping	3.0 x 1.9 x 1.0
Bedded Shale	Room and Pillar	3.0 x 1.8 x 1.1
Slatty Greenstone	Backcut and Fill	4.3 x 2.4 x 1.2
Porphyry Copper	Gravity Block Cave	2.7 x 1.5 x 0.9
	Average All Mines	3.1 x 1.9 x 1.1

Fragment Size Distribution (5)

	Percent of Ore Size, Ft.			
Block Cave Mine	5 plus	2-3	1-2	minus 1
Creighton	30	20	40	--
Thetford	20	25	25	30
Mather	5	10	15	70
San Manuel	Fine Ore			
Climax	7	24	23	46
Grace	50	20	20	10
Cornwall	10	20	20	50
Urad	40	15	15	30

determine the percentage of ore exceeding the stated oversize. The shape trend of this data (3:2:1) is more interesting, indicating a condition somewhere between block and slabby. Larger variations in size of oversize are supported by another study (5) which was concerned with block caving mines. Results of this study, also presented in Table I, characterize the block cave mine of the preceding study as having "fine ore". There is clearly no single optimum crusher feed opening for these, let alone all, block caving mines, although it is probably safe to say that block caving permits the least control of fragment size and can thus be expected to present highly variable conditions.

Mining plans relying on drilling and blasting for fragmentation control will, no doubt, show greater uniformity in size of oversize, but great variations are to be expected in the size distribution of ROM ore from mine to mine. Assuming a successful crusher can avoid direct attack of the three-to-five foot major fragment dimension indicated in Table I, and assuming some form of control over occasional abnormal oversize*, it is likely that minimum or "critical" feed openings in the 30-36 inch range will satisfy a very large percentage of mines.

2.3 The Output from the System

To establish approximate product size, let us assume that the product is to be belt conveyed. In most cases this will be true, and it is expected that maximum economic benefit will occur in this combination. The feeder-breaker, so successfully used on coal mine section belts, is generally set to produce nine inch maximum lumps for 36 inch belts (5). For first-cost and other reasons, this belt width appears to be very common for section and feeder applications, and for the denser-than-coal ores found in the hard rock industry, a maximum product size in the range of 6-8 inches is appropriate. It is interesting to note that even for very large oil shale installations (very wide belts) a six inch product is recommended (4).

2.4 Summary of Crusher Requirements

In summary, approximate parameters for the development of portable underground hard rock crushers are as follows:

---

*Feed breakage is discussed separately in Section 8.

Input	Hard, Abrasive Ore and Rock
Discharge	To Standard Conveyor
Critical Input Dimension (CID)	30-36 inches
Product Size	6-8 inches
Throughput	100-300 tons per hour
Height (installed)	7-9 feet
Width (installed & tramming)	8-10 feet
Site preparation	Little or none, one shift move

It appears that there is relatively little need to simultaneously develop a range of machinery between these small units and the large central primaries now being used. Ultimately a range of intermediate sizes will be desirable, of course, but this can easily be developed from low head room equipment meeting the above specifications.

As will be illustrated in the following section, these requirements cannot be met by existing hard rock crushing equipment. In fact, noting that the desired dimensions include whatever overhead clearance is needed to load the crusher proper, and space underneath to deliver its product (assuming a typical vertical jaw or gyratory design), it is obvious that standard machines are far from satisfactory. It follows, then, that satisfactory new concepts cannot be found among minor variations of standard concepts: the sought after design will differ substantially from present designs. At the same time, it would be comforting if a new concept did not depart substantially from the basic comminution means of proven designs. Economical crushing of hard rock, day in and day out, through many millions of tons, is, after all, a rather difficult task, even without severe space limitations, and proven means should not be so quickly discarded.

The inventor's task is not quite so formidable as the preceeding may suggest. In comparison to a typical aggregate production application for example, some aspects of the portable application actually ease the design problems: The crusher is needed only for oversize (unbeltable) material. Thus, while the crusher should avoid fines, it has no rigid product size requirement other than maximum size, and essentially no product shape requirement (a requirement that justifies some rather subtle variations of crusher geometry in many conventional applications). Furthermore, if the crusher is designed to pass undersize material freely, or if its feed mechanism provides scalping to bypass smaller material, much of the throughput will be "free", a provision which will also reduce the production of fines, and, more importantly, dust.

Section 9 describes low head room, hard rock, portable crusher concepts which may meet the indicated requirements, and one of these, at least, uses the proven principles of conventional jaw crushers.

SECTION THREE

SURVEY OF PRIMARY CRUSHERS & PRIMARY CRUSHING

Many manufacturers were contacted in an extensive effort to include all available equipment and manufacturing capability in this study. Appendix A is a list containing the names and (if available) addresses of those manufacturers who were contacted. Although not all were responsive, many were quite helpful and the majority expresses the opinion that they would need the results of this study if the industry or any single manufacturer were to consider the development of portable, underground, hardrock crushers.

An extensive literature search was also conducted, and the pertinent work is included in the bibliography. References to this list are found throughout this report.

3.1 Definition of the Application

This study was neither intended, nor will it attempt, to instruct the reader in the complete art of primary rock crushing. There are many good references in this area; notable among these is McGrew (6). Our goal is to define the optimum parameters for the design of a portable, underground, hard rock crusher in order to insure that future development will lead to maximum utilization by the industry.

In summary then, we want to study present crusher types with an eye toward moving them around in hard-rock mines. Though small, these units will handle essentially as mined or ROM material, and should rightfully be called "primary crushers".

3.2 Crusher Types and Operating Characteristics

There are three basic classes of crushers, which, when restricted to the task of underground primary (large feed) crushing can be listed as follows:

(1) Pressure Crushers--This category includes gyratory and three types of jaw crushers.

(2) Impact Crushers--The only "primaries" in this category are the hammermill and the impactor.

(3) Combination (Sledging) Crushers--Included here are single or double sledging roll crushers and the relatively new feeder-breaker.

3.2.1 Pressure Crushers

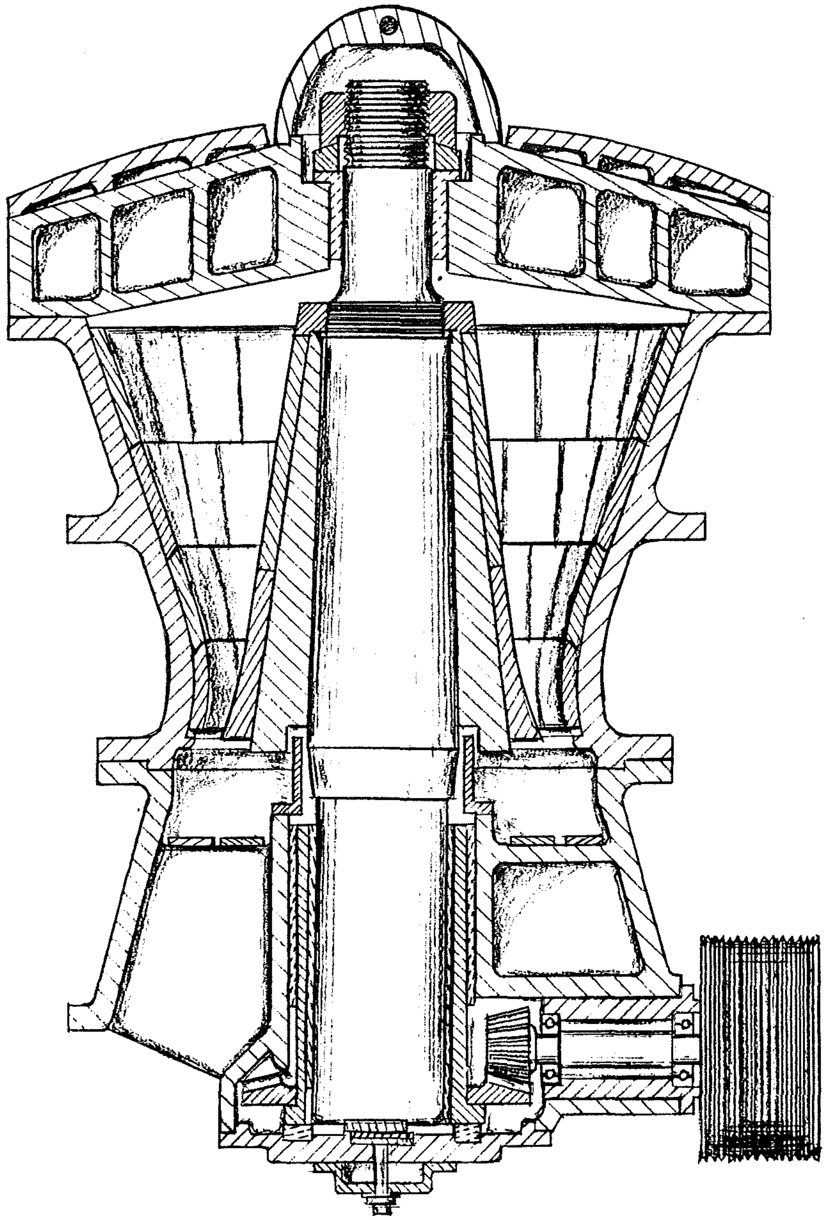
This class of crusher historically has been used on the strongest ores. Crushing is accomplished by relatively slow moving members exerting very high force levels. Understandably, these crushers are typically very big, very strong, and heavy.

3.2.1.1 Gyratory Crushers

Figure 1 shows a simplified section of a typical gravity fed gyratory crusher. Clearly the typical portable underground crusher requirements presented in Section 2 cannot be met by a standard gyratory. However, because the crushing action of the gyratory works well on hard rock, the portable crusher designer should be aware of the favorable features exhibited by this important member of the primary field:

Features of Gyratory Crushers (6)

1. High capacity per dollar of investment.
2. Annular discharge opening minimizes slabbing; makes for more cubical product.
3. Shape of receiving openings favorable for slabby material. This, plus point 2, gives the machine a distinct advantage over the jaw for handling thinly stratified stone.
4. Long receiving openings, plus large area, tend to minimize bridging.
5. Double receiving openings permit dumping from two sides of crusher.
6. Relatively low flywheel effect minimizes starting peaks; also allows the machine to stop quickly when power is cut off due to over-loads caused by tramp iron or choking.
7. Machine can be serviced by simple overhead crawl-type hoist, whereas jaw crusher requires crane with travel in two directions to properly handle parts.
8. Relatively high pinion shaft speeds permit use of higher speed motors, and lower-ratio drives.
9. Lubrication is simpler and more economical than is possible to achieve in the jaw crusher.



Typical Gravity Fed Gyratory Crusher

Figure 1

10. Cost of foundation will usually be lower than for the jaw crusher.
11. Necessary safety guards are less extensive than for the jaw crusher.

3.2.1.2 Jaw Crushers

There are two popular types of jaw crushers; the Blake or double toggle type as shown in Figure 2, and the overhead eccentric or single toggle type shown in Figure 3.

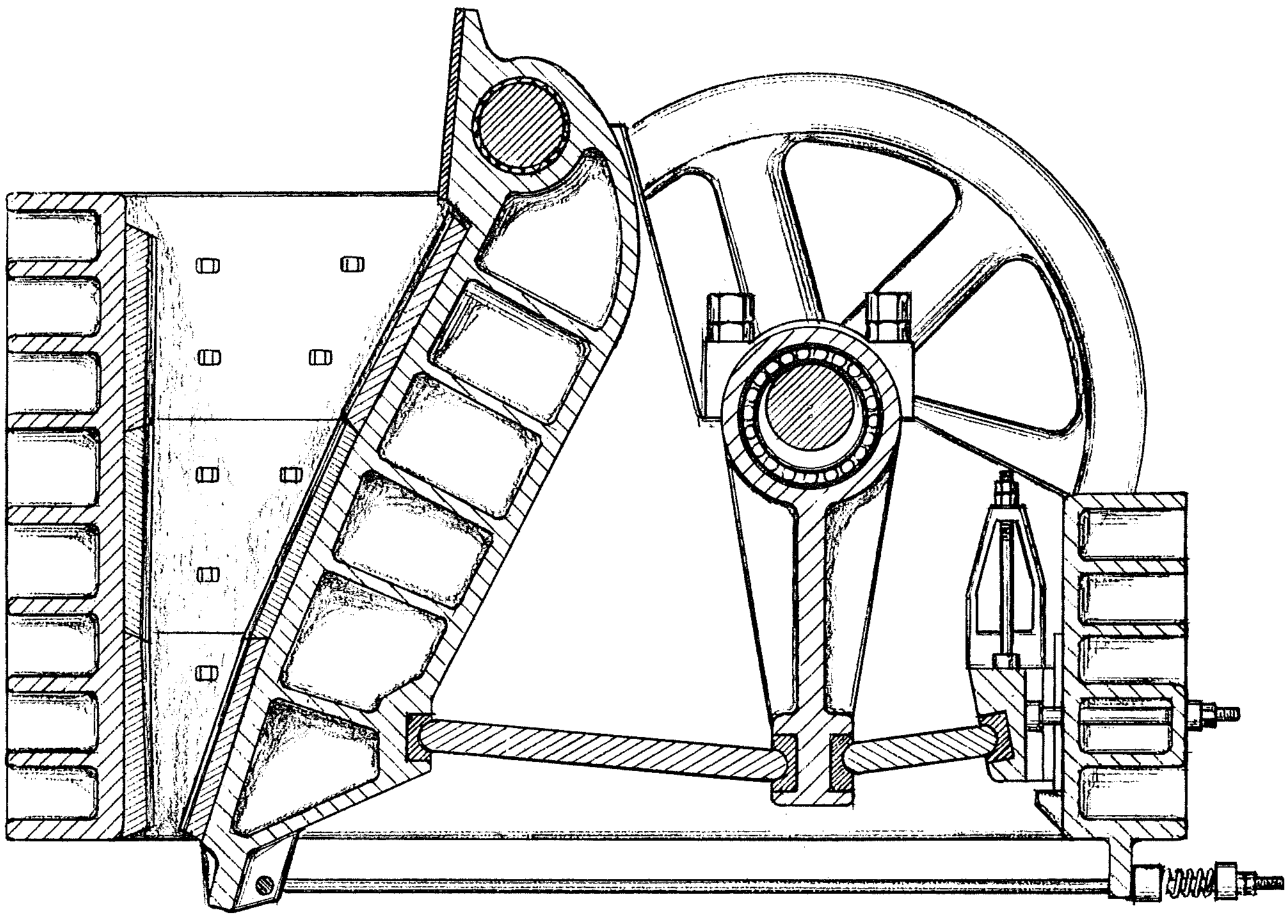
As a class, jaw crushers exhibit the following characteristics:

Features Of Jaw Crushers (6)

1. Large receiving opening per dollar of investment.
2. Shape of receiving opening favorable for blocky feed. This, plus point 1, gives the jaw a definite advantage over the gyratory, except in the very large sizes, for handling rock of massive formation.
3. The jaw crusher is more easily adjusted, to compensate for wear of liners. This is particularly true in the larger sizes, and the range of adjustment is greater in all sizes.
4. The jaw crusher will handle sticky or dirty feed better than the gyratory, there being no diaphragm below the crushing chamber on which such material can pack.
5. Routine maintenance and repair jobs are generally more easily accomplished on the jaw crusher than on the gyratory. Major repairs are about a standoff.
6. For crushing extremely hard, tough materials, extra strength can be built into the jaw crusher at less extra expense than in the gyratory. So-called "standard" designs, i.e., unreinforced, are usually more rugged than the standard design of gyratory.

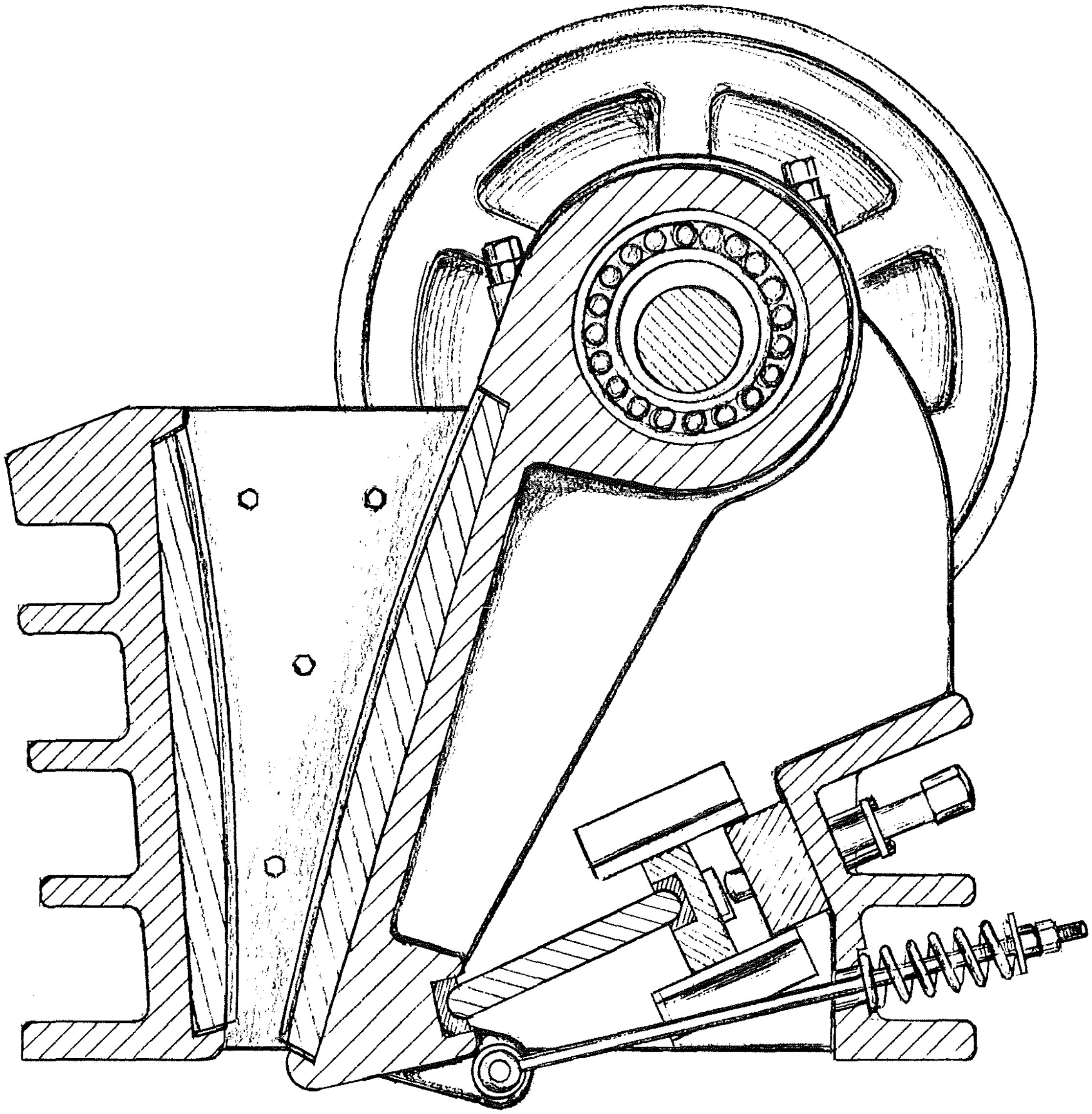
Single and double toggle jaw crushers differ in the motion characteristics of the moving jaw, which results in somewhat different operating characteristics. Jaw action in the Blake (double toggle) type is a simple pivoting motion about a stationary bearing near the receiving opening. Displacement is thus a maximum at the discharge, tapering to zero at the pivot.

Because of its simplicity, the overhead eccentric (single toggle type) exhibits lighter weight, much lower cost, and a greater potential for portability, although it is not significantly shorter than



Blake, or Double Toggle Jaw Crusher

Figure 2



Overhead Eccentric, or
Single Toggle Jaw Crusher

Figure 3

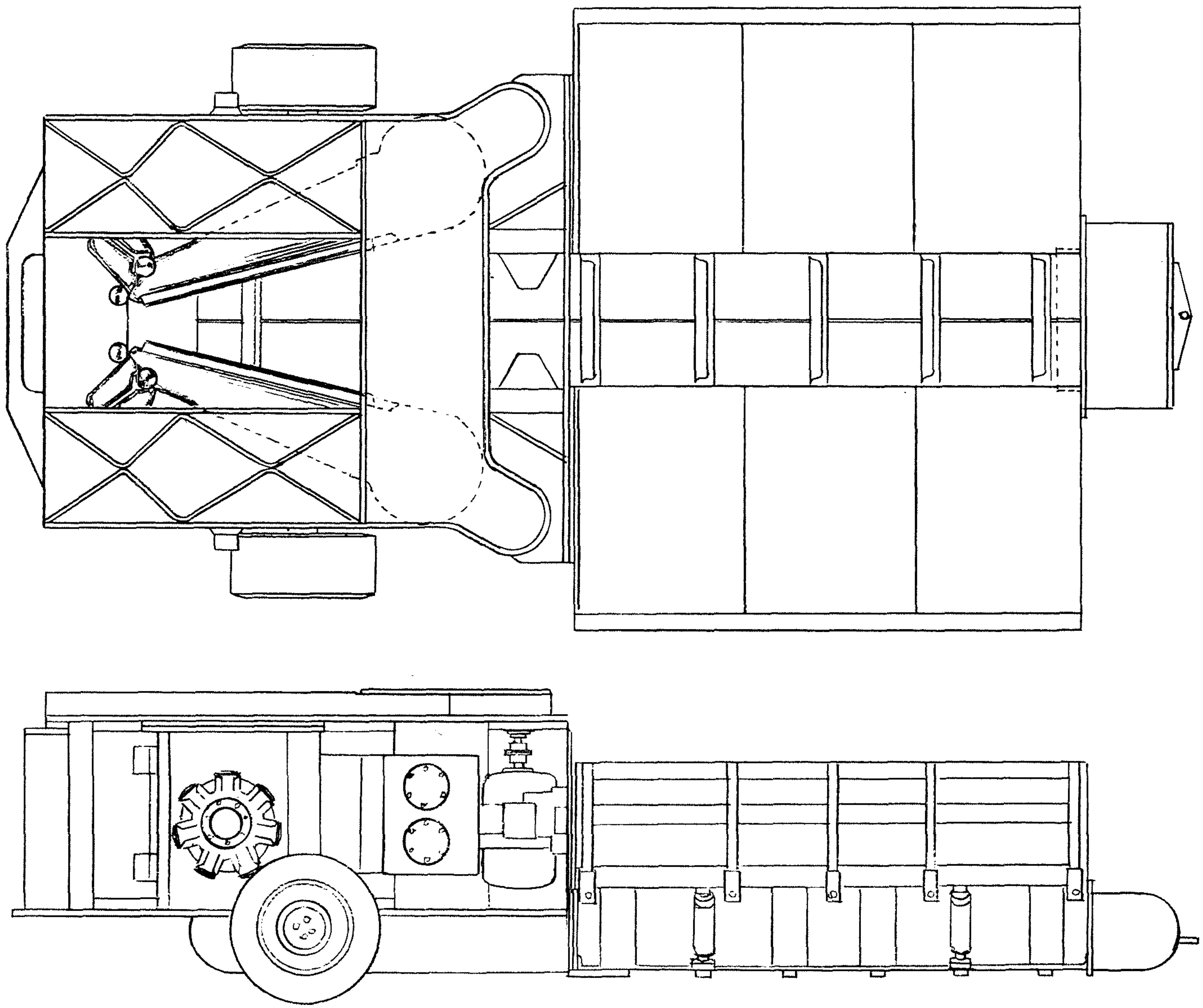
the Blake (double toggle type). Due to the pronounced vertical components of motion from the overhead eccentric, its elliptical wiping motion provides good feeding action, and hence capacity. The price for this action is, of course, accelerated wear of the jaw plates in addition to increased shock loading on the eccentric and shaft bearings caused by the large jaw motion (relative to Blake type machines) at the receiving opening. Consequently, Blake types, with their low scrubbing motion and great leverage on larger feed, tend to be favored for highly abrasive or very hard, tough rock.

3.2.1.3 Horizontal Jaw Crushers

The basic overhead eccentric jaw motion has been built in a vertical double-eccentric version (both jaws moving in unison), with the intention of providing more capacity for a given feed opening and longer jaw life due to reduced scrubbing provided by lower relative jaw velocity. The Eimco Division of Envirotech, and the Westfalia Company of Germany, have tipped this arrangement on edge (eccentrics vertical), thereby changing the feed direction from vertical to horizontal and greatly reducing machine height.

Little is known about the German machines, as none are in use in North America and none are believed to be handling predominately hard rock. Eimco, on the other hand, has built two prototypes which have been tested in medium and hard rock in low headroom conditions. The Eimco crusher, shown in Figure 4, utilizes a feeder-breaker style chain flite conveyor which pulls material from the bottom of the surge pile and stuffs it into the jaw region. Discharge occurs immediately after the choke region of the jaws, onto a customer supplied conveying means. The chain conveyor obviously must pass beneath the active region between the jaws, severely diminishing or eliminating its feeding ability, particularly during the crushing stroke. To achieve better feeding in the crushing zone, Eimco has modified the common overhead eccentric toggle geometry so that both jaws close everywhere at the same time, with the crushing stroke strongly oriented in the feed direction. These measures enable a second generation machine to achieve throughputs approaching (perhaps 80%) the capacity of a vertical, single overhead eccentric crusher of comparable inlet dimensions. The Eimco inlet is approximately 40x40 inches.

Both prototypes were tested at White Pine Copper in White Pine, Michigan. Problems were encountered and changes were made, as with most prototypes, but large blocks of 20-28,000 psi sandstone were successfully handled on a regular basis. Since that time, mining



Eimco Horizontal Jaw Crusher

Figure 4

at White Pine has been concentrated in medium strength shale, where the horizontal jaw is not sufficiently perfected to be competitive with heavy duty feeder-breakers, about which more is presented in subsequent sections. Very strong ores have not been tried on a significant scale in the horizontal jaw.

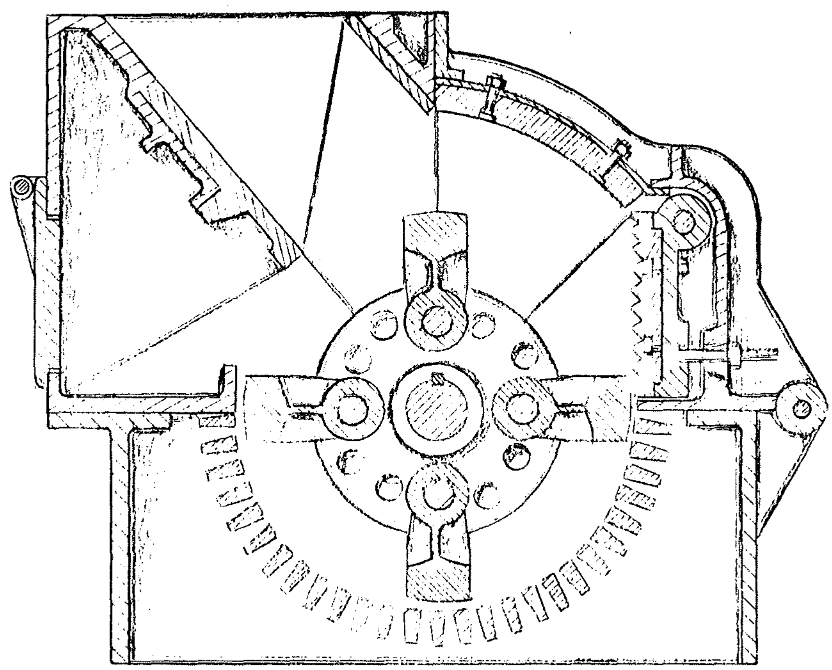
Though low in profile, this crusher design utilizes a feed means that tends to orient slabby material horizontally, hence the wide, square jaw opening. Slabs that do get fed on edge can be passed untouched through the jaws, a common problem with vertically fed jaw crushers as well. Dimensionally, horizontal jaw crushers are quite acceptable, though they could use elevating discharge means to reduce site excavation requirements, and with more development in hard rock applications, this concept may become an economical alternative candidate for the subject application.

3.2.2 Impact Crushers

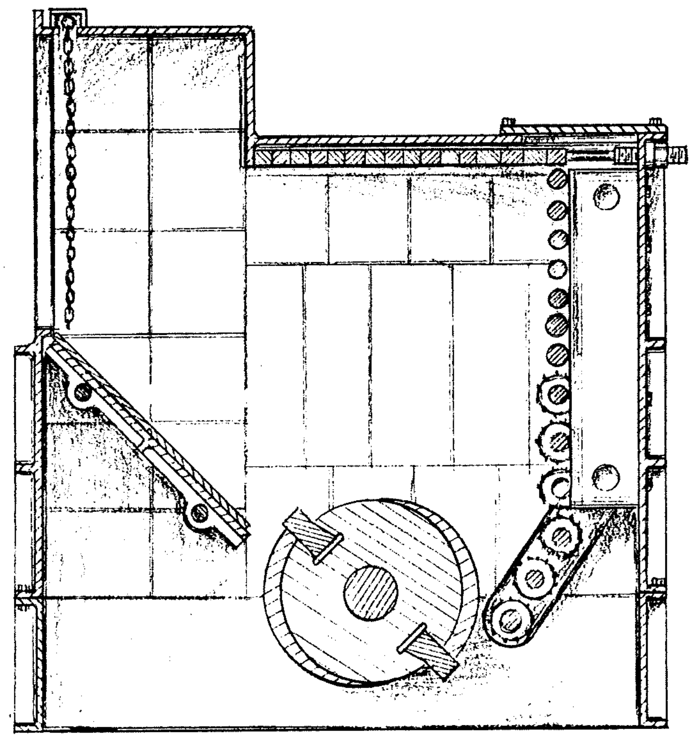
True impact crushers for primary crushing are limited to "hammer" types. They are included here only because there may be a specialized situation justifying their unique characteristics. Figure 5 shows a section of a typical hammermill; Figure 6 shows an impactor.

Impact type crushers are high reduction machines (up to 40:1 vs. 8:1 for a jaw). In part because of this, they produce a considerably finer product than is necessary to achieve mechanized underground haulage. Very large feed, as is common with ROM material, is not easily handled by the hammermill because of its impact principle of operation. Crushing is accomplished by the high velocity impact (5000 fpm) between the hammers (and liners) and individual pieces of rock in the feed, with the only means of support of rock fragments being the inertia of the rock itself. Under these conditions the rock fragments should not only be less massive than the hammer, but also quite friable. Abrasive feeds cannot be economically handled by hammermills or by impactors.

Impactors, as Figure 6 indicates, are better suited to large feeds than is the hammermill. This type uses fewer and stouter hammers, but, like the hammermill, relies on the inertia of the feed to "hold" the rock while it is chipped away. Primary crushing, even of non-abrasive and friable material, and particularly underground, is better handled by other machines unless very special conditions exist. An admittedly unlikely example of a situation in which an impact type crusher could be successfully employed as a portable underground primary crusher might be described by the



Typical Hammermill Crusher
Figure 5



Typical Impactor Crusher
Figure 6

following conditions:

(a) abnormally small ROM material suitable for impactor feed but too big to be conveyed.

(b) very friable, non-abrasive feed. material.

(c) fine product allows less expensive form of mechanized haulage and eliminates the need for secondary crushing equipment.

Due to the specialized and unlikely nature of this hypothetical application, pure impact crushers are excluded from further consideration for the purposes of this study.

3.2.3 Combination (Sledging) Crushers

'Roll crushers" is a term sometimes used to describe the combination (impact & pressure) class of crushers. "Sledging roll crushers" is a more suitable name, since it is distinguishing from the impact and pressure terminology and, in fact, the rotor in a roll crusher is frequently called a sledging roll. Sledging roll crushers are characterized by a medium velocity impact (500 fpm or less) between a rotor protrusion and the feed material while the feed is supported in the crusher, hence the term sledging.

The term "roll" is used in a wide variety of non-sledging equipment types and needs clarification here. "Crushing rolls", two-roll feed-pinching machines, are really a high speed continuous pressure class of crusher used for secondary and tertiary crushing. Sometimes they are confusingly called two-roll crushers, or double roll crushers, or four-roll crushers. The roll surfaces are usually smooth or nearly so, and impact (or even sledging) does not play a significant part in the comminution process. "Roll crusher" may also be used to describe a high speed machine in which the feed is neither supported by the crusher nor "nipped" by the roll protrusions. As described in the previous section, this is a high reduction pure impact class crusher sometimes used to avoid secondary crushing.

3.2.3.1 Single Roll Sledging Crushers

Sledging roll crushers may be of the single- or double-roll type, the latter being distinguishable from smooth pressure class crushing rolls by the characteristic protrusions (sledges) which work on the feed material. Double-roll sledging crushers usually employ more impact and less sledging by virtue of higher tip speeds, and are principally used for secondary crushing. Figure 7 shows a typical single-roll sledging crusher. There are several features of this type of crusher worthy of mention.

Features of Sledging Roll Crushers

(1) A dumped load of feed experiences vigorous agitation, immediately sifting smaller pieces down into the crushing chamber.

(2) This sorting action holds up larger pieces on top of the roll where they are worked on by slugger teeth until material is small enough to be nipped between the rotor and the anvil.

(3) The pure impact action which takes place on top of the roll on very large feed makes these machines unsuited for stone of massive or blocky structure unless it is friable.

(4) Maximum feed size for non-friable material should not exceed that which can be nipped, except that breakage of long slabs can and does take place on top of the roll by beam bending.

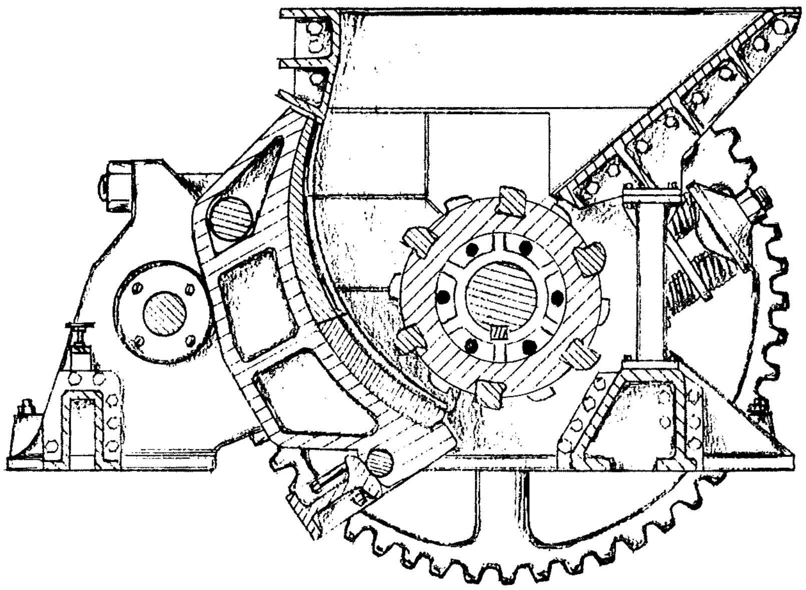
(5) Agitation in the chamber and hopper reduces bridging and improves feeding.

(6) The impact and moderate velocity aspects of this crusher class make it unsuited for abrasive silica bearing materials, and strength of feed is usually limited to about 15,000 psi compressive strength.

(7) Sledging roll crushers have been found to be generally well suited to crushing oil shale. (4)

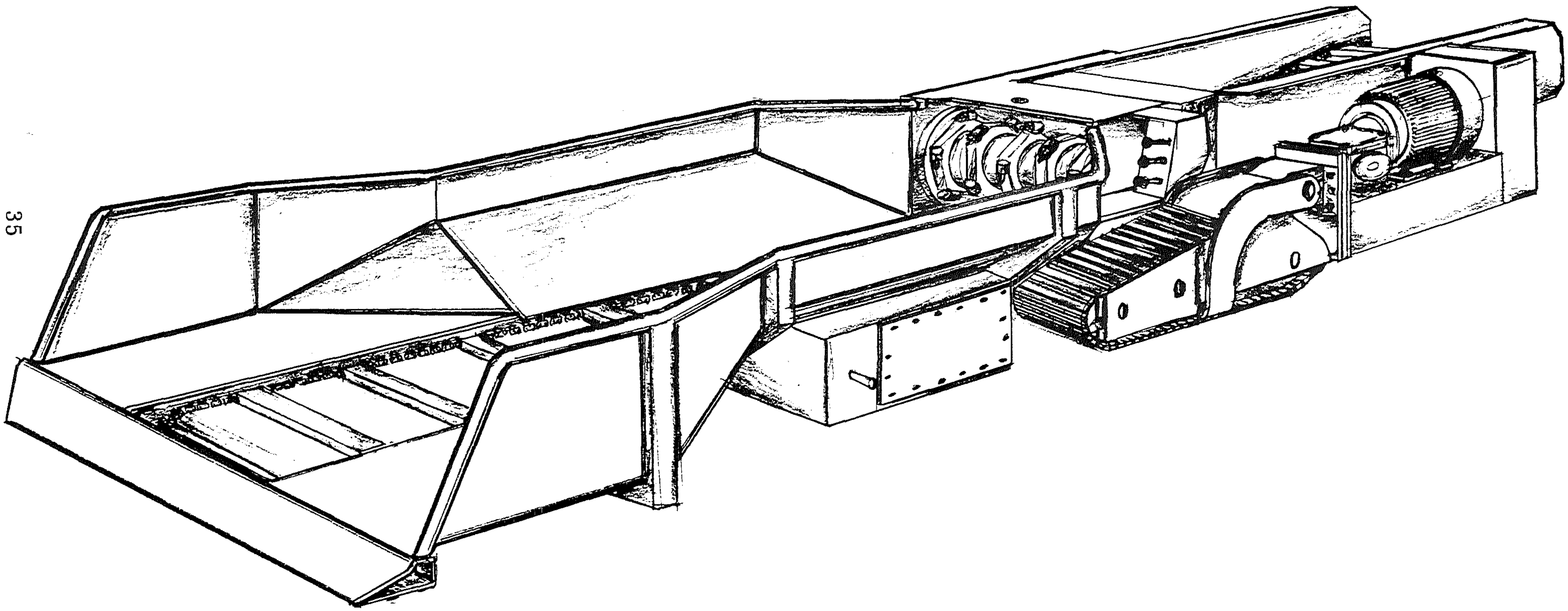
3.2.3.2 Feeder-Breakers

The feeder-breaker is an adaptation of the single roll-sledging crusher developed specifically for portability and use in low headroom coal mines. Since it has found successful use in a number of non-coal mines it is therefore worthy of mention. Figure 8 shows a typical feeder breaker.



Typical Sledging Roll Crusher

Figure 7



Typical Coal-Type Feeder Breaker

Figure 8

To achieve low profile, this specialized machine passes material horizontally under the roll, or breaker shaft as it is usually called. The anvil (or bed in this configuration) is flat, and feed is accomplished by a chain-flite conveyor which pulls feed from under the pile of material in the attached surge hopper, and, after passing through the breaking zone, continues on to feed at a relatively controlled rate over the conveyor head pulley, hence the name feeder-breaker. Another characteristic of this single-roll sledging crusher is the shape of the breaker teeth, or picks, as they are generally called. They are relatively few in number (particularly for weak material), replaceable, and pointed, generally being carbide tipped.

Feeder breakers have greatly advanced the practice of conveyorized haulage in coal mines, and during recent years beefed-up versions, pioneered by the W. R. Stamler Corporation, have been successfully employed in a variety of non-coal mines. Among these are underground salt, potash, trona, iron, copper mines, and some open pit mines. These mines use a wide variety of primary short haulage means, but they all make use of low labor, high capacity conveyor systems made possible by the feeder-breaker.

When applied to stronger and/or more abrasive ores, feeder breaker crushing costs naturally escalate to levels well above those of conventional hard rock (i.e., jaw) crushers. In fact it appears that feeder-breakers are used, in some applications, solely because of their low headroom characteristics, and despite crushing costs from 3 to 5 times what could be expected of a jaw crusher in the same material. However, sufficient savings are achieved elsewhere in the haulage system, so that feeder-breakers are the economic choice in one copper mine where the ore is routinely between 12-20,000 psi compressive strength, and also abrasive. That mine also uses feeder-breakers in sandstone sections where ore strength runs to 28,000 psi. Maintenance and rebuild costs are higher in such areas, and this is considered by many to be about the hard rock limit of feeder breakers as a class of crusher.

3.2.3.3 Longwall Breakers

A narrow version of the feeder-breaker has been developed by a German company for use on longwall systems. Various sledge configurations (not sharp picks) are used, and the unit is generally incorporated in a chain-flite bridge conveyor between the longwall system and a headgate conveyor. Two such units are in use on longwalls in U.S. trona mines (7000 psi max.), which accounts in part for their mention here. The concept (sizing of longwall discharge) is worth noting, in view of U. S. research efforts to apply new technology and longwall methods to hard rock mines.

3.2.4 Comminution Without Crushing

There are many other comminution processes that one could bring to mind. Among these would be all the primary and secondary breakage methods, grinding and milling methods, thermomechanical, and even ballistic and nuclear concepts. These are not considered here because there are no presently available machines using these processes. Other comminution methods in general will be considered in the concepts section (Section 9) after the problem statement has been fully developed and conclusions drawn.

3.3 Suitability of Present Crushers

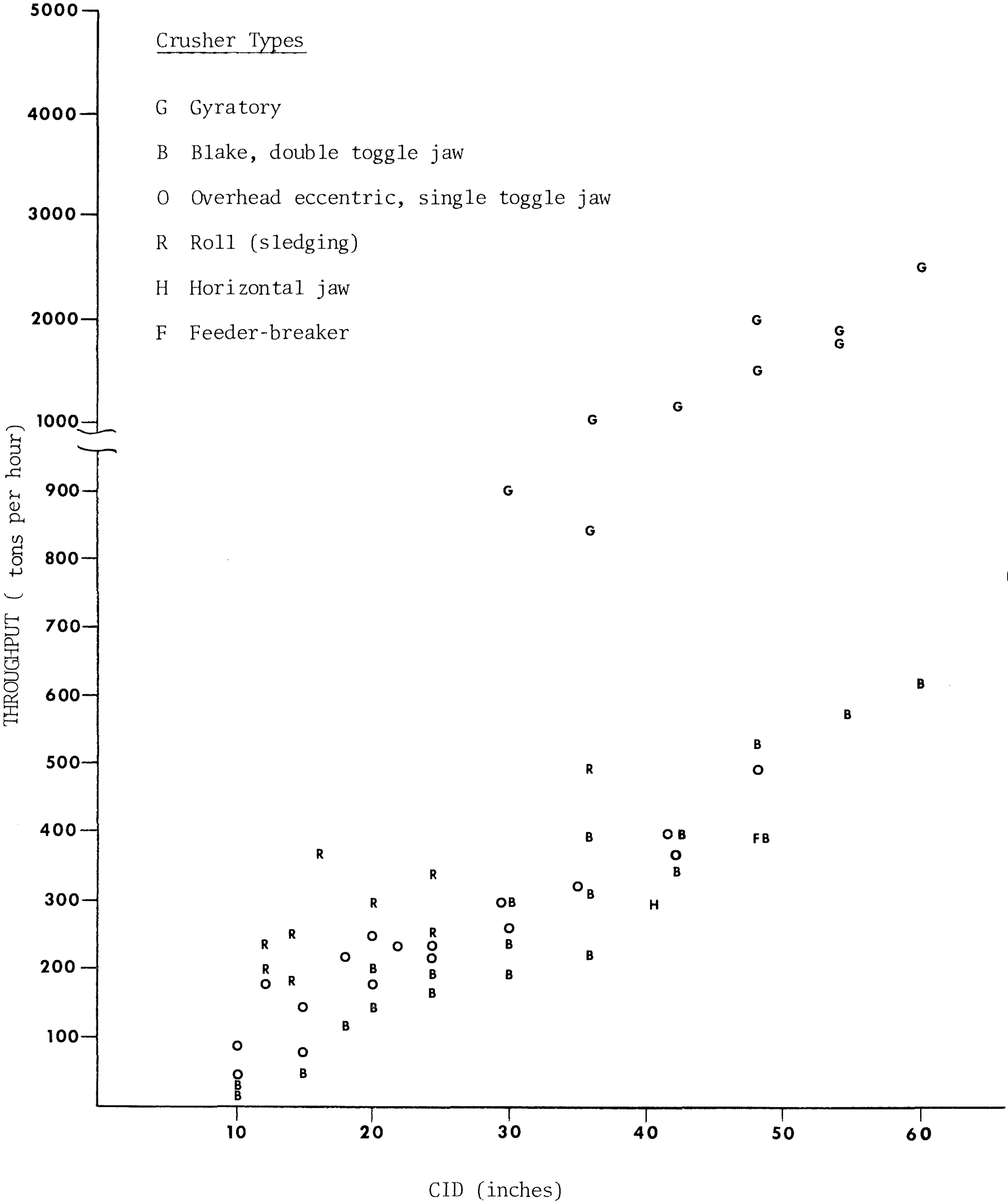
Having discussed the various classes and types of hard rock primary crushers, we can examine their potential for meeting the general requirements previewed in Section 2. Those requirements call for a crusher of low height, large feed opening, and modest throughput. Since multiple small crushers will be less efficient to operate and more costly to purchase than one central crusher, we must also consider cost as a factor in suitability.

3.3.1 Critical Input Dimension (CID)

The one mining parameter that is least controllable in a given mine and has the greatest influence on crusher selection is size of feed. Although drift dimensions obviously cannot be specified by the crusher designer, machine height, to some extent, is in his hands. Accordingly, machine height, throughput, and cost will be examined with respect to the common parameter, feed opening. Since "feed opening" implies a two dimensional passageway for material, the smaller or Critical Input Dimension (CID) will be used where appropriate. The implication is that most any crusher can (and should) be fed so as to avoid direct attack of the largest dimension of the feed material. Also implied, but perhaps less obvious, is the desire and intention to feed material so as to attack the smallest dimension of the feed, not the middle dimension.

3.3.2 Throughput

Figure 9 presents representative manufacturer's throughput data as a function of CID for 3 classes of crushers totalling six different types. Capacities have been "normalized" on medium



Crusher Throughput versus
Critical Input Dimension
Figure 9

limestone and minus 6 inch product in most cases. Gyratories are clearly high capacity machines at any feed size, and they tend to be applied to very large material. The Blake type jaw crushers are considerably lower in capacity, reflecting to some extent their application to very hard and abrasive feeds. Also noticeable is the range of capacities available for a given CID, a favorable feature afforded by variable jaw or rotor width. The tremendous forces encountered in crushing very large feed tend to leave the stronger Blake as the only jaw type in this region.

Getting down into the throughputs of most concern (400 tph and less), both Blake and overhead eccentric types appear, with the edge in capacity going to the overhead eccentrics. Also appearing are the horizontal jaw crushers and the sledging class, both single roll and feeder-breaker types. Maximum feed size for a given CID will be somewhat less in the case of horizontal jaws because the feed mechanism for this type tends to cause attack of the middle, rather than the smallest dimension of the feed material.

This data seems to indicate the following with respect to the general requirements established in Section 2, that is; 30-36 inch CID and 100-300 tph:

(1) At the required CID, more than ample capacity (throughput) is available from a variety of machines.

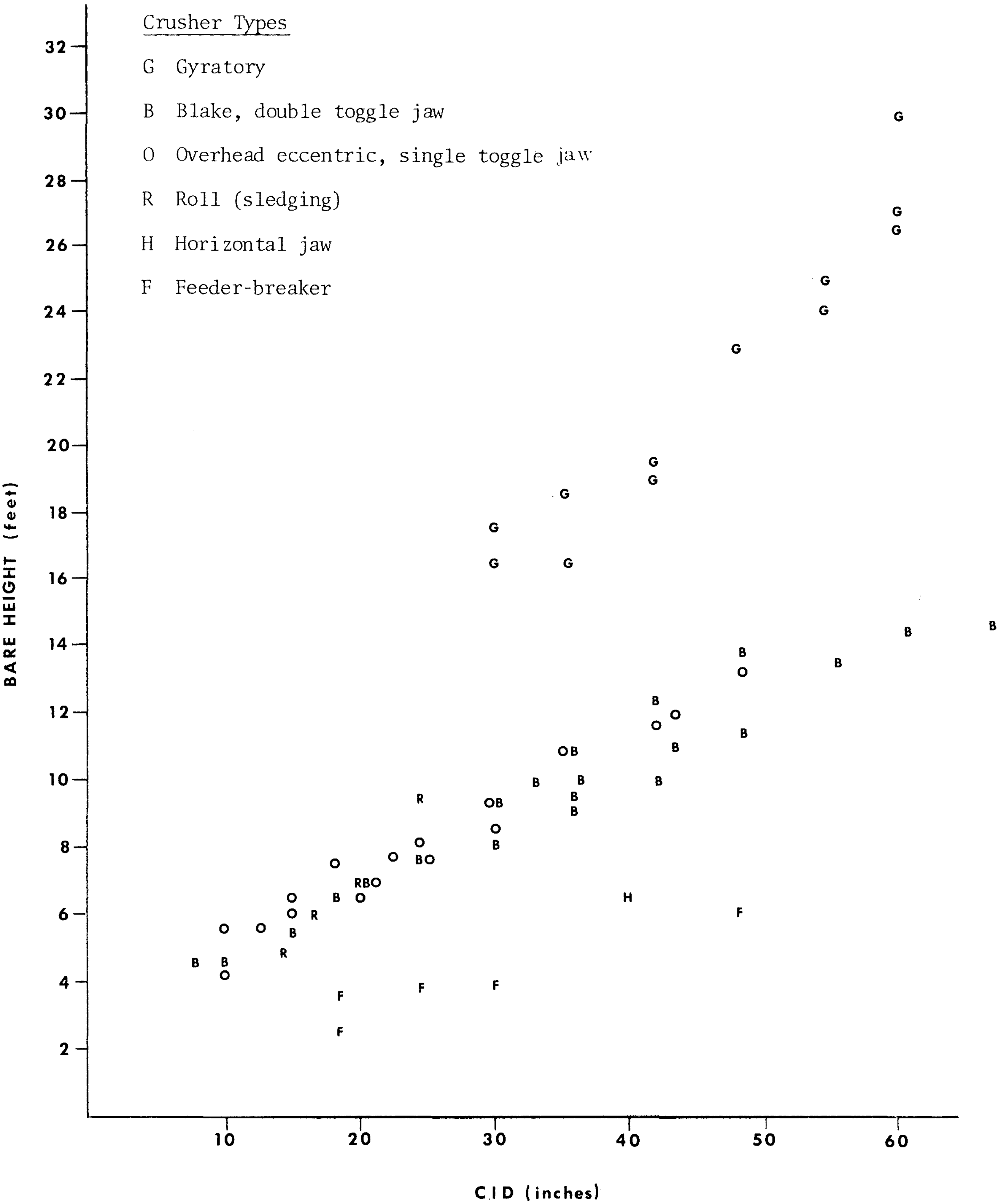
(2) Gyratories are too much machine--in physical size and capacity.

(3) Low capacity--large feed is a unique combination not well satisfied by existing hard-rock machines.

3.3.3 Machine Height

Figure 10 is a plot of bare machine height as a function of CID for the same six types of crushers. Keeping in mind that bare height is exclusive of any foundations (if required) or feeding and discharge means, all conventional gyratory and vertical jaw types are clearly beyond our need for 7-9 foot installed height at 30-36 inch CID. Nor can these standard machines be significantly shortened, as an examination of earlier figures will reveal.

We are left, at present, with horizontal jaws and the sledging class of crusher. But sledging roll crushers and to a lesser extent, feeder breakers, reach their economic limit at medium strength ore, characterized by (among other things) compressive strengths



Crusher Height versus
Critical Input Dimension

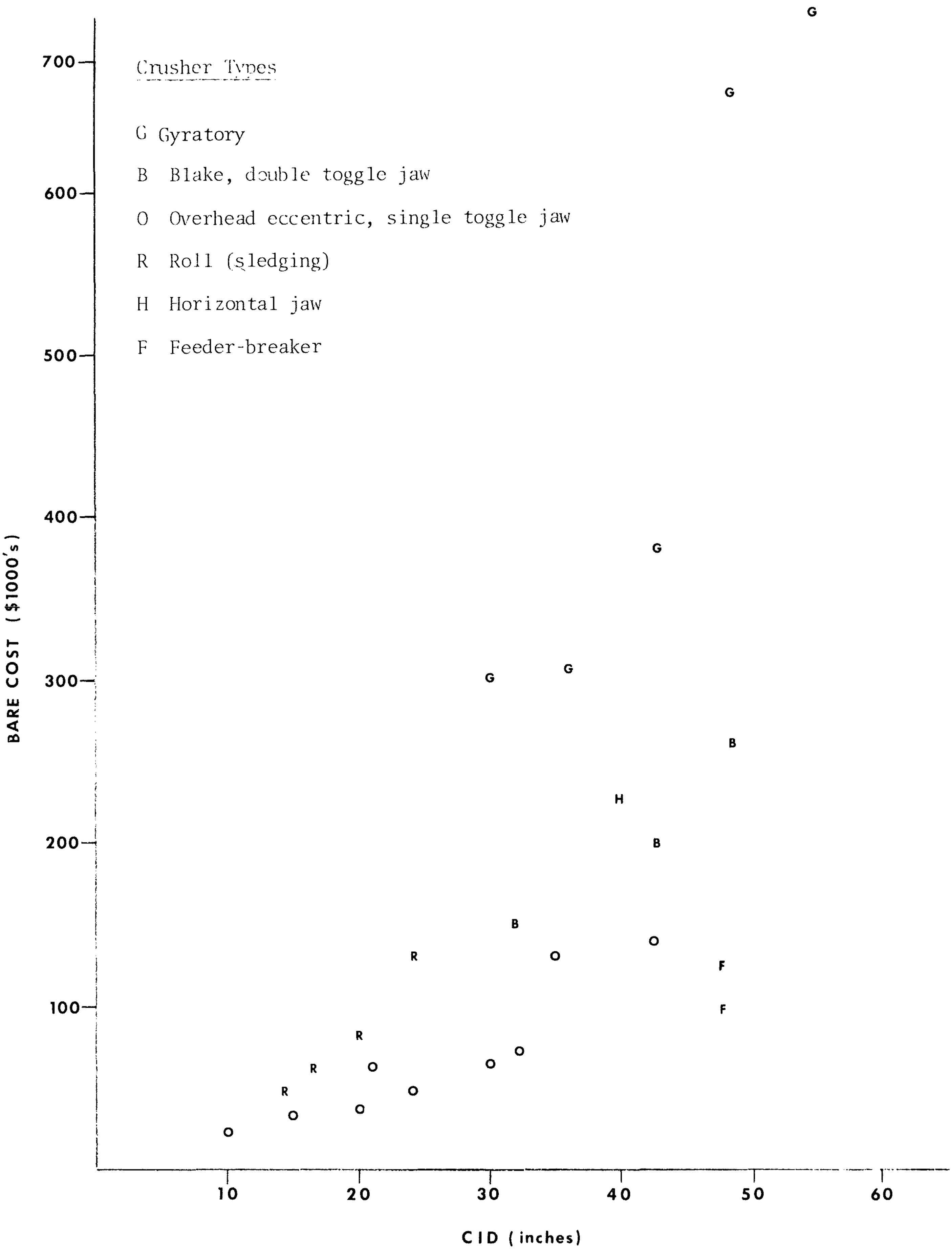
Figure 10

in the 12-20,000 psi range and, even then, only under specialized conditions. The horizontal jaw crusher would appear to be the lone contestant, but it is relatively new and little can be learned about its economic performance at this time. Westfalia, a German manufacturer of longwall and other mining equipment, developed the concept, and, although machines are in use in Europe, no information is available regarding hard or very strong ore applications, and none are in service in North America. Eimco Division of Envirotech is the U.S. pioneer of horizontal jaw crushers, having built two generations of machines. These machines were technically successful in crushing a regular diet of stronger ore (20-28,000 psi) but could not compete economically in the medium strength range against the then highly developed heavy duty feeder-breakers, a statement which most certainly would apply to weaker ores as well. Dimensionally, the horizontal jaw is virtually identical to the successful feeder-breaker (Eimco data is plotted) and with further experience this basic concept may prove to be one answer to low profile hard-rock crushing.

3.3.4 Machine Cost

Figure 11 shows the bare cost (no drives, hoppers, feeders, etc.) of the various crushers under discussion. Some of the data are approximations, but the plot is useful in several respects. It shows, for instance, that something must be sacrificed to get low profile. In the case of horizontal jaws, increased initial cost is the penalty. Feeder-breakers, the low profile member of the sledging class, cannot economically handle the stronger ores. To work on the very hard or abrasive ores, machine height aside, requires that one choose the more expensive Blake type vertical jaw instead of the lighter overhead eccentric. Gyratories having the required CID again are inherently much too much machine for this application.

Using the larger Blake type or gyratories as an example (they dominate as centralized crushers in hard-rock mines) we can get an idea of the capital investment against which a multiplicity of portable crushers must inevitably be judged. Suppose a 7000 tpd mine would need a 48x60 Blake type jaw crushing 500 tph of minus 6 inch product. Such a crusher would cost perhaps $350,000 including significant installation costs. An equivalent portable crusher system might involve five machines, four of which would be in service, with each capable of 250 tph. The greater total crushing capacity of the portable system is necessitated by its need to keep moving up, and by its vulnerability to downstream haulage interruptions. If these five portables cost in the vicinity of $200,000



Crusher Cost Versus
Critical Input Dimension

Figure 11

each (a reasonable assumption for hard rock), the capital investment for portables becomes one million dollars versus $350,000 for a fixed installation. In addition, since the operating and maintenance costs of the two crusher systems are likely to be in about the same ratio, it is clear that the portable system must achieve great savings in other categories. These would likely include primary and secondary haulage costs (capital and labor) and productivity.

SECTION FOUR

MINING TYPES RELATED TO DECENTRALIZED CRUSHER USE

In Section 2 we dismissed those "big-room" applications not needing fundamentally new equipment, and lumped all the rest together. Now, as we examine specific mine types, it is appropriate to differentiate within these categories the manner in which portable crushers might be used, and the consequent effect on desired machine parameters. The common yardstick by which we will measure all these mining methods is the basic decentralized crusher concept, beyond which portability, or the degree thereof, will be the special and distinguishing feature. Accordingly, underground hard-rock mines are divided into three major groups, listed below with their distinguishing characteristics.

(1) Low Head Room Room and Pillar.
Most similar to coal mines in their mining methods, this group exhibits more rapidly moving mining fronts and the greatest need for portability. Machine height is critical, but other dimensions may be more flexible due to room size and single level mine plans. Great portability also demands minimal site preparation.

(2) High Head Room Room and Pillar.
No particular height problems are encountered here. Slow moving mining fronts (on single or multi-levels) allow less frequent crusher moves and generally create greater throughputs from a single mining unit.

(3) Non Room and Pillar.
This large group includes many different mining plans, but most are characterized by multi-level mining and vertical, as well as horizontal, ore haulage. In addition, access and haulage drifts are frequently quite small both in height and width, which makes crusher size the critical parameters. Crusher move-ups may be less frequent, allowing more extensive site preparation.

4.1 Low Head Room Room and Pillar

With 75% of all U.S. "hard rock" mines over 1200 tpd using the room and pillar method, this group becomes the most important for the purposes of this study. Supporting this conclusion is the fact that equipment useable in low headroom situations is also useable in high headroom mines. The reverse is obviously not true, and high headroom operations might even prefer low profile equipment, as we shall discuss in Section 4.2.

Low headroom causes these mines to rely on LHD's, loaders, shuttle cars, and low ore trucks for face haulage. While these machines provide great flexibility and, in the case of LHD's, multi-function in a single vehicle, they all have one thing in common: Costs escalate and productivity drops with increasing haul distances, at a greater rate than with larger, taller equipment. The mining industry is experiencing increasing acceptance of LHD type equipment because one man, operating one machine, is not disrupted by uncoordinated equipment cycles. The resulting greater productivity (and reduced labor) more than offsets higher per-hour operating costs (perhaps 50% higher) for vehicle proper, as compared to haul-only or load-only machines. Clearly then, the haul portion of the load-haul-dump cycle is better left to specialized equipment when distances become excessive. In order of increasing haul distance, the typical equipment selection for ROM ore is as follows:*

FEL (front end loader) only
LHD (load haul dump) only
FEL & two trucks
LHD & two trucks
FEL or LHD & three or more trucks

From the "pocket", long hauls are best handled by modern rail (ROM ore), but if a crusher can be installed, belt conveyors are by far the lowest ton-mile method. Clearly then, there is incentive to get the crusher and conveyor as close to the face as possible, thereby eliminating as many costly intermediate pieces of equipment (and operators), and as much rehandling, as possible. Inevitably, we must reach a compromise, but the optimum would surely be represented by one type of face haulage equipment (FEL or LHD) operating over as short a distance as possible.

The trade off, of course, is haul distance versus crusher and belt move-up costs. Haul distance can be kept down only by <u>frequent</u> moveups, and move-up costs can be kept down only <u>quick,</u>

---

*Gathering arm loaders and/or shuttle cars fit into this list, but their use is declining, particularly in hard rock. Low head room may exclude FEL's as a candidate.

easy, installations. We have thus zeroed in on the key characteristic of decentralized crushers for this mine group: Portability.

Expanding further, let us examine the typical mining cycle in greater detail, in an attempt to quantify portability. The concensus among mine operators is that face haulage costs begin to escalate at a disproportionate rate when average distances exceed 400-500 feet, depending primarily on the payload of a given vehicle (three to seven yard buckets predominate in low headroom). Traffic and blasting considerations limit minimum distances to around 250 feet, so the maximum desired distance becomes about 650 feet, and the moveup distance is 400 feet. Very wide panels may require two crushers, thus minimizing haulage distance to the flanks, and allowing one crusher to operate while the other is moved. Variations in panel width (and crusher location) will obviously influence not only these numbers, but advance rate as well. For the example cited, a mining advance rate of 100 feet per month would require a (single) crusher moveup every four months.

Site preparation should, of course, be kept to a minimum; but with only four month's tonnage over which to amortize its cost, the required minimum, for all pratical purposes, is virtually zero. In addition, site preparation should not interfere with normal operations prior to the move, a fact which strongly influences the design of the conveyor system. Moveups should be accomplished in one shift or less to allow minimum disruption to production. This achievement can be facilitated by "leapfrogging" spare crushers from the maintenance department if production is sufficient to justify spares. Quick moves (and servicing) are also enhanced by modular components, such as hopper-feeder and crusher, or hopper-feeder and crusher and discharge conveyor. Wheels (perhaps removeable) and/or skids are entirely satisfactory for moveups.

The crusher hopper should be able to handle at least two full loads (10-20 yards) from the face haulage equipment. Due to minimal site preparation, the dump must essentially be at floor level, and the hopper-feeder must elevate the muck if the crusher so requires. Excavations for the panel ("section" or "feeder") belt are to be avoided, so the crusher must discharge material, elevating it if necessary, to a typical height of about three feet.

Other crusher parameters (feed opening, for instance) depend on specific mining conditions, and are discussed elsewhere, as is the handling of oversize in conjunction with crusher operation. This mine group does, however, offer the possibility of handling oversize at any location in the mining section, including (if absolutely necessary) at the crusher, with a mobile, impactor-equipped, inexpensive vehicle.

In summary, this group needs a hard rock crusher distinguished by the following characteristics:

(1) low profile
(2) zero (or minimal) site preparation
(3) one shift moveups
(4) floor level dump
(5) elevated discharge
(6) modular (probably) sub-functions

4.2 High Head Room Room and Pillar

By its very name, this class of mines would appear to be outside the scope of this study. While this is strictly true, and the needs of industry are most acute in lower headrooms, we will learn by studying the methods of this group just as we learned by studying potash and other soft mineral mines.

The availability of generous headroom greatly simplifies the crushing task per se, but may not allow improved ore handling unless used wisely. Historically, operators have used high backs to employ larger and more efficient haulage vehicles, still tramming to a central crusher, with a recent emphasis on trackless rather than rail methods for main haulage. Due to the high tire cost associated with truck haulage, a new concept is beginning to appear in an attempt to control truck haul distances. Some open pit mines (the ultimate in high head room) are foregoing ever larger trucks over even longer hauls in favor of portable crushers. These mines have found that large primary crushers can be made portable for little more than the cost of one permanent installation (12, 13). Hoppers with elevating feed conveyors are used in conjunction with portable discharge conveyors, and at least one non U.S. underground mine is using this portable primary approach. A variety of crusher types have been made portable, but all are basically standard, very tall machines like those presented in Section 3.

Portability of a large open pit primary crusher has merits because production sites, though moving, are not so numerous and widespread that trucks become economical. The situation underground is a little different, however, because even high head room mines have some height restrictions (particularly on entry), truck payloads are smaller, and traffic and tramming speed limitations are greater. As a result, portability and decentralization of crushing becomes imperative if haul distances and costs are to be reduced.

Decentralized portable crushing, even of hard rock, could be achieved in high head room room and pillar mines by custom-designed combinations of standard or near standard, crushers, hoppers, feeders, conveyors, grizzlies, etc.. However, if suitable hard-rock, low head room crushers are forthcoming as a result of this study, these, as well as open pit applications, may represent an additional market base. Three quite different applications are worth noting.

4.2.1 Limestone Mines

Many underground limestone mines need crusher types better suited to hard abrasive materials then are feeder-breakers. While many would have to be considered of low or medium headroom, some high room operations can consider using near standard crushers in a decentralized arrangement. One new mine in Kentucky has done just that, and is singled out in Sections 5 and 7 as being worthy of special note.

Room and pillar mining in these mines usually calls for a heading and bench plan. This provides an opportunity to situate a fairly tall portable crusher at the bench, which, in turn, allows adequate dumping conditions for the face haulage equipment. Crusher discharge is easily conveyed, but haulage vehicles from the lower level must negotiate a connecting ramp to reach the bench for dumping.

Horizontally fed (i. e., low profile) crushers, perhaps used on both levels, would allow the bench and ramp to be divorced from the crusher, further reducing haulage distances, and adding more flexibility to the mining and traffic patterns. If headroom is generous, standard (tall)crushers could be used if provided with feed-elevating means at floor-level dumps. However, more effective decentralization and portability would appear to be provided by low-profile crushers meeting the requirements set forth in Section 2.

4.2.2 Lead Mines

Due to their geological setting and ore body shape, the Missouri lead mines are both high and medium headroom operations. Simple room and pillar, heading and bench, and shrinkage methods are used simultaneously in reaching the ore boundaries. Main haulage is by LHD, truck, or by rail, with the recent trend being toward trackless methods. Jaw and gyratory type primary crushers are used.

These mines are unique among room and pillar mines because the common practice of leaving irregular pillar patterns is not compatible with belt conveyors. Conversion to belts for main haulage would have to be a case by case decision, and might be feasible only for new developments in a given mine. Decentralized portable crushers are, however, a potentially attractive alternative to present methods, and most of the comments from the preceeding section on limestone mines would apply here as well. Since the very high rooms in these mines are created by connecting two separately developed not-so-high room and pillar levels, low profile and floor-level dumping characteristics would be desirable in a portable crusher. Consequently, these mines, though potentially served by custom arrangements of standard (tall) hard rock crushers, are also potential candidates for the subject low head room portable units.

4.2.3 Oil Shale

It has been determined by others (4, 15, 16, 17) that oil shale can be effectively "sized" for belt haulage by feeder-breakers, and by sledging type (toothed) roll crushers, as well as by traditional primaries, the gyratory and jaw types. In a study of mining methods for deep, thick, oil shale deposits, Cameron Engineers (4) investigated six candidate mining plans for a 30 million tpy operation. Two of these plans were modified room and pillar geometries, each with drift and room heights sufficient to allow a standard sledging roll crusher to be moved around underground. Both plans were based on ten 1000 tph portable crushers, fed by LHD face haulage equipment, and discharging eight inch material onto a 36 and/or 60 inch belt system.

At 1000 tph per crusher, these "decentralized" crushers are really portable multiple primaries when compared to most mines, and resemble the open pit "portables" already discussed. Oil shale, though tough, is really neither hard nor highly abrasive, but the results of the Cameron study do represent another indication of the potential of the decentralized crusher concept for hard rock mines. Both decentralized systems were strong contenders, if not outright winners, in the economic analysis section of the study, and more will be presented on this subject in Section 7.

4.3 Non Room and Pillar Mines

Some of the similarities among the many mine plans in this group have already been listed. In addition to multi-level mining and vertical/horizontal ore handling, these mines also tend, as a group, to have the strongest ore and country rock. Some form of rail haulage is another oft-common denominator. In order to intelligently discuss decentralized crusher concepts for this group, it is appropriate to take the major mine plans one at a time and investigate the potential for improved ore handling methods.

4.3.1 Block Caving

This is the large scale, high development, low cost mining method used (where applicable) in many enormous or low grade ore bodies. Gravity fragmentation allows this mine plan the least control of any over muck size, and muck size distribution tends to vary widely from mine to mine as Table I of Section 2 indicated. Production sites tend to be very numerous, and gravity is freqently employed to "gather" the ore into fewer loading stations for transfer to the main haulage system. Besides being numerous (and therefore of low average throughput) production sites historically have been served by rather small extraction drifts. The trend, however, is away from slushers toward mechanized loading and hauling, and this is causing larger drifts to come into use. The use of LHD equipment in extraction drifts also reduces somewhat the need for secondary breakage, but the general problem of interrupted ore handling due to oversize remains, causing one chief engineer to write of block caving in general (7): "small portable crushers that could be installed at various points throughout the mine and conveyors that could handle fair-size rock fragments would considerably simplify the problem of ore transport in the mine".

In the limiting case, one could consider portable crushers at all active production sites and a fully mechanized downstream ore handling system. However, this extreme degree of decentralization is probably not justified *, and some form of primary haulage (i. e., ore "gathering") would be more adaptable to portable crushers.

If we look at a hypothetical (though typical) mechanized block cave mine of 30, 000 tpd, we can see where crushers might be used. A three-shift production would likely be loaded by LHD equipment at many dozens of drawpoints and trammed to perhaps as many as 40 active pockets, depending on efficient haul distances, block size, etc.. Portable crushers placed at each pocket would see only 50 tph based on five operating hour per shift, and would have to function on the crowded extraction level. These forty dump pockets would typically converge, via a series of connecting ore passes and transfer raises, to only ten or so loading points (chutes) where the main

*Throughout per crusher would be very low, feed size very large, drift size very small, and conveyors would be needed everywhere.

haulage system (presumably rail) would take over. At 200 tons per hour, these ten chutes are a more likely and uncongested location for portable crushers, and transfer to a belt system could be made at this or a lower level.

The life of a typical chute is many months, perhaps 2-3 years, and new chutes might be created and retired at the rate of several per year, depending on block dimensions and other factors. Site preparation could then be amortized over significant time periods, but the need for crusher portability is probably not diminished by this rather extended installation life because rapid changeout would be needed for major overhaul of the crushers.

It would appear that we have defined a 200-plus ton per hour ROM crusher capable of moving around on a haulage level. There are, with this approach, two major problems particularly acute in block cave mines, but common to most non-room and pillar mines as well. First, conversion of main haulageways from rail to conveyor precludes the use of those drifts for significant movement of men, materials, and certainly of crushers. In addition, typically curved rail systems are difficult if not impossible to convert to straight-line belt conveyors. The answer would seem to be separate drifts or, more likely, separate levels for crushers and main belt haulage. However, to economically justify an entirely new haulage level (and system) in a mine with a working rail system is improbable, and indeed, most operators interviewed expressed this opinion. Consequently, new mines and new levels or developments in existing mines, are probably the only legitimate candidates for radically new ore handling schemes based on decentralized crushers. One new block cave mine did in fact consider conveyorized ore handling in the planning stage before choosing a modern rail system. Among the reasons given for its rejection were the inability to belt ROM ore, and the cost and extent of an underground crushing system based on available equipment. The decision might well have been reversed, and haulage costs reduced, had suitable portable hardrock crushers been available.

The point to be made is that high development plans like block caving are the least flexible and represent perhaps the most difficult situation in which to attempt conversion to portable crushers, regardless of their state of development. This does not imply that decentralized crushing is inherently unattractive for block cave methods; it simply means that <u>early successful</u> application of decentralized crushing will likely <u>occur in mines</u> employing more flexible plans.

The second major problem with decentralized crushing in block cave mines is old and well known: It is oversize muck, not in the beltable context, but oversize to the extent that serious disruptions occur in the ore handling system resulting in lost production and increased accidents. Dravo (1) and Theodore Barry (2) both reported the widespread existance of this problem in all mines and recommended several solutions, with most utilizing some arrangement of hydraulic impact breakers.

Successful implementation of any decentralized crusher concept in a block cave mine must be accompanied by a workable solution to the oversize problem, a problem which will be accentuated by efforts to reduce crusher size. An obvious solution is to make the feed opening of the crusher very large, but this is incompatible with portability and does nothing to relieve existing hangups ahead of the crusher site. A better solution would be to eliminate oversize as early as is practicable, thus improving flow through ore passes and the like, and allowing a reasonably sized portable crusher to efficiently recieve conditioned feed. In the example cited, oversize breakers could be built into the LHD dump pockets, perhaps allowing use of smaller ore passes, or into the extraction drifts, after Barry (2).

Many "secondary breakage" means have been developed into prototypes (8, 9, 10), but of those methods applicable to a variety of hard rock types, hydraulic impact breakers are the only devices achieving commerical-scale application with any significant success (11). The "secondary" or "oversize" problem is outside the scope of this study, but its solution, about which more is said in subsequent sections, holds a key to the successful application of decentralized crushing in many block cave mines. Another key is, of course, the crushers themselves, but even very-fine ore mines may need "oversize breakers".

We have not intentionally omitted those block cave mines still predominately slusher or gravity oriented, but they too are difficult to convert for economic reasons. New developments within such mines should consider decentralized crushing when suitable proven equipment is available.

4.3.2 Sublevel Caving

Although a caving method, fragmentation control for this plan is intended to be by blasting. Occasional muck still tends to be quite large, as in many block caves, but production sites are far fewer, they are multi-level, and continually moving, hence the popularity of versatile LHD equipment for "face" haulage. Ore is typically passed from sublevels to haulage levels where it is trammed by rail to either the shaft, or to a large crusher from which it may be belted to the shaft. This latter arrangement would be more likely in a mine having more than one underground crusher, or a laterally extensive ore body with workings far from the shaft. It is significant that, where crushers are located in the ore body, conveyors are the predominant choice for haulage to the shaft.

Ore handling on a given sublevel or at a given ore pass is, by the very nature of this mining method, a part-time activity, perhaps precluding efficient utilization of crushers at numerous, multi-level LHD dump pockets. However, less numerous chutes at the lower (rail) haulageways are usually supplied with ore from somewhere above, and these would be more suitable sites for crusher placement. Average throughputs would be modest (as opposed to high but intermittent rates of rail car loading), in the 60 tph range for each of 3-6 LHD's delivering ore. Lateral movement of crushed material could take place on the crusher level, but in order to minimize congestion, crushed ore might better be passed directly through surges to a lower main belt. This approach is more applicable to the narrower ore bodies of sublevel caves (as opposed to block caves), and allows main belt levels to become crusher levels as mining goes deeper. Due to the use of trackless equipment on sublevels and main levels, drift size is reasonable (10x13 ft. minimum) and ramps are frequently employed between levels.

Long and somewhat narrow (medium-width) ore body shapes are frequent candidates for sublevel cave, and the resulting main haul distances make this plan well suited to decentralized crushing. The increased use of large crushers away from the shaft is a beginning step in this direction, but only portable crushers will eliminate costly small scale rail tramming and retramming. However, to justify an attempt at decentralized crushing, the mine plan must be based on and designed around proven equipment. Conversion (at new lower levels) is more feasible than with block caves, but that first step is a big one and probably cannot be an experiment.

Added to this problem is the recurring characteristic of non-room and pillar mines, namely the significant tonnage of very large muck. In this respect, sublevel and block caves are very similar; that is, portable crushers (like large central crushers) should not, and probably cannot, be made to take all ROM ore. There will always be muck too big to handle at the face, and some of that which can be handled is still big enough to cause problems ahead of and independent of the crusher. In short, the oversize problem will always exist, but some mines will solve it more easily than others.

We have suggested the possiblity of "oversize breakers" at dump pockets for block caves. The same approach could be used for sublevel cave, influenced somewhat by the aforementioned part-time and multi-level aspects of those pockets. Oversize control could also be accomplished at the crusher level, perhaps incorporated into a portable feeder or feeder-scalper module ahead of the crusher. Oversize breakage, scalping, and modularization in general are all excellent and perhaps necessary means to provide portability and respectable throughput in a hard rock, underground crusher. Obviously the feed size capability of any successful new crusher will determine, for a given mine, the extent and degree of oversize breakage required. If we assume a critical input dimension of 36 inches (the larger range should apply to non-room and pillar) then the tonnage falling in the oversize category may be only a few percent of the total.

4.3.3 Sublevel Stoping

From an ore handling point of view, sublevel stoping represents a mixture of block and sublevel cave procedures. As in a block cave, ore is drawn from stationary cone drawpoints into a nearby rail haulage system by a variety of slusher, grizzly, and boxhole arrangements. As in a sublevel cave, fragmentation control is by blasting, production (hauling) may be taking place on multiple levels simultaneously, and in newer mechanized developments LHD's may be used, loading into mine cars or tramming to ore passes.

Sublevel stoping is "adaptable" (as opposed to "convertible"), to decentralized crushing. Since main belt galleries must be straight and cannot be shared by large mobile equipment, they would have to be located on separate levels or in separate drifts. Crushers and LHD equipment could conceivably share the extraction level, but a more flexible and higher surge capacity arrangement would involve passing to a portable crusher on a lower (future) main or extraction level, followed by another pass to a similarly situated main belt. Economical conversion of existing stopes is very unlikely, but new developments should be able to consider decentralized crushing. Comments relating to "oversize breakers" apply as they would to sublevel caves.

4.3.4 Mechanized Cut & Fill

The term "mechanized" is used here to imply, in addition to a kind of ore handling equipment, a certain level of production requiring, and justifying, multiple crushers and belt conveyors. As a general mining method, cut and fill is singled out for attention because its usage is increasing, due to the need for subsidence control, and aided by improvements in productivity (mechanization).

There are many variations of the basic method too numerous to mention in detail, but some features are common and worth noting. Large room-like stopes, some with pillars, are common, lending a room and pillar aspect to face haulage. Dump pockets (ore passes) may be man-made in the fill, or driven in the waste, and LHD-type equipment seems to predominate in the larger operations.

Very good fragmentation control is achievable with this plan, greatly reducing the need for oversize breakage capability in conjunction with a portable crusher and improving (via scalping) the capacity of any given crusher. Crusher location is highly dependent on variations within the basic mine plan, but most comments applicable to sublevel cave will apply here as well, including those relating to conversion of existing rail systems and haulage levels to conveyorized ore handling. Decentralized crushing is potentially more economical for new developments, and the required machine parameters are within the limits already listed.

4.3.5 Minor and Combination Methods

There are many non-room and pillar mining plans in use in addition to the four discussed. They include top slicing, breast stoping, overhand, underhand, and shrinkage stoping, horizontal and inclined cut and fill, undercut and fill, and many timbered arrangements. Most tend to be small, and possibly narrow-vien, operations, and would use few (or one) seldom-moved crushers. Any new or converting mine must plan on the basis of existing proven equipment, but all are considered potential candidates for portable crushers.

SECTION FIVE

COMMENTS ON SELECTED MINES

Visits were made to mines representing almost all types of non-coal minerals, mining plans, and methods. Some were selected for their successful and instructive ore handling systems, and others for their potential as candidates for portable, decentralized, hard rock crusher systems. The significant time and assistance provided by the personnel of these mines was greatly appreciated, and was most instrumental in the preparation of this report.

In this section we will look in detail at a few key mines, or groups of mines, that utilize operating methods or equipment of a particularly pertinent nature. The economic aspects of selected mines and mine plans will be treated separately in Section 7.

5.1 The White Pine Copper Company

The White Pine Copper mine is unique among all mines, particularly in terms of the goals of this study. It is the only "hard" rock mine using decentralized, low profile, portable crushers, and represents the current state of the art for this concept. Accordingly, the White Pine story occupies a place of prominence in this investigation.

A great deal of assistance was provided by White Pine personnel in conducting this investigation and preparing this report; their efforts made possible this instructive and pertinent case study. In addition to the management of White Pine Copper Company, the assistance of the following is gratefully appreciated.

The Industrial Engineering Dept.
White Pine Copper Co.

Mr. Robert Niemela
Supt. Crushing and Conveying

Mr. Ronald Whiton
General Supt., Services

Mr. Eugene Mattila
Research Engineer

5.1.1 Mining Conditions

White Pine's geology consists of laminated shales and siltstones in the lower 20 feet of the Precambrian formation known as the Nonesuch Shales. Mineralization occurs as chalcocite with occasional inclusions of native copper and silver. The mineralized beds also contain feldspars, quartz, and mica in geologic bonds with clays, silicates, and carbonates. The physical properties of the ore are as follows:

110 lbs. per cu. ft. broken density
175 lbs. per cu. ft. bulk density
12,000-28,000 psi compressive strength
Very Abrasive

White Pine is mining a slightly dipping ore body with superimposed undulations which bring the local dip to ± 20%. Minor fault spacing can sometimes be less than 50 feet. Major fault displacements occasionally approach 100 feet.

The ore body is mined using conventional room and pillar methods. A typical mining unit consists of 10-15 entries, 24-32 feet wide. Mining height varies from 7.9 feet to 15 feet, depending on existing ore grades. Pillars may vary in shape (square or rectangular) depending on location and geology, resulting in lateral pillar dimensions ranging between 25 and 75 feet. Single unit production averages about 1600 tons per day and 100 feet of advance per month. At full capacity about 20 such units are operating with the following equipment selection:

1. Two drill jumbos
2. Three roof bolters
3. Two to four LHD units (5 ton capacity)
   OR one LHD and two ore cars (15 ton, rubber tired)
   OR one LHD and three ore cars
4. One platform explosives vehicle
5. One materials and clean-up scoop

5.1.2 History of White Pine's Portable Crushers

Pressed by the needs for higher production (from about 19,000 tpd in 1967 to 28,000 tpd in 1975) and lower headroom mining for grade control, White Pine commissioned the Hewitt Robins Co. to perform an extensive study of their ore handling system.

The 1967 system utilized 2-4 ore cars dumping into receiving pockets, 1000-2000 feet from the face. The pockets fed a 48 inch conveyor which moved the ore to a stationary crusher, after which the ore was conveyed to surface. The problems with this run of mine (ROM) system were indicated in the results of the study.*

> "The present [1967] system has adequate capacity for present production. However, handling of excessively large material, and design inadequacies at transfer and crusher stations, caused serious restrictions in material flow. These restrictions necessitate very irregular operating procedures with a resultant loss of production potential and excessive operating personnel requirements."

As a result of these conclusions, a prototype, portable, horizontal jaw crusher was produced by Eimco and tested at White Pine. Numerous major and minor modifications to this unit were made. Finally, in 1973 the prototype crusher was operating satisfactorily on a steady feed of blocky sandstone chunks. This success prompted Eimco and White Pine to proceed to another generation of development. Concurrently, White Pine purchased, took delivery of, and operated a very heavy duty version of a coal type feeder-breaker from Stamler. This machine was an instant success, particularly when operated in the softer shales.

The second generation horizontal jaw crusher came into the White Pine mine in 1974. It was operated with a feed of chunky shales and 4-5 cubic foot blocks of sandstone. In that situation, and without provision for scalping, the portable crusher could not match the throughput of the feeder-breaker.

5.1.3 Justification for Feeder-Breaker Systems

White Pine's conversion to a feeder-breaker and 36 inch belt system was expected to require expenditures of $1.5 million for capital equipment in just over one year. The economic justification for these expenditures was based on the following assumptions and estimates presented in Table II. As Table II indicates, it was estimated that overall ore handling costs would be reduced 8% if the

*Report of Systems Engineering Study of the White Pine Mine Material Handling Systems by Hewitt-Robins, Inc. 1967.

feeder-breaker system were incorporated. This would in turn contribute an estimated 1.6% savings in total per ton mining costs.

Basing a decision solely on economic estimates related to haulage, it was difficult to justify proceeding with the capital expenditures which the feeder-breaker system necessitated. However, several other advantages could be assumed. They were as follows:

1. Upper shale mining units could potentially mine at the lower 7.5 foot headroom using LHD haulage equipment (without trucks). This would minimize dilution, increase grade, and potentially increase reserves (which are based on 20 lb/ton grade). The increase in grade alone (from 20.3 to 23.0 lb/ton), could reflect a 13% increase in saleable copper if other productivity factors could be maintained.

2. ROM Conveyor availability was being reduced from 93% to 83% primarily because of oversize ore problems. This could be eliminated.

3. Reduction of stockpiling at the dump pocket which was costing $.25 per rehandled ton at that time.

5.1.4 Results of the Improved Ore Handling System

In addition to the control of muck size afforded by feeder-breakers, the overall ore handling system at White Pine benefitted from the following programs implemented between 1973 and 1975:

1. Testing and inclusion of portable feeder-breakers into the conveying system.
2. Smaller fragmentation due to improved blasting techniques.
3. Reorganization of conveying system into sections, providing improved labor and cost control.
4. Timely replacement of deteriorated belts.
5. Increased vulcanizing program.
6. Modifications to transfers, chutes, and poorly designed belt lines.
7. Extensive under-belt and belt drift cleanups.
8. Systematic control of surges and conveyor belts.

TABLE II

Predicted Operational & Cost Comparison of Feeder-Breakers and Conventional Crusher Systems

	Feeder-Breaker to 36" Belt	ROM via 48" Belt to Conventional Crusher
1. Mining Height	7.5 feet	8.5 feet
2. Entry Width	24-32 feet	24-32 feet
3. Monthly Advance Rate	100 feet	90 feet
4. Estimate Output Per Panel (30 months life)	1,440,000	1,440,000
5. Ore Grade	23.08 lb/ton	20.34 lb/ton
6. Estimated Belt Moveup	500 feet	1000 feet
7. Haulage Equipment	LHD only	LHD & Trucks
8. Crushed vs. ROM Belt Life	3/1	

		36" Belt w/FB compared with 48" ROM Belt and Conventional Crusher
A. Capital Equipment Cost *		27% less
B. Ore Handling Cost		4% less
1. Face Haulage	(9% less)	
2. Crushing	(190% more)	
3. Conveyor System Labor	(44% more)	
4. Conveyor Maintenance (labor and material)	(30% less)	
C. Total Ore Handling		8% less
D. Overall Mining Cost per ton **		1.6% less

* Includes appropriate salvage values.
** Does not account for increased grade.

By 1975, 85% of the ore entering the conveyor system was sized by feeder-breakers (the remaining 15% is conveyed over 48" ROM belts, through a conventional jaw crusher, then to surface, as described in the previous section). Feeder-breakers were located near the center entry of each unit, and resulted in LHD haulage of 350-1100 feet. Each feeder-breaker accepts ROM ore from four LHD units, which can complete a cycle in as little as five minutes, and discharges a steady 400 tph onto a 36 inch feeder-conveyor. Ore is then conveyed to surface by a 48 and 54 inch belt system, as shown in Figure 12. The feeder-breakers are fed ore ranging from fines up to 2.5 ft. cubes, and the discharge is a minus six inch conveyable product.

Feeder-breakers are moved up every 6-8 months an average distance of 750 feet. A move-up consists of towing the feeder-breaker out of the existing site and setting it onto a steel structure above the newly advanced 36 inch conveyor. The tow vehicle was fabricated from a retired 18 ton ore car. A site excavation of approximately 1200 cu. yds. is required to allow sufficient clearance over the conveyor, for maintenance room above the breaker shaft for changeout, and to allow for proper drainage and clean-up. Table III shows a comparison of actual feeder-breaker and conventional crusher system performance. Even with these figures, it is still difficult to evaluate the actual economic impact (positive or negative) that feeder-breakers and a 36 inch conveyor system provide. It is indicated that little or no economic advantage was gained in the haulage system directly, however gains were made in other less tangible factors influencing total per ton mining cost and productivity.

A 50% reduction in stockpiling (at fifty cents per rehandled ton) was realized, making possible the reassignment of 56 men over a comparable ROM system, with a potential for a further reassignment of 6 men if the feeder-breakers were automated. A reduction of 50% in material expenditures for belts was achieved due to lower initial costs of the 36 inch system. The elimination of oversize muck reduced spillage from belts, resulted in lower maintenance costs, and produced a significant reduction in lost time accidents, as the following shows:

No. of Accidents (caused by oversize)		Time Lost
1973	10	54 weeks 2 days
1974	3	4 weeks 5 days
1975 thru April	0	0

White Pine Conveyor Belt Layout

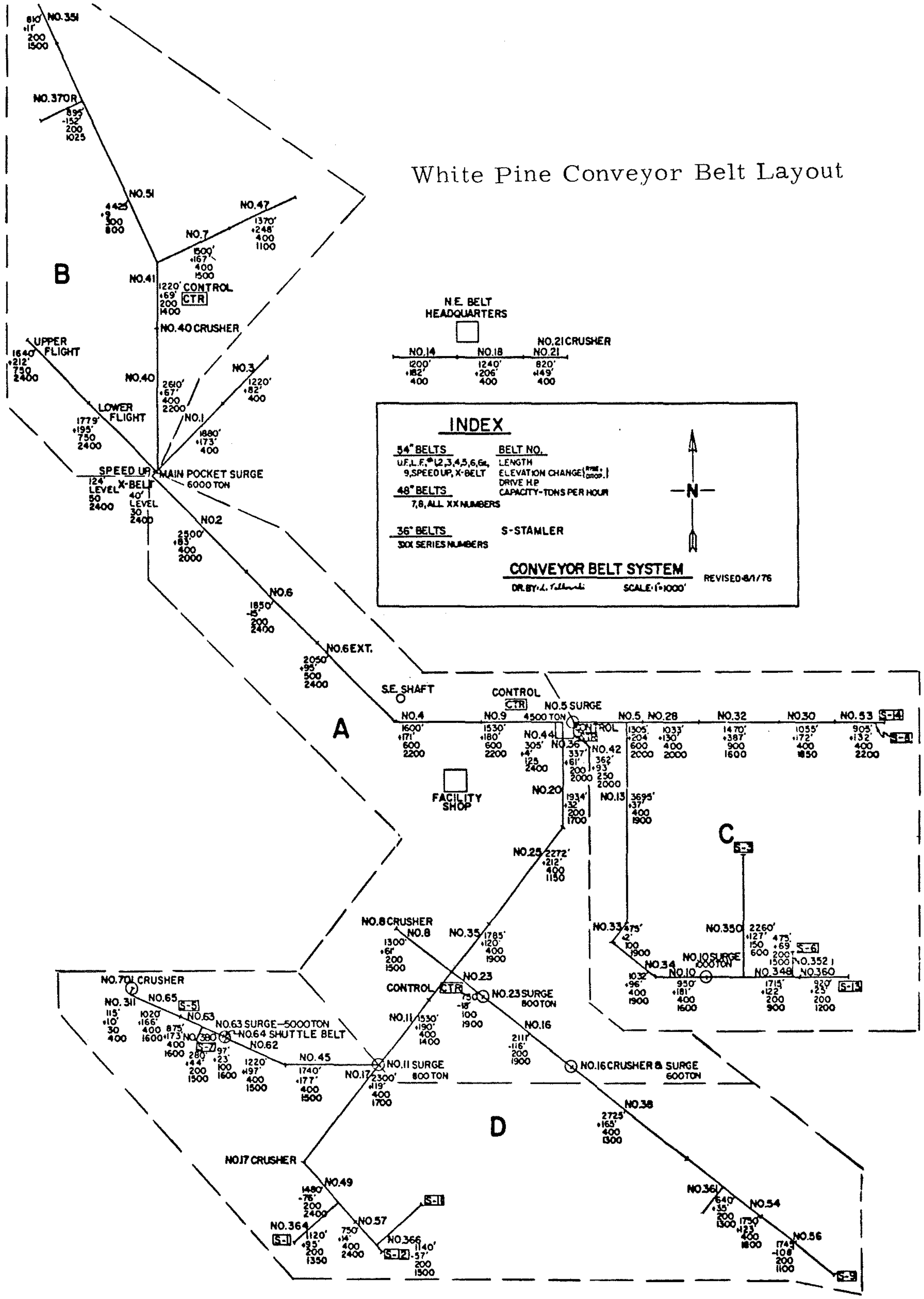


Figure 12

TABLE III

Historical Comparison of Feeder-Breakers and Conventional Crusher Systems

		Portable Feeder-Breakers with 36" belts	Standard dump pocket, with 48 inch ROM belt to Conventional Crusher
1.	Desired Haulage Distance	150-750 feet	200-2000 feet
2.	Actual Haulage Distance	350-1100 feet	1000 feet
3.	Typical Moveup Distance	750 feet	1500 feet
4.	Average Moveup Frequency	once in 6 months	once in 13 months
5.	Typical Mining Unit	3-4 LHD's 0-2 Trucks	1-2 LHD's 4-6 Trucks
6.	Typical Throughputs	300-400 TPH	600 TPH
7.	Dump Frequency	1 load every 1-3 min.	1 load every 1-5 min.
8.	Site Preparation		
	A. Excavation	1900 tons 220 manhours	2200 tons 300 manhours
	B. Belt Installation*	4.00 manhours/ft.	3.70 manhours/ft.
	C. Pocket (or FB) Installation	1500 manhours	2000 manhours
9.	Belt Maintenance (labor)**	40% less	
10.	Crushing Cost/Ton		86% less
11.	Total Ore Handling Cost	approximately equal	approximately equal

*Includes two 36" tail section moveups for each 48" moveup.

**Maintenance material cost accounts are misleading because of high utilization of "liberated" 48 inch components when making such repairs. There were no 36 inch systems available for "liberation".

Upon inspection of Tables II and III, it is observed that projected system characteristics were not achieved for either of the two alternatives. Actual moveup distances are approximately 50 % greater than anticipated for both the feeder-breaker and conventional systems, and the feeder-breakers, while reducing average haulage distances, did not cut the distances as much as expected.

Several unique disadvantages of the feeder-breaker system must be pointed out in conjunction with its previously mentioned advantages. The excavation and construction requirements are double those of an equivalent ROM system, since feeder-breaker moveups are twice as frequent (and still require three shifts downtime to complete) as ROM systems moves. Single move costs are approximately equal for both systems in spite of the portable nature of the feeder-breakers, due to the extensive excavation employed by White Pine. The massive supporting structure, LHD dumping requirements, servicing headroom, and cleaning and drainage requirements cause some parts of site excavation to approach 20 feet in height, even though the feeder-breaker is only six feet high. Any improvements that could be made to this condition would tend to promote more frequent moveups, further improving the overall system.

Increased crushing costs for the pick type feeder-breaker partially offset haulage cost savings mainly due to increased maintenance. Pick replacement is a significant short term maintenance item, and a complete rebuild is required every 1,000,000 tons in normal shale operations and every 500,000 tons in sandstone. The cost of consumables and the total tons throughput per major overhaul would be (is) considerably lower for a truly hard rock (jaw) crusher.

5.2 Trona Mines

Four trona mines in Southwest Wyoming were visited. The four -- Stauffer Chemical, Texas Gulf, FMC, and Allied Chemical -- all near Green River, were enough alike in their mining plan that they are handled here as a single unit. It is not a recommendation of this study that the material handling systems of the trona mines could be significantly improved. Instead, it was felt that these systems represent nearly idealized mining conditions and equipment, for which other underground operations might strive, given substantial improvements in hard rock crushing technology.

5.2.1 Mining Conditions

The Wyoming trona deposits exist as some forty distinct, flat lying, and unfaulted seams, each of varying thickness, extent, and physical properties. Mines are operating in formations (or combinations of formations) having strengths ranging from 3000 to 9000 psi. Room and pillar plans are used, with 8-10 foot high haulageways. Even the hardest of these deposits can be economically "cut" with heavy duty versions of coal equipment. Trona is nonabrasive, and reasonably non-corrosive. The mines employ continuous miners, borer type miners, longwall shearers, as well as conventional drill and blast units. In most conventionalunits a relief slot is first opened with a cutting machine.

5.2.2 Ore Handling System

The practices of trona mines exemplify the material handling system recommended by this study. In these mines, rubber tired transport of material is kept to an absolute minimum by maintaining the dump pocket (feeder-breaker) as close as possible to the mining face. In most cases the feeder-breakers are advanced every week or two. In order to economically justify a non-productive activity happening that frequently, the activity must be carried out quickly and efficiently. In the visited mines, a typical belt move-up approaching 200 ft. is often carried out in less than one shift.

Feeder-breaker and belt moveup are facilitated by careful planning and supervision of the following events:

1. Before the belt drift is bolted, surveyors mark locations where conveyor supports are to be hung.

2. The bolting crew then carefully positions two rows of bolts for the conveyor supports and installs special roof bolt plates containing "bitch link" openings for the support chains.

3. The moveup crew hangs support chain from the roof bolt plates and distributes conveyor components (cables, belt, troughing and return idlers) along the sides of the belt drift where they will be convenient.

4. The feeder-breaker (sometimes pulling the tail pulley terminal section) is trammed along the belt drift somewhat past its intended installation.

5. The conveyor tail section is aligned and secured to pins in the floor with turnbuckles. Simultaneously, the cables and idlers are installed. After the line structure has been secured, a standard length of belt is added using mechanical splices.

6. The feeder-breaker is then returned to its position over the tail pulley and, occasionally, secured with turnbuckles to floor pins.

7. Advancement of the feeder-breaker starter, training of the newly installed belt, and buildup of a loading ramp of muck, completes the moveup and readies the system for continued ore handling.

Rapid installation of the feeder-breaker (or the conveyor tail section) is facilitated by the comparatively "casual" foundation which secures the equipment. In most cases, the mounting platform is no more than a few wooden timbers and/or a pile of muck. Such an installation is difficult to comprehend if one is accustomed to the installation practices associated with stationary gyratory or large jaw crushers. The life of a feeder-breaker installation, it must be remembered, is only a couple of weeks.

5.3 Potash Mines

Four potash mines were visited in the Carlsbad, New Mexico area. They were Duval (Nashdraw mine), IMC (International mine), National Potash (Lea Mine), and AMAX (Carlsbad shaft 1 & 2).

5.3.1 Mining Conditions

Drill and blast, room and pillar methods are used with mining heights varying from 4.5 to 7.5 feet. Cutter bars, continuous loaders, and shuttle cars, predominate. Ore strength ranges up to 15,000 psi, and some formations are fairly abrasive.

5.3.2 Ore Handling Systems

Crushers are maintained very close to the face, with 300 feet considered a typical maximum haul distance. Moveups occur as often as every one or two weeks, and typically require ten men less than one shift. Crushers accept fines up to 2.5 foot cubes, and crush to minus six inch. Throughputs are in the 300-500 tph range.

Most of these mines converted to the feeder-breaker system from some other less satisfactory method. Some had been using rail haulage, and some had employed ROM belts with poor results. Standard roll crushers were also tried, but their great height and site preparation requirements made them costly. After finally arriving at low profile, very portable machines, these mines were able to achieve tremendous documented improvements in productivity, safety, and maintenance. All felt that their operations were at or near optimum conditions from an ore handling point of view. Section 7 details the economic benefits these mines derived from the introduction of feeder-breakers.

5.4 Dravo Lime, Maysville Operations

Dravo Lime Co. is developing a new limestone mine in Maysville, Kentucky. This adit, room and pillar mine should, when it becomes operational, be a model of the decentralized hard rock crushing concept as employed in a high head room room and pillar mine.

5.4.1 Mining Conditions

Mining depth is approximately 950 feet, and the ore is blocky, fine-medium bedded, competent and brittle, with a compressive strength of about 22,000 psi. Jaw type crushers are preferred. Production is planned for 11,000 tons per two-shift day. Two 1000 foot wide panels will be developed, with about 48 headings in each. Rooms will be 35 feet wide and 35 feet high; pillars will be 25 by 50 feet, perpendicular to belt lines. Mining will progress in a top cut of 22 foot height, followed by a 13 foot bench with ramps interconnecting.

5.4.2 Ore Handling System

The LHD-crusher-belt arrangement will be used in each of the two panels. Wagner ST11 LHD's (11 yard) will tram to and dump into a 42 by 48 inch Universal quarry type jaw crusher located at the 13 foot bench. This customized crusher is sectionalized, two-piece, and skidded. One section comprises a 50 ton hopper and a scalping grizzly feeder. The second section is the crusher with its delivery conveyor. No site preparation is required, other than a cast concrete slab, and the two sections bolt together in place.

The top of the 50 ton hopper is 22 feet high, which, with the 13 foot bench, gives the LHD s a dump height of 9 feet from their position on top of the bench. LHD's from the lower level must negotiate a ramp to reach the bench for dumping.

Average haul distances will be kept below 500 feet, enabling each LHD to produce about 1200 tons per shift. Haul distances are expected to vary between 150 and 750 feet, resulting in a 600 foot crusher moveup, occuring approximately every nine months. During a move-up, which is expected to consume seven working days, haulage vehicles and mining cr ews will work in the other panel.

The scalping grizzly is used to reduce fines (they are unsaleable) and to increase the total capacity of a given size jaw crusher. Set at eight inches, the crusher has a capacity of about 500 tph, or half the grizzly feeder capacity, and about 60% of the feed is expected to pass through the crusher. This combination of scalping and crushing will also enable one unit to turn out about 75% of full production while the other crusher is being moved or repaired. Crusher discharge is by gravity to a built-in 42 inch, 27 foot long, elevating delivery conveyor, which discharges at a four foot height onto a 42 inch panel belt. Each panel installation has a total capacity of 1000 tph, and downstream belt transfers are fitted with small surge hoppers and automatic feed controls.

This mining method is similar to one proposed for oil shale, and is potentially suited to high head room lead mines currently operating rubber tired trucks over long distances. Other arrangements are also possible with this near-standard equipment. For instance, a separate module comprising an elevating conveyor could be employed to raise ROM ore from a floor level dump to the hopper, thus freeing the lower level LHD's from negotiating a ramp.

Smaller, low profile crushers (developed for low head room mines) could also be used. Employed on both levels, and divorced from the bench, they could further reduce haul distances and allow the bench to be advanced in normal fashion. Low profile types might also be the choice for single level mines with lower, but not low, backs.

SECTION SIX

RESULTS OF MINE SURVEY

While only 5.9 percent of the total U.S. mine capacity is produced by underground methods, significant, if not all domestic supplies of many key products are recovered underground (1) (19). This study is confined to all non-fuel minerals, representing an annual production of 153 million tons of crude ore in 1971, 127 millions ton of which was produced by 95 mines of 1200 tpd minimum capacity.

Four common mining methods are considered for statistical purposes: (a) room and pillar; (b) caving (block or sublevel); (c) vein (cut and fill, and shrinkage); and (d) sublevel stoping. Of mines greater than 1200 tpd, room and pillar is the predominant method both in terms of tons produced and number of mines, accounting for over 75% of the mines and more than 60% of the tonnage. Almost all nonmetallic and construction materials, and 16.2% of all metallic materials, are mined by room and pillar.

Block caving mines are the biggest single producers, with seven mines producing half the tonnage of more than seventy room and pillar operations. Tables IV & V compiled from (1, 19) and the 1971 USBM Minerals Yearbook, present various breakdowns of the industry by mine plan, capacity, and product.

In the course of this study, approximately forty-four mines were contacted, and twenty-one were visited. Due to the capital intensive nature of the proposed portable crusher concept, the twenty-one visits were concentrated primarily among twenty-three mines with production capacities in excess of 5000 tpd.

Table VI presents a tabulation of the mine survey results. Critical parameters such as ore strength, muck size, and drift dimensions are listed, in addition to the equipment selections comprising the various ore handling systems. This list is not intended to be a complete compilation of all mines, but it does provide a picture of the enviroment in which a successful portable crusher must function.

TABLE IV

U.S. Underground Non-Fuel Capacity

By Product and Size

Product Classification	Capacity(tpy)	%Total
Metallic Ores	80,000,000	52.3
Nonmetallic Ores	41,000,000	26.8
Construction Materials	32,000,000	20.9
Totals	153,000,000	100%

Mine Size (tpd)	Mines	Capacity (tpy)	%Total
5000 plus	23	80,000,000	52.3
1200-5000	72	47,300,000	30.9
Less than 1200	N.A.	25,700,000	16.8
Totals	95	153,000,000	100%

TABLE V

Distribution of Mines and Capacity By Mining Methods

	Medium Capacity 1200-5000 tpd		Large Capacity 5000 plus tpd	
Mining Method	Mines	tons/year	Mines	tons/year
Room & Pillar	57	38,440,000	15	38,450,000
Caving	2	1,770,000	5	34,590,000
Vein Mining	5	2,750,000	1	1,800,000
Sublevel Stoping	8	4,330,000	2	5,140,000
Totals	72	47,290,000	23	79,980,000

All Mines Over 1200 tpd

Mining Method	Mines	% Total	tons/year	% Total
Room & Pillar	72	76	76,900,000	60
Caving	7	7	36,400,000	29
Vein Mining	6	6	4,500,000	4
Sublevel Stoping	10	11	9,500,000	7
Totals	95	100%	127,300,000	100%

TABLE VI - MINE SURVEY RESULTS

MINE NO.	MINING PLAN	TONS PER DAY	PRODUCT	CHUNK SIZE * (feet)	ABRASIVE	ORE STRENGTH (psi)	ORE HAULAGE SYSTEM	CRUSHER	HAULAGE DRIFT SIZE (feet)
1	R&P	25,000	Copper	2x2x3	Very	12-27,000	LHD-SC-JCR-BLT-SRG-BLT LHD-FB-BLT-JCR-BLT-SRG-BLT LHD-BLT-JCR-SRG-BLT-SRG-BLT	JCR	8 1/2x22-30
2	R&P	9,000	Copper Silver			42,000	(Proposed) LHD-JCR-BLT	JCR	15x60
3	R&P	7,500	Potash		NO	Low	LDR-SC-FB-BLT-SRG-H	None	7-9x28
4	R&P	6,000	Potash	3x3x3	NO	Low	LDR-SC-FB-BLT-SRG-H	None	6x26
5	R&P	7,600	Potash	2 1/2x2x3	NO	Low	LDR-SC-FB-BLT-SRG-H	None	4-6x32
6	R&P	14,000	Potash	2 1/2x2x3	NO	Low	LDR-SC-FB-BLT-SRG-H	None	6 1/2x32
7	R&P	10,000 (4 mines)	Zinc	2 1/2x2 1/2x 2 1/2		25,000	LHD-OP-RR-JCR-SRG-H	36x48 JCR	12-14x40
8	R&P	6,200	Trona	1x1 1/2x2	NO	3-5,000	CM-SC-FB-BLT-SRG-H LDR-SC-FB-BLT-SRG-H	None	8-10x22-30

BC=Block Caving
R&P=Room & Pillar
SLC=Sublevel Caving
C&F=Cut & Fill
SLS=Sublevel Stoping

LHD=Load Haul Dump
FEL=Front End Loader
LDR=Gathering Type Loader
SC=Shuttle Car
TRK=Truck

RR=Rail
OP=Ore Pass
BLT=Belt
SRG=Surge
H=Hoist

JCR=Jaw Crusher
GCR=Gyratory Crusher
FB=Feeder Breaker
CM=Continuous Miner
RCR=Roll Crusher

*Size of muck which must be handled by some means at least once per shift.

TABLE VI - MINE SURVEY RESULTS (Cont.)

MINE NO.	MINING PLAN	TONS PER DAY	PRODUCT	CHUNK SIZE* (feet)	ABRASIVE	ORE STRENGTH (psi)	ORE HAULAGE SYSTEM	CRUSHER	HAULAGE DRIFT SIZE (feet)
9	R&P	7,300	Trona	1x1 1/2x2	NO	3-5,000	(Proposed) CM-SC-FB-BLT SRG-H	None	8-10x22-30
10	R&P	5,700	Trona	1x1 1/2x2	NO	7-9,000	CM-SC-FB-BLT-SRG-H LDR-SC-FB-BLT-SRG-H	None	8-10x22-30
11	R&P	4,000	Trona		NO	7-9,000	Longwall	Roll	8-10x22-30
12	R&P	5,000	Lead	2x2 1/2x5	Medium	20-25,000	FEL-TRK-GRC-SRG-H	None	14x25-35
13	R&P	4,200	Lead	2x2 1/2x5	Medium	20-25,000	FEL-TRK-SRG-JCR-BLT-SRG-H (Remote Located Crusher Proposed)	42x48 JCR	14x25-35
14	R&P	6,000	Lead	2x2 1/2x5	Medium	20-25,000	LHD-TRK-SRG-GCR-BLT-SRG-H LHD-SRG-RR-SRG-GCR-BLT-SRG-H	GCR	14x25-35
15	R&P	6,000	Lead	2x2 1/2x5	Medium	20-25,000	LHD-SRG-RR-SRG-GCR-BLT-SRG-H	46GCR	14x25-35

BC=Block Caving
R&P=Room & Pillar
SLC=Sublevel Caving
C&F=Cut & Fill
SLS=Sublevel Stoping

LHD=Load Haul Dump
FEL=Front End Loader
LDR=Gathering Type Loader
SC=Shuttle Car
TRK=Truck

RR=Rail
OP=Ore Pass
BLT=Belt
SRG=Surge
H=Hoist

JCR=Jaw Crusher
GCR=Gyratory Crusher
FB=Feeder Breaker
CM=Continuous Miner
RCR=Roll Crusher

*Size of muck which must be handled by some means at least once per shift.

TABLE VI - MINE SURVEY RESULTS (Cont.)

MINE NO.	MINING PLAN	TONS PER DAY	PRODUCT	CHUNK SIZE (feet)*	ABRASIVE	ORE STRENGTH (psi)	ORE HAULAGE SYSTEM	CRUSHER	HAULAGE DRIFT SIZE (feet)
16	R&P	6,000	Salt	5x5x10	NO		LHD-FB-BLT		
17	R&P		Salt	5x5x10	NO				
18	R&P		Salt	5x5x10	NO				
19	R&P	6,000	Salt		NO		FEL-TRK-FB-BLT-SRG-H FEL-TRK-RCR-BLT-SRG-H		17x35
20	R&P	11,000	Lime-stone			22,000	(Proposed) LHD-JCR-BLT-SRG-BLT	42x48 JCR	22x35
21	R&P	6,500	Lime-stone	3x3x3	NO	Medium	FEL-TRK	None	32x60
22	R&P	6,000	Lime-stone				FEL-TRK-SRG-JCR-BLT	30x42 JCR	24x31
23	SLS	7,000 (3 mines)	Sulfide			15,000	LHD-OP-SRG-TRK-OP-SCR-SRG-H	48x60 JCR	12x18

BC=Block Caving
R&P=Room & Pillar
SLC=Sublevel Caving
C&F=Cut & Fill
SLS=Sublevel Stoping

LHD=Load Haul Dump
FEL=Front End Loader
LDR=Gathering Type Loader
SC=Shuttle Car
TRK=Truck

RR=Rail
OP=Ore Pass
BLT=Belt
SRG=Surge
H=Hoist

JCR=Jaw Crusher
GCR=Gyratory Crusher
FB=Feeder Breaker
CM=Continuous Miner
RCR=Roll Crusher

*Size of muck which must be handled by some means at least once per shift.

TABLE VI - MINE SURVEY RESULTS (Cont.)

MINE NO.	MINING PLAN	TONS PER DAY	PRODUCT	CHUNK SIZE (feet)*	ABRASIVE	ORE STRENGTH (psi)	ORE HAULAGE SYSTEM	CRUSHER	HAULAGE DRIFT SIZE (feet)
24	SLS	14,000 (with 31 & 32)	Nickel	3x4x5		20-40,000	LHD-OP-SRG-JCR-SRG-H LHD-OP-RR-SRG-JCR-BLT SRG-H	JCR	
25	SLS	11,000	Iron	5x5x5	Very	50,000	LHD-GCR-BLT-SRG-H LHD-OP-SRG-GCR-BLT-SRG-H	42GCR	13x15
26	SLS	8,300	Iron	5x5x5	Very	50,000	LHD-OP-SRG-JCR-BLT-SRG-H	42x48 JCR	13x15
27	BC	6,000	Iron			Medium	LHD-GRC-OP-JCR-(or GCR) BLT-H LHD-JCR-(or GCR)-BLT-H	36x48 JCR 54GCR	14x12
28	BC	7,500	Iron	4			SL-OP-RR-SRG-JCR-SRG-H SL-OP-RR-SRG-JCR-BLT-SRG-H		
29	BC	38,000	Moly.	5+			SL-OP-RR-SRG-JCR		

BC=Block Caving
R&P=Room & Pillar
SLC=Sublevel Caving
C&F=Cut & Fill
SLS=Sublevel Stoping

LHD=Load Haul Dump
FEL=Front End Loader
LDR=Gathering Type Loader
SC=Shuttle Car
TRK=Truck

RR=Rail
OP=Ore Pass
BLT=Belt
SRG=Surge
H=Hoist

JCR=Jaw Crusher
GCR=Gyratory Crusher
FB=Feeder Breaker
CM=Continuous Miner
RCR=Roll Crusher

*Size of muck which must be handled by some means at least once per shift.

TABLE VI - MINE SURVEY RESULTS (Cont.)

MINE NO.	MINING PLAN	TONS PER DAY	PRODUCT	CHUNK SIZE (feet) *	ABRASIVE	ORE STRENGTH (psi)	ORE HAULAGE SYSTEM	CRUSHER	HAULAGE DRIFT SIZE (feet)
30	BC	6, 300	Moly.				SL-OP-RR-SRG-JCR		
31	C&F	14, 000 (with 24 & 32)	Nickel	3x4x5		20-40,000	LHD-OP-SRG-JCR-SRG-H LHD-OP-RR-SRG-JCR-BLT-SRG-H		
32	SLC	14, 000 (with 24 & 31)	Nickel	3x4x5		20-40,000	Same as above		

BC=Block Caving
R&P=Room & Pillar
SLC=Sublevel Caving
C&F=Cut & Fill
SLS=Sublevel Stoping

LHD=Load Haul Dump
FEL=Front End Loader
LDR=Gathering Type Loader
SC=Shuttle Car
TRK=Truck

RR=Rail
OP=Ore Pass
BLT=Belt
SRG=Surge
H=Hoist

JCR=Jaw Crusher
GCR=Gyratory Crusher
FB=Feeder Breaker
CM=Continuous Miner
RCR=Roll Crusher

*Size of muck which must be handled by some means at least once per shift.

SECTION SEVEN

ECONOMIC BENEFITS OF DECENTRALIZED CRUSHING

The best indication of the economic benefits that may be derived from the introduction of portable crushers can be found in operations experienced in their use. Hence this study included visits to mines handling soft materials for which present portable feeder-breaker equipment is entirely satisfactory. Not surprisingly, these visits were to low head room room and pillar mines, the type most adaptable to decentralized crushing and conveyorized ore handling. It is felt, however, that these case studies realistically reflect the potential of the decentralized low head room crusher concept for the hard rock industry.

7.1 Low Head Room Room and Pillar Mines

Salt, potash, trona, and copper mines have successfully employed portable crushers. Much of the trona is machine mineable, so the drill and blast methods of the other mines are more appropriate for an economic analysis. The copper mine is a medium to hard rock mine and deserves separate scrutiny.

7.1.1 Salt and Potash Mines

Specifically, one salt and four potash mines were selected, all employing the decentralized crusher concept. Operations were quite similar, and all believed their use of the equipment to be optimum -- hence their experience represents a true measure of the full potential of portable crushers.

One potash mine, facing expensive face haulage problems and long (as long as five miles), inefficient rail haulage, started a modernization program in 1967. An initial attempt at a 48-inch main belt, fed by rail and ROM ore resulted in severe alignment and spillage problems -- in fact the belt was abandoned for a period of about one year because of excessive haulage delays (roughly 2-3 hours lost time per shift). Alignment and spillage problems were alleviated with the introduction of feeder-breakers at shuttle car discharge points in 1970. Lost time related to haulage was completely eliminated, and a manpower reduction was possible. The mine went completely to feeder-breakers and belts in 1972.

Productivity, at roughly 100 tons per man shift with the original rail system, dropped to 84 tons/manshift with the introduction of ROM belting, and has since risen to 153 tons/manshift with feeder-breakers and belts. Presently, belt life is considered to be unlimited, with minimal, largely routine, maintenance. Crushing and conveying cost is presently $.15/ton ($1.93/ton/total mining cost) as compared to $.24/ton haulage cost alone prior to 1968. Feeder-breakers run untended, although a mechanic visits each one twice per shift. Crew size has been reduced from 9 or 10 to 7. In this time span, mining costs have been reduced 3.5%, despite labor and material cost increases of about 40%. Safety has also been enhanced: three fatalities were associated with the rail haulage system prior to 1972; none have been experienced since.

As would be the case in any mine, this modernization program was not limited solely to the introduction of a better haulage system--hence the improvements cannot be ascribed entirely to the use of portable crushers. The program also included new face mining equipment, improved maintenance training, improved blasting practices, and an improved safety program. Still, the use of portable crushers and the accompanying major haulage advantages played a dominant role in the striking results.

A second potash mine had been using "portable" standard roll crushers that required about four feet of installation excavation, complete with a concrete base, and required 50 man shifts per move. Introduction of truly portable feeder-breaker units reduced crushing costs by about 50% and significantly increased the availability of other equipment due to shorter face haulage distances. Thus, less than optimum portable equipment, though perhaps satisfactory in comparison to other alternatives, can fall far short of the full potential of the proper equipment.

A third potash mine was experiencing an oversize problem while conveying ROM ore. Introduction of feeder-breakers reduced conveying costs from the former $.15/ton to $.07/ton, and reduced conveyor downtime to 10% of its former value. Furthermore, the ability to eliminate oversize material at the feeder-breaker allowed a reduction in face drilling from a 27 to a 16 hole pattern. Larger loaders were also used, and an increase in productivity, from 125 tons/manshift to 200 tons/ manshift was experienced, with major credit being given to the use of portable crushers.

The fourth potash mine has just changed to portable feeder-breakers. Previous ROM belts suffered excessive maintenance problems, with up to 2 hours lost time per shift. In line with experience in similar nearby mines, feeder-breakers are expected to provide a crushing and conveying cost of roughly $.15/ton, a 30% increase in tons/manshift, elimination of one laborer per crew, and "unlimited" belt life with minimal maintenance.

The salt mine (14) was also using a roll crusher, a large unit requiring a 26 foot deep site excavation and a 200 foot long conveyor ramp. Every installation (moveup) cost $20,000 to $35,000 and required three months time, in spite of rather generous 18-20 foot high backs. A full time operator was required, and haul distances were excessive for much of the three year life of the installation.

A conversion from loaders and trucks to LHD's coincided with the introduction of feeder-breakers. With the new multi-crusher system, maximum haul distances were reduced from 4400 feet to 750 feet, and moveups were reduced from three months to two shifts. Equipment investment costs are 8.75 cents per ton per year versus 17.5 cents for the old system. Operating labor was reduced by 50.3%, maintenance labor by 39.1%, maintenance materials by 57.9%, and the crusher operator has been eliminated.

It is worth noting again that these examples have been selected as representative of optimum conditions, unlimited by machine shortcomings. All use short (150 to 300 ft) average haul distances, and short, rapid (1-2 shifts) crusher moves which require relatively little labor (10 man shifts) and little or no site preparation.

7.1.2 White Pine Copper Mine

The situation at White Pine is not so clearly advantageous as the preceeding situations, largely because White Pine's system is far from that optimum that would exist in the absence of machine shortcomings. This particular mine is, of course, of special interest to this study because it represents the state of the art in portable hard rock crushing.

At the present time, in comparison to present alternatives, portable crushers are the system of choice at White Pine, even though clear savings in crushing and conveying as startling as those in potash and salt mines, are not demonstrable. As discussed in Section 5.1, other advantages, believed to be substantial but certainly difficult to quantify, justify the system.

But what could be achieved "in the absence of machine shortcomings?" Present major shortcomings at White Pine include high crushing cost--three to five times as high as conventional (albeit non-portable) hard rock crushers handling the same material, and, as used at White Pine, lack of portability.* The latter results not only in excessive cost and downtime for moving; it also renders the benefits of optimum haul distances unattainable, as Table III in Section 5.1 indicated. The situation is remarkably similar to that mentioned above in the second potash mine: an initial system, which, though presumably better than other alternatives, was substantially short of its full potential because of the shortcomings of the key portable crusher element. Thus, with development of a truly satisfactory hard rock portable crusher, there is no reason to believe that the substantial economic benefits enjoyed by the soft rock industry cannot be enjoyed by this mine and the rest of the hard rock industry.

7.2 High Head Room Room and Pillar Mines

Projected potential economic benefits of portable crushers are difficult to obtain for this category because there are no existing operations with published data on which to base estimates. There are, however, two significant cases worthy of mention.

7.2.1 Dravo Lime, Maysville, Kentucky

Operational details for this new 11,000 tpd mine were presented in Section 5.4, but a few items bear repeating. Thirty-five foot backs allow this mine to utilize modified (for portability) quarry equipment. The rock is sufficiently strong (22,000 psi) that jaw type crushers are preferred, making this a hard rock application.

Projected mining costs are not published, and, as the mine is still on development, cost histories do not yet exist. What is interesting to note is that of all available mining plans and equipment alternatives, this new mine decided on a decentralized, semi-portable crusher/belt arrangement utilizing proven hard rock crushing principles. This choice was made in spite of the fact that both vertically fed crushers are "married" to a bench because of

*In the narrow sense defined for this study, then, White Pine is a hard rock mine since the ore is not economically crushed by present equipment.

their dump height requirements. Low profile crushers loaded at floor level might have made an even greater contribution toward reduction of ore handling costs.

Only two panels are being worked at Maysville, so greater decentralization of the crushing function is perhaps not justified. However, the lead mines, and other, perhaps not so high limestone mines, could well be future beneficiaries of the advances currently being attempted by Dravo.

7.2.2 Oil Shale

In Section 4.2.3 we discussed a Cameron Engineers study (4) of six large scale oil shale mining plans, two of which were high head room room and pillar methods based on portable crushers.* The results of the economic analysis portion of that study were most interesting from the point of view of this study. Both portable crusher mining plans were lowest in per ton preproduction cost, and one (chamber and pillar) was the lowest in production cost as well. Capital costs for the ten decentralized crushers were lower than those for the large fixed crushers of the other four plans, and underground personnel requirements for the chamber and pillar method were the lowest of all plans.

Oil shale is not really hard rock, and the portable crushers selected in the Cameron study were not, and did not need to be, hard rock crushers. In spite of this, portable crushers, used in conjunction with belt conveyors, appear to be an impressive tool in the effort to control high head room room and pillar mining costs. With proper equipment, these benefits should be attainable in hard rock mines as well.

7.3 Non Room and Pillar Mines

In spite of the overwhelming number of room and pillar mines, the non room and pillar group accounts for much of the total tons mined underground in this country. Consequently, if portable crushers for low head room room and pillar mines were adaptable to this group, the impact on the industry as a whole would indeed be tremendous. Since no mines in this group are presently using portable crushers, and none are known to be contemplating such use, we cannot cite case histories of savings so gained. In addition, since rather sweeping changes in traditional mine plans

*Of the others, two were block caves, and two were sublevel stoping geometries, all using rail main haulage.

would be required in order to incorporate portable crushers, and since suitable crushers do not exist at this time, accurate prediction of the potential benefits is beyond the scope of this study.

A trend was found, however, toward decentralized, if not portable, crushing. In order to eliminate costly rehandling and retramming of ROM ore, some mines have located their central, or perhaps a second, primary crusher in the ore body away from the shaft. In virtually all cases, belt conveyors were used between the crusher and the shaft, and all felt that this arrangement was preferrable to longer rail or truck hauls of ROM material. The portable crusher concept under study here is really nothing more than an extension of this trend, and with mining plans based on successful portable crushers, non room and pillar mines should be able to realize reductions in ore handling costs.

SECTION EIGHT

CONCLUSIONS

A number of significant conclusions have been reached as a result of this study. They are presented in this section, together with amplification or summarized rationale.

The first conclusion is, in part, a restatement of the premise upon which this study was based:

> Portable crushers close to production sites would provide ore handling cost reductions in room and pillar mines, and decentralized crushers (i.e., small to fit within headings but not necessarily frequently moved)could provide savings in many non room and pillar mines. The earliest applications of portable crushers would be in room and pillar mines where the savings are greater and where the flexibility of the system permits a relatively easy switch to new, conveyorized methods. Early development work should concentrate on this application.

Regarding the present state of the art and the suitability of currently available equipment:

> At the present time, portable crushers in use on medium to hard rock in this country are based upon feeder-breaker principles developed for coal and other soft minerals. In terms of machine size, throughput, and critical inlet dimensions, they are quite satisfactory. When viewed simply as hard rock crushers, however, crushing costs for these machines are well above those typical of conventional designs intended for hard rock. The latter, in turn, simply cannot meet the necessary dimensional requirements for portability. Thus there is a clear need for the development of a new, compact, portable crusher <u>fundamentally suited</u> to handling hard rock.

> For hard rock, jaw crushers, or units using similar principles, are preferred, at least within, or nearly within, conventional means. Three novel low head room concepts will be presented, although only one, utilizing jaw crusher principles, is recommended for immediate development.

Economical belt conveyor haulage is not compatible with ROM ore. However, the use of crushers to obtain a beltable product at or near production sites should not be construed as a complete solution to the oversize problem:

> Virtually any crusher, regardless of type or size, will occasionally be fed material too large for its critical inlet dimension. Present means for handling oversize range from the "double jack" (sledge hammer) to dynamite. As machine size is decreased in the interest of portability, it can be concluded that the handling of oversize feed will be of increasing importance. The development of truly portable hard rock crushers will be greatly enhanced by the parallel development of automated, reliable means to reduce occasional oversize in the feed to manageable dimensions.
>
> The greatest oversize problem in non room and pillar mines occurs as large chunks right at the production site. Because of the number of such sites, the relatively low average "throughput" at each site, and the frequency of such chunks, portable crushers cannot be justified at each production site.
>
> Once oversize problems are successfully handled, perhaps by mobile impactors in extraction drifts, or by impact or other means at dump pockets, decentralized crushers placed at collection points of adequate throughput could provide significant haulage savings in conjunction with a (new) mine development geared to economical belt haulage.

Unlike fixed central installations, decentralized crushing requires a departure from the bigger-is-better approach to productivity and equipment availability:

> Portability and maintainability can both be enhanced by employing separate units such as hopper-feeder and crusher, or hopper-feeder-scalper and crusher. Separate units become mandatory as the number of features increases to include surge capacity, feeding, scalping, oversize breakage, and crushing.

Using the data of Section Six and the references cited therein, the potential market for portable underground hard rock crushers can be estimated as follows: Total annual, underground non-fuel mineral production was 153 million tons in 1971. The exclusion of mines producing less than 1200 tons per day reduces this figure to 127 million tons per year, produced by 95 mines. If one assumes that room and pillar mines represent the only realistic near and medium term market, another 50 million tpy are excluded resulting in a 77 million tpy market. Longwall, feeder-breaker, and other coal-type hardware has already been found acceptable in salt, potash, and trona mines producing perhaps 35 million tpy. Exclusion of these mines leaves approximately 50 mines producing about 42 million tpy, or about 140 thousand tons per day, 27 percent of the total industry. The market breakdown is as follows:

	Production		
Mine Type	Millions tons/year	tons/day	% of Industry
Small Mines (under 1200 tpd)	26	87,000	17.0
Non Room & Pillar	50	167,000	32.7
Room & Pillar Mines Soft Rock	35	117,000	22.9
Room & Pillar Medium-Hard Rock	42	140,000	27.4
	153	511,000	100%

Having narrowed the market so drastically to that 27% having a clear need, no hardware alternatives, and maximum adaptability to belt conveyors and decentralized crushing, a near term penetration of 50 percent of this market segment would seem conservative (70 thousand tons per day). With very rough estimates for availability, utilization, shifts per day, etc., this production could be handled by perhaps 50 machines rated at 200 tons per hour. At a guestimated price of $250,000 including related hoppers, feeders, discharge conveyors, and the like, the dollar market becomes $12.5 million exclusive of replacements, rebuilds, and spare parts.

Half of the medium and hard rock room and pillar mines are considered to be the readily reachable near term market. They number about 25 mines producing 21 million tpy (70,000 tpd) and represent 14 percent of the total industry production.

The dollar value of this portion of the market, for crusher system hardware only, is estimated to be approximately $12.5 million for about 50 systems.

The cost of mine-wide conversion to decentralized crushing depends in large part on the existance, or absence, of a workable belt conveyor system within a given mine. Where conveyors are lacking, this cost far exceeds the cost of the portable crushers alone.

The preceding market estimations are deliberately conservative, and evidence exists to indicate that early success would eventually lead to much greater usage of the portable crusher/belt conveyor concept. The salt and potash mines are prime examples: Where suitable portable crushers are available (in this case feeder-breakers) they are the economic system of choice in room and pillar mines. Full acceptance by room and pillar mines would result in a doubling of the previous market estimates, particularly if some of the smaller mines (under 1200 tpd) are included.

Non room and pillar mines produce 40 percent of all production over 1200 tpd. Because of the costly and complex aspects of conversion to decentralized crushing and (probably) conveyorized haulage, penetration of this segment of the market will necessarily follow successful acceptance by the room and pillar mines. Some mines will undoubtedly find conversion too costly or impossible, but there is no fundamental reason why non room and pillar mining geometries cannot be planned to take advantage of the economies of decentralized crushing and low cost conveyorized haulage.

Additional markets are, or will be, accessible to the successful low profile, portable, hard rock crusher. These would be oil shale mines, open pit mines, quarries, as well as Canadian and other non domestic mining industries. These markets, though potentially large, are beyond the scope of the present study.

As far as machine parameters are concerned, the market for portable hard rock crushers is broadly divided into those mining applications that require, or do not require, crusher concepts dictated entirely by the need for a low profile configuration:

Where installed crusher size is not a deterrent (high head room, room and pillar mines like limestone and, perhaps oil shale), significantly new crusher concepts are not required, and adequate throughput, though large is already available. However, improvements in portability can be made by better design of modular assemblies, and new low-profile concepts would be applicable, perhaps preferred. Manufacturers have indicated a willingness to undertake development of such improvements to customer specifications.

Where machine dimensions are the principle deterrent to portability (low head room room and pillar and, later, most non room and pillar mines), a portable hard rock crusher should have the following design parameters:

Height	7-9 feet
Width	8-10 feet
Length	Not critical except in transit
Weight	Not critical within expected values
Critical Input Dimension	30-36 inches
Product Size	Minus 6 to minus 8 inches
Throughput	100-300 tons/hour
Site Preparation	Little or none
Headroom	8-12 feet
Moveups	One shift downtime

Of these, height will be the most difficult to satisfy for the selected critical input dimensions. Throughput, which might otherwise be of considerable concern, will not be difficult to provide for the selected input dimensions, although scalping will likely be required for the higher throughputs. Scalping of feed should be provided, where possible, to improve capacity and avoid unnecessary crushing of beltable material.

When one is desireous of portability, there is always a trade-off between machine size and machine capacity. Within these dimensional limits, it is expected that most mine operators will desire crushers closer to the small end of the range; that is, seven feet high and eight feet wide, and perhaps even lower in height during tramming. A small machine can be used in a large-drift mine, but the reverse is obviously not true. If a seven foot high crusher can achieve 200-300 tons per hour, there may be no appreciable underground market for nine foot machines regardless of their throughput. In short, we need to know more about what is achievable within the seven foot height, from a designer's point of view, before we can say there is an underground market for taller or larger machines.

> The vast majority of underground applications in the near term will require a machine capable of achieving a seven foot height, at least during tramming. Modular construction for entry into shaft mines is a requirement.
>
> Those medium and high head room mines able to consider significantly taller machines (primarily limestone mines) represent perhaps 20% of the applications.
>
> For a given mine, the tramming dimensions of their largest LHD (or similar) equipment provide a good yardstick for determining the maximum desired crusher size.
>
> Long term markets (non room and pillar mines) will probably require the smaller crushers, even if the mine plan is based on decentralized crushing.

Scalping, rather than a larger crusher, may be the least expensive method of achieving greater throughput. On the other hand, a larger crusher could presumably handle larger ore. This introduces the whole question of oversize ore, how and where it is handled, and by what means. These are obviously questions having different answers for different mines:

> The middle of the throughput range, 200 tons per hour, is a capacity that can realistically be made portable in a low profile. It is also compatible with typical production rates from a single mining unit. Higher <u>unit</u> capacities are available through varied combinations of face haulage equipment, traffic patterns, surge capacity, and scalping.

SECTION NINE

CONCEPTS FOR CRUSHING HARD ROCK

An objective of the present contract is to "provide a concept for the design of a portable underground hard rock crusher in order to insure that future development will lead to maximum utilization by industry". The preceding section has concluded that the industry can indeed use such a machine and that, within desired performance and dimensional parameters defined by this study, no standard crushers are suitable for handling hard rock.

As indicated in Section 3, and stated in standard references such as (5), and (6), hard rock of large feed dimensions is best handled by jaw and gyratory crushers. This conclusion is of little value for present purposes unless we can determine fundamentally why these machines, and only these machines, are satisfactory. Using this knowledge, then, we stand a much better chance of devising satisfactory new concepts.

An examination of jaw and gyratory crushers, in comparison to other types used on weaker materials, indicates that the former are distinguished by the following fundamental characteristics:

(1) They are stronger. This characteristic is terribly obvious, and increasing strength (and drive force) is one means to upgrade the capability of a given crusher type in this respect. (For example, compare rotating pick type feeder-breakers used on copper ore with the same type used on coal.) Great strength also forces other fundamental design features that are not so obvious. In particular, strength requires that the machine contact the rock only with broad, extremely blunt surfaces.

(2) Their crushing action utilizes a limited movement relative to the rock surface that is very small in comparison to feed dimensions, though of course capable of great force within that small movement.

(3) They possess a feed means that absolutely prevents advance of any rock fragment to a position that would require a large deformation. This feature is an unavoidable consequence of the limited crushing motion

and broad crushing surfaces noted above. However, on some new crusher concepts this feature may not be unavoidable, and unsatisfactory results (jamming, stalling, or machine breakage) may follow.

The following section describes three new crusher concepts, one of which, though earlier thought to be an attractive new concept, can be discarded (for hard rock) because it clearly does not have the third fundamental characteristic mentioned above.

In view of the strong, and perhaps obvious, conclusion that portable crushers will accentuate the need for breaking occasional oversize feed fragments, some thoughts on handling this problem are also presented.

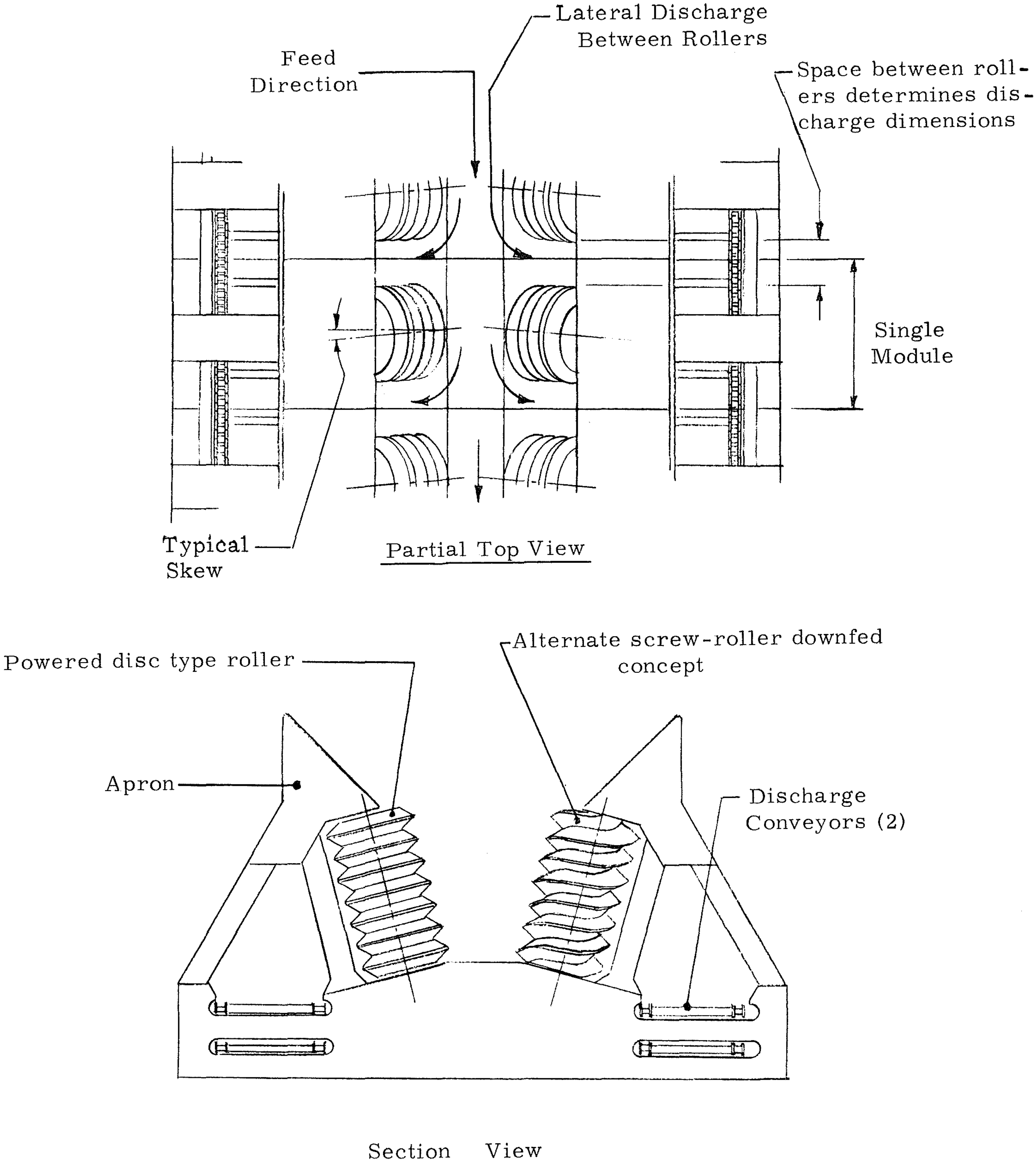
9.1 New Portable Crusher Concepts

Each of the following subsections presents a new crusher concept for hard-rock, portable, underground applications. The first, which will be rejected, is discussed in part to illustrate the importance of the previously noted fundamental characteristics of successful hard rock crusher concepts. The third, on the other hand, indicates that, while valid for reasonably conventional concepts, it would be inappropriate and restrictive to apply such conventional design criteria to unconventional concepts.

9.1.1 "V" Roller Crusher

Based on the successful development of the RAPIDEX conical reamer, a skewed rolling element crusher was conceived using the same principles. The conical reamer is a roller cutter device which is self-advancing by virtue of its wedge-like shape and skewed rollers A crusher using the principles would be essentially "inside out", and it would self-feed rock fragments between the rollers.

Figure 13 is a sketch of basic concept, which consists of opposed rollers arranged in a row of "V" shaped pairs. The rollers are powered (i.e., rotated) and skewed (tilted forward) such that a rock fragment placed within the "V" will be simultaneously propelled forward and drawn downward until it is crushed. Product size is determined by the (adjustable) axial space between rollers. Downward and outward flow of product would provide quick clearing of smaller material, thus allowing effective crushing of larger material carried forward between the rollers.



Powered, skewed rollers, assembled in two-roller modules, carry muck forward and downward. Crushed and undersize material discharges downward and outward between rollers.

RAPIDEX Wedge Crusher Concept
Figure 13

While all of these features would be desirable, it was noted that a large fragment could simply fall downward between two "V" sections rather than feed downward gradually as intended. From this position a fragment would then be driven forward and crushed substantially in a single, large compaction, in violation of the third listed desirable characteristic of a hard rock crusher. Large downward motion between rollers could be avoided, or at least reduced, by placing baffles between rollers, but this would also stop the free discharge of undersize material--one of the major claimed virtues of the concept.

In conclusion, the "V" roller crusher is judged to be unsuitable for hard rock crushing. It would be suitable , and would provide a good, free flowing design, for coarse crushing of softer of friable materials that can now be handled by conventional roll crushers.

9.1.2 Rotary Jaw Crushers

The jaw crusher, either Blake or overhead eccentric as appropriate, is the conventional machine most nearly satisfactory for the subject hard rock portable application. It is entirely satisfactory in terms of crushing performance -- feed size, hard rock capability, reduction ratio, product characteristics, throughput, and economy. However, it cannot meet the necessary installed dimension requirements, particularly with regard to headroom. Although basic crusher dimensions (i. e., the jaws themselves) are not too bad, the conventional top feed arrangement requires much too much headroom, particular if slabby material (which would have to be vertically oriented) is to be handled.

It is appropriate, then, to search for a horizontal feed jaw crusher concept. One obvious approach, tipping a basically conventional jaw crusher on its edge, (i. e., with the eccentric shaft vertical) has been attempted in this country, and several such units are said to be in use in an iron mine (hematite) in Europe. All use a horizontal chain conveyor traveling just beneath the lower edge of the jaws to move material through the machine. Although this configuration obviously does work, it must do so at some sacrifice in performance. It seems clear that a feed mechanism working only at one edge of the jaws must be at a disadvantage relative to the uniform (gravity) feed of the standard upright configuration. In fact, gravity acting transverse to the horizontal throughflow causes a downward migration of finer material, thus encouraging early choking in the vicinity of the chain conveyor.

Furthermore, the conveyor is itself a high maintenance item, particularly when simultaneously subjected to some crushing forces (as is also the case in rotating pick feeder breakers).

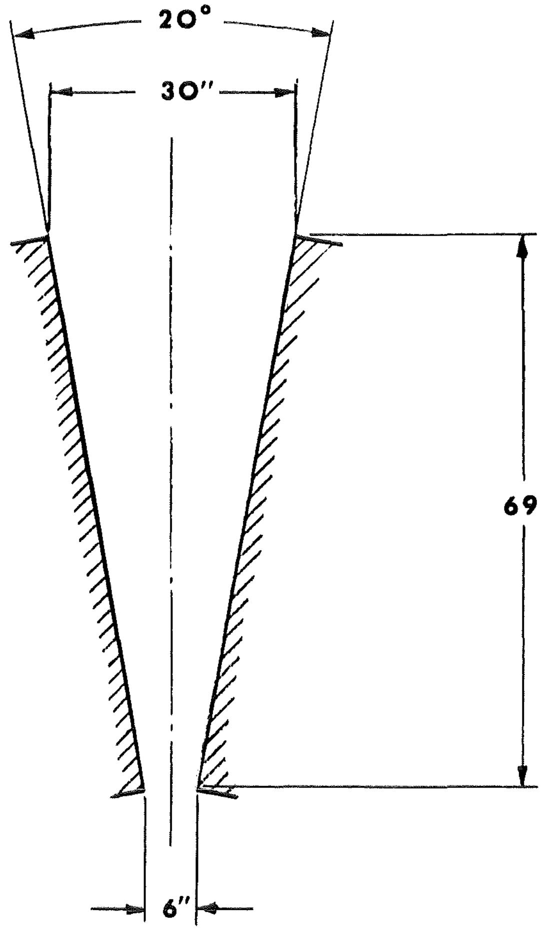
The "rotary jaw crusher", to be described, employs a curved flow path in an attempt to both decrease the vertical dimension of the jaws themselves and provide for horizontal feed without the above problems. It achieves uniform feed distribution across the jaws, with at least a portion of this being gravitational, while avoiding transverse migration of material within the jaws. It uses no conveyor within the crushing zone (although for low headroom applications a conveyor may be used to feed the crusher.)

Figure 14a illustrates a typical jaw crusher profile in simplest schematic form neglecting curved "non-choking" jaw features, all of which can be provided later as necessary. After Mc Grew (6) let us assume that the included angle between jaw faces is 20^{o}, that is, a small value for hard rock. Then, for vertical jaws having a 30 inch inlet and a 6" discharge, the bare jaw height must be 69 inches. (Recall the striking uniformity of conventional machine heights noted in Section 3.) Figure 14b illustrates a schematic of an equivalent jaw crusher in which inlet and discharge dimensions and mean path length (hence convergence angle) are preserved while wrapping the mean path around a 180^{o} curve.* For these dimensions, the curved path results in a decrease of 7 inches in height (assuming for the moment a circular mean path). While this is not an enormous saving in itself, the configuration does provide horizontal feed, and this <u>is</u> a substantial improvement. Other advantages will become evident as the concept is further described.

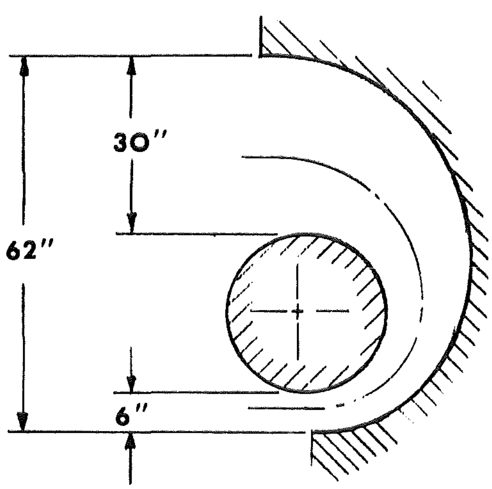
Crushing motion of the curved jaw machine may be provided by several means, the most obvious of which would be oscillation of the "external" jaw (the right-hand element in Figure 14b) against a stationary "internal" member. Jaw motion may be maximum at the discharge, in a Blake-type action, or near the inlet, in an overhead eccentric type action, depending upon the choice of the designer. However, it is believed that neither of these will provide the best design.

---

*The 180^{o} wrap is not necessarily the optimum design -- it is presented here only as an illustration and as a logical limiting case.



(a) Standard Jaw Profile



(b) Curved Jaw Profile

STANDARD and CURVED
JAW PROFILE

Figure 14

Figure 15 illustrates what we shall call a rotary jaw crusher having the preferred inner element crushing motion. A cylindrical inner element is driven in an orbiting motion by a central eccentric shaft, essentially identical to that of an overhead eccentric crusher.* It is expected that this orbiting motion will require less force than would oscillation of the outer elements, and less force than is required by conventional jaw designs. The latter must subject their entire rock charge to crushing forces simultaneously as the jaws converge everywhere at the same time.** Furthermore, with conventional gravity feed of reasonably graded material, it is virtually certain that rock fragments will in fact be tightly lodged throughout the converging crushing zone as the crushing stroke commences. In contrast, the orbiting cylinder of the rotary jaw crusher produces only a local zone of maximum convergence which travels through the rock charge. Hence, although crushing the enclosed rock charge in approximately 180^o of eccentric motion (like conventional designs), it does not crush the entire charge simultaneously. The rotary jaw eccentric bearing should thus see a force that is reasonably uniformly spread through 180^o, rather than the conventional force which rises to a peak at the end of 180^o.

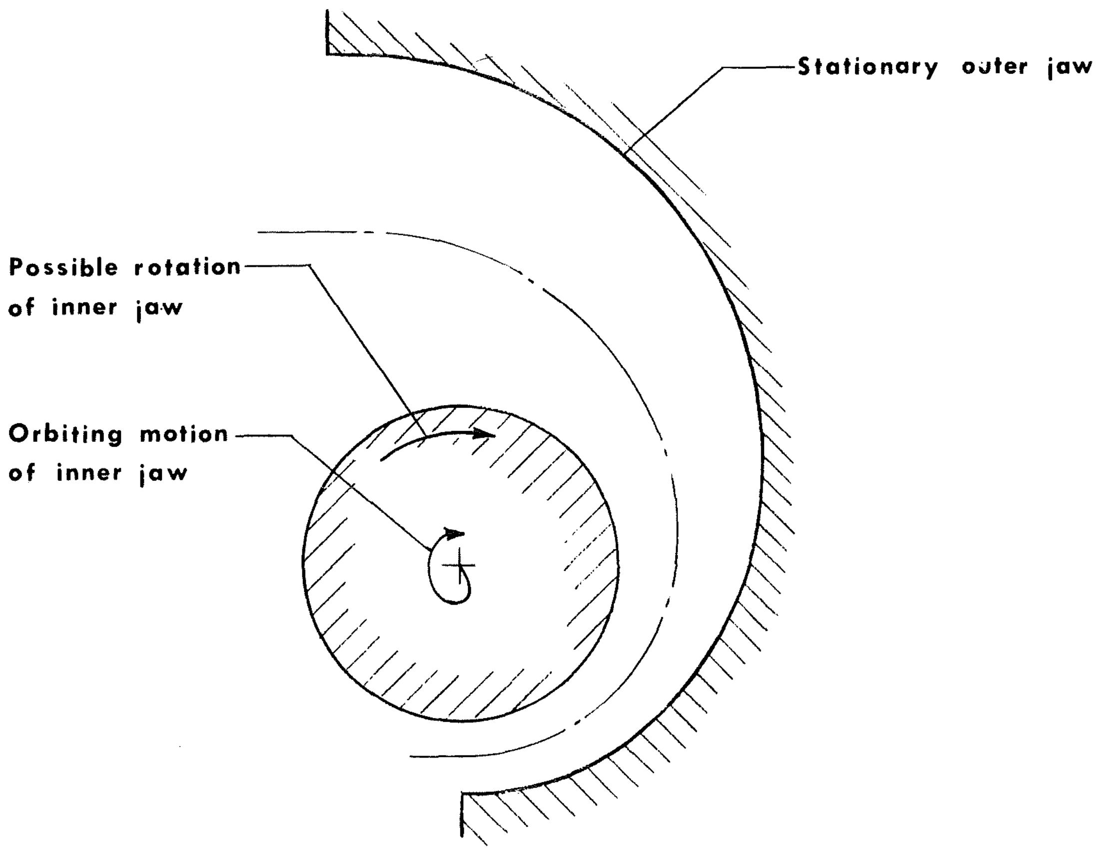
Orbiting motion of the inner element provides one more major advantage if the motion is in the "forward" direction illustrated in Figure 15. In this case, the crushing action moves through the rock charge in the flow direction. providing a peristaltic pumping action to assist throughput.

With regard to throughput, disruption of the simple straight through gravity flow of conventional designs is clearly the major drawback of the rotary design. Refering to the limiting 180^o design of Figure 15, gravity feed will be effective only in the middle half of the passage. Feed can no doubt be enhanced in the inlet quarter of the passage by "stuffing" this region with a forcing conveyor feed, but no such assistance is available in the discharge region.

With the peristaltic action described above, it is quite possible that no throughput problems will be encountered (particularly if the discharge region is cut back as discussed below . However, if difficulties are encountered, it is expected that rotation of the cylindrical inner element about its own axis will be very effective in urging material through the crusher. If simple feed enhancement

*The possibilities of rotary motion of the cylinder about its own axis will be discussed later.

**Depending on toggle orientation, overhead eccentric designs may crush some material near the throat on the up stroke of the moving jaw.



Rotary Jaw Crusher
Concept

Figure 15

is all that is desired, rotary drive via a torque source that acts when large crushing forces are absent would suffice. On the other hand, perhaps considerably more rotary torque would benefit crushing action as well, via shearing forces on the rock (like those of an overhead eccentric design). In fact, one might consider a family of designs which distribute orbiting and rotating power differently for different rocks: ranging from pure orbiting on one extreme to pure rotary (i.e., a single sledging roll crusher) on the other. *

Rotation of the inner element (either freely or driven) also provides for balanced wear between the two jaw surfaces, since the full circumference of the inner element is about equal to the total length of the outer jaw. Obviously, both jaws would be provided with replaceable wear surfaces. It may also be beneficial to use different surfaces (for example ribbed or smooth), depending on the proportions of crushing and shearing desired.

Although complete rotary jaw crusher design is beyond the scope of this study, Figure 16 illustrates schematically a more complete concept. Refering back to Figure 15, clearly the greatest throughput problems will occur near the discharge, where neither gravity nor force feed are effective, and where choking would be most likely to occur in a "straight" (i.e., continuously converging) design in any case, (6). Proven methods, described by McGrew (6), can be used to design "non-choking" discharge regions to ease this problem, but it may also be necessary to simply move the crusher discharge point up as shown in Figure 16 to completely eliminate the problem. Furthermore, since the complete crusher must incorporate a discharge conveyor, the higher discharge point (and correspondingly higher inlet) may not result in an overall taller machine if it allows the elevated conveyor placement illustrated in Figure 16.

The rotary jaw crusher concept has been described in schematic form and certain of its important advantages have been cited. Other advantages are also derived from the curved mean path geometry. In summary, the following features are expected to be

*There may be an interesting and useful analogy here with percussive, rotary-percussive, and pure rotary drilling. The purely crushing action of the former is analogous to pure orbital crushing, while the shearing action of rotary drilling and of single roll crushing are analogous. As in drilling, crushing may be greatly enhanced by combining these two actions in optimum proportions for each rock type.

of special advantage in portable, low head room, hard rock crushing applications:

1. Use of proven jaw crusher principles for hard rock crushing for the desired feed size range and throughput.
2. Slightly reduced jaw height.
3. Horizontal feed at a point below the top of the machine.
4. Very simple eccentric drive, at less than conventional force levels.
5. Compact, stiff geometry, probably even more rugged than conventional jaw geometries.
6. High efficiency.*
7. The possibility of simple performance improvement by varying crushing and shearing actions to match rock properties (not important in hard rock applications, but of interest in extending the range of the device).
8. Uniform feed across the jaws, with no conveyor inside the crushing zone.
9. Superior slab-breaking capabilities.
10. Little or no danger of discharge conveyor damage caused by slabs extending from the discharge to drag against the conveyor.

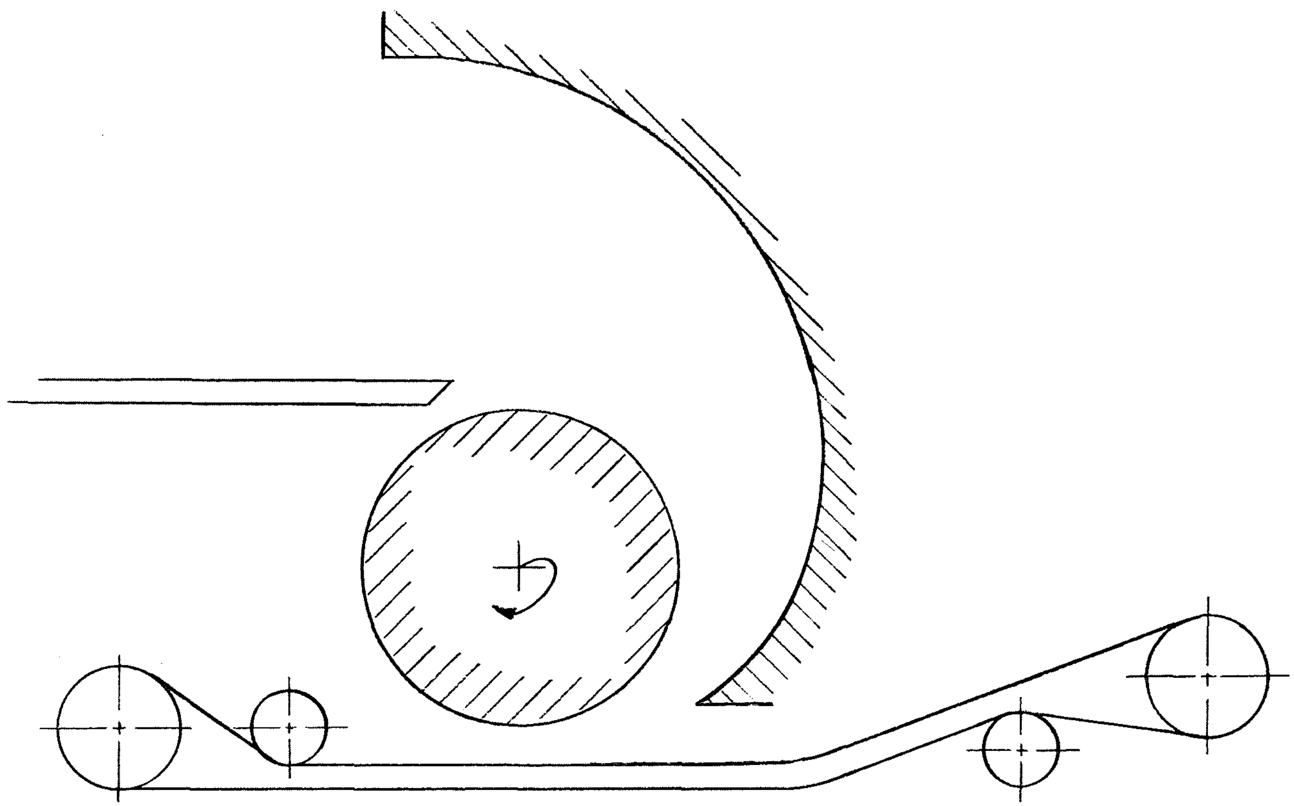
Some of these advantages, like slab breaking, high efficiency, and compact, rugged design, are obviously of benefit in any situation.

9.1.3 Hammer "Crushers"

Section 9.2 discusses the use of impact hammers, probably hydraulically actuated, to break occasional abnormally large material feeding the portable crusher. If suitable means are developed for impact breaking occasional large pieces, then it would be a logical extension of that development to attempt automated breakage of all unbeltable material, particularly when the latter constitutes a reasonably small fraction of total production. Such development should follow that of the occasional oversize breaking system (particularly its automated actuation) and, although no overall concept is presented here, the idea is suggested as a goal of impact breakage systems. It would seem to promise extreme portability together with the ability to handle widely varying feed dimensions.

---

*The rotary jaw crusher does not employ the highly wasteful oscillating motion of conventional jaw crushers. In fact, in this respect it is closer to gyratory action, and the latter typically use less power than equivalent jaw crushers.



Gravity Fed Rotary Jaw Crusher With Discharge Conveyor

Figure 16

This idea is also present to point out the limitations inherent in the preceding selection of hard rock crusher characteristics. There is great danger in setting up restrictive design criteria and then attempting to apply these criteria too broadly.

Obviously, an impact breaker has to be strong, but meaningful strength parameters for an impacting machine are quite different from those of a conventional machine which uses essentially static forces and brute strength. For example, an impact bit cannot be blunt, at least in the same sense as a crusher jaw, but other design features, like assuring proper orientation, can compensate for this. In contrast to conventional machines, an impact breaker definitely should not have a limited motion, since the rock to be broken cannot be well restrained at the time of impact. Thus, the second conventional characteristic actually is not correct for this particular unconventional approach. Finally, since an impact breaker would be intended to produce major fracture in a single blow, the third conventional characteristic is also simply not appropriate in this case.

In summary, fundamental characteristics of successful conventional hard rock crushers have been noted. It is believed that these are very useful in judging the suitability of new concepts utilizing the same basic crushing means, but they are not appropriate, and should not be restrictively used, in judging concepts utilizing different crushing or breaking principles.

9.2 Handling of Oversize

As concluded in Section 8, breaking of oversize feed material will be increasingly important as crusher dimensions are reduced to enhance portability. Indeed, the importance of feed size in crusher design suggests that the handling of oversize should be considered an integral part of the hard rock portable crusher development program. Hence, although impact breaker design and application in general are beyond the scope of this study, it is appropriate to discuss breaker problems and features insofar as they relate to portable crusher development. Although oversize feed may be handled at a variety of locations, that most directly related to crusher development would be immediately upstream of the crusher, and it is primarily this location that will be considered.

9.2.1 Problems of Oversize Breakage in Portable Crusher Feed

As a single example most closely allied to crusher design, consider a hydraulic impactor mounted just ahead of the crusher, positioned to break oversize fragments as feed is conveyed past.

Ideally, the device should run without an operator, breaking all oversize material wihout interrupting throughput. The following are, very briefly, the major problems that can be expected in the development of such a system.

The first problem will be to identify those fragments which are oversize. Once located, each oversize fragment must be properly positioned relative to the hammer, by moving either the rock, or the hammer, or perhaps both. Preferably, if slabby material is being handled, proper positioning will also include advantageous orientation of the rock. When properly positioned, the hammer should strike the rock with enough energy to fracture the piece in a single blow*. If the rock does not fracture, or if fragments are still oversize, this must be quickly determined and another blow struck. Proper support of the oversize rock at impact is important, both to promote effective energy transfer from the impacting device, and to insure that impact does not damage the supporting machinery. In view of the variability of rock size and shape, and the possibility of its motion upon impact, the impacting memeber must be capable of sustaining glancing, or even entirely missed, blows without damage.

Many of these problems are already handled to some degree by present feeder units. For example, the typical feeder that utilizes a chain flite conveyor to pull material from the bottom of a surge bin generally extracts small material first. In slabby material the larger fragments are usually well oriented, with the maximum dimension parallel to the conveyor motion, and the minimum dimension normal to the conveyor surface. Combined with suitable gates, sensing devices, and hammers, it is not unreasonable to expect that such a feeder can be equipped to automatically reduce all feed material to a size which can be handled by a portable crusher. It can also be expected that considerable development effort and operating experience will be required before untended operation of such a system becomes routine.

Handling oversize material is a very important mine problem in general, and worthy of considerable attention. The preceding example, though selected because it relates directly to portable crusher design, illustrates many of the problems that might be expected in the development of any automated impact type breaker system, whether it be applied at a draw point, over a grizzly,

---

*This is not in agreement with the Theodore Barry study (2), which recommends multiple blows at relatively low energy. Single blows are more efficient (8) and much simpler in terms of positioning and holding the fragment.

or on a feeder conveyor, and many of the comments in the following subsection are thus of general interest.

9.2.2 Suggested Impact Breaker Characteristics

In a complete study of handling oversize material it would not be appropriate to assume that hydraulically actuated impact devices represent the best or only breaking means. For the purpose of this crusher study, we shall limit this discussion to such devices simply because they are the most nearly suitable of today's readily available means. That is not to say, however, that a typical off the shelf hydraulic demolition tool is ideally suited to this task.

For the hard rock, portable crushers contemplated in this study, fragments having minimum dimensions of the order of 30 inches would be considered oversize. It is desireable to break such a fragment in a single blow if possible, both to minimize positioning and holding problems and to avoid throughput interruptions, and because it is more efficient (8). One manufacturer suggests that this requires 1000 to 3000 foot pounds per blow, obviously depending on rock properties. This same manufacturer has found that repeated blows of too little energy tend to drill holes in large fragments without causing fracture.

In view of the generally poor confinement of target fragments and likely positioning errors at the time of impact, an efficient impactor should be capable of delivering an effective blow throughout a rather long stroke -- perhaps as long as 12 inches. In this sense, the typical demolition hammer, although certainly the most suitable off the shelf item, is not ideal.

Depending upon overall system design, rapid automatic blow capability may not be required. Thus the rapid cyclic action of a conventional hammer may be economically omitted in favor of a simpler design that triggers discrete blows after proper hammer position is established.

These two features, very long stroke and discrete blows, suggest that it may be appropriate to reexamine the "hurled bit" or "projectile bit" (after reference 8) concept. As the name indicates, this device uses a one-piece bit-piston which is (hydraulically) hurled directly against the rock without the internal metal--to-metal impact of conventional "struck bit" designs. The major virtue of the hurled bit concept is the substantial reduction of peak stress within the steel (for a given rock stress), which in turn, for a given blow energy, permits the use of a lighter machine at higher impact velocities. Many of the admitted design difficulties of the concept have to do with rapid sequencing, a feature that may not be required in this application. Furthermore, with proper actuator design, the hurled bit breaker is compatible with very long effective strokes.

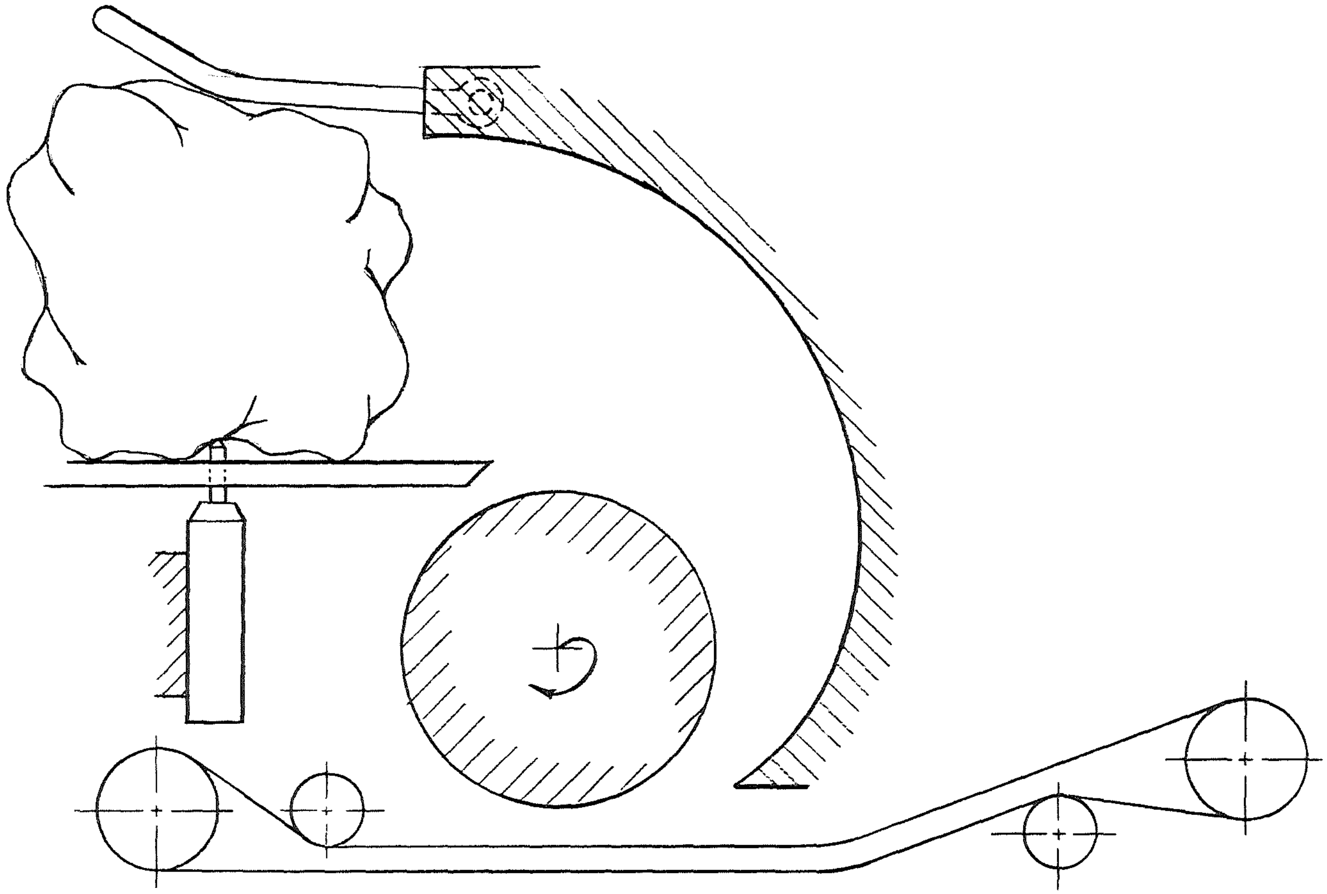
Single blow breaking, although fast and efficient, does have one obvious drawback: the required high blow energy may cause damage to the supporting structure. Figure 17 illustrates a novel concept in which the oversize fragment is struck from below, with reaction coming solely from the inertia of the fragment itself, rather than the surrounding machinery. This figure also illustrates a simple gating arrangement which might be used to trigger the impact. Such a design might well use multiple fixed impactors triggered by multiple gates (for example, spread across the width of the feed conveyor) to avoid the complexities of moveable components. The assembly would also require means to contain fragments.

9.2.3 Oversize Breakage in Standard Ore Handling Systems

There is a need, often cited by others (2), for a better method of controlling oversize, independent of the existance or use of portable crushers. One grizzly-drift block cave mine is experimenting with a low profile crawler mounted impactor (11), capable of servicing several drifts and many drawpoints, and results to date are promising. The Maysville Operation at Dravo Lime is also using an impactor, mounted on a tractor, to service their "portable" jaw crushers and all the working faces.

Non room and pillar mines using mechanized (non-slusher) face haulage have a common characteristic; namely, the ability to load quite large muck and haul it to a few (relative to production sites) dump points. Grizzlies at the dump pocket represent one method of filtering out problem-causing muck, but the oversize remains, to be handled by costly "secondary" means. These mines may not be able to convert existing rail systems to belts and (if they existed) crusher, but they can consider automatic, untended "devices" at the pockets to break oversize.

A successful "pocket breaker" must be funded (i.e., justified) by savings derived from increased productivity (fewer disruptions), reduced secondary breakage costs, reduced ore pass and chute maintenance, reduced spillage and wear in main haulage, and, perhaps, reduced ore pass costs (size). While these effects are far



Impact Breakage of Oversize Crusher Feed

Figure 17

reaching, no single item predominates, none are easily estimated, and it is clear that the pocket breaker must be very simple and inexpensive. Impact breakers represent only one potential solution, and since they may not be the most satisfactory or economical, we should consider other means.

Muck at the pocket may have major dimensions exceeding six feet and minor dimensions approaching three feet. Discharge from the pocket breaker should be in the minus 20 to minus 26 inch range in order to eliminate downstream problems (and to enhance eventual conversion to low profile crushers). The tonnage requiring breakage, and the reduction ratio, are therefore quite small, indicating that the pocket breaker need not "run" all the time. A simple jaw, or a vise, perhaps actuated by cylinders, driven by a source of high peak (but low average) power, might be sufficiently simple. Shafts and bearings could be eliminated in favor of less expensive pivots. Servicing should be simple, and the pocket should be useable even if the breaker is not functioning, perhaps by automatically (passively) shunting aside the very large oversize.

Other, and perhaps more exotic, means, may come to mind,* but a full treatment is not an objective of this study. Recommendations for this application will follow in Section 10.

9.3 Modular Assemblies

The portable crusher performs three basic functions:

1. It accepts run of mine material from a very unsteady source, such as a load-haul-dump unit carrying perhaps seven tons, or twice that from a telescoping haul unit.

2. It feeds this material to and through a crusher at an acceptable, essentially steady rate.

3. It delivers crushed material at an essentially steady rate to a discharge conveyor (or perhaps an ore chute or other haulage element).

---

*Electrical (9, 10), thermal, thermomechanical (18), and others have been attempted.

Obviously the portable crusher must include some sort of hopper or surge bin to accomodate this highly unsteady delivery, and the hopper design must be compatible with the low head room restrictions and the dumping geometry of the load-haul-dump (or other) haul equipment within those restrictions. Present machines, both the coal feeder-breaker type in use and the horizontal jaw crushers that have been tested, are one-piece machines that feed from the hopper via a chain type conveyor. The feed conveyor also travels through, and is an integral part of, the crushing mechanism.

In soft materials like coal, potash, and trona, feeder-breakers are often self-propelled, offering the ultimate in portability. Applications in harder materials have not enjoyed this degree of portability, although size alone has not been the major problem. Rather, portability has been substantially restricted because of costly and time consuming site preparations deemed necessary in the heavy duty applications. For example, rather extensive foundation structures, requiring subgrade excavation, have been used to avoid damage caused by impact from discharging haul vehicles, and to accomodate the discharge belt. Furthermore, in a wet application any sub-grade excavation must allow additional room to accomodate drainage and clean out functions. Complications such as these make it abundantly clear that the desired hard rock portable crusher should require essentially no site preparation, or at least no site excavation.

After some thought, it becomes clear from the foregoing that the desired portable crusher might better consist of a least two independent pieces: a hopper-feeder unit, and a crusher-discharge unit. The former can be virtually identical to the simple, proven hopper end of present machines. The latter, being independent of the present integral feed conveyor, cannot be identical to the present machines. Several significant advantages may be derived from this multiple piece approach:

1. The independent pieces can clearly be much smaller and more easily moved than the one-piece present machine.

2. With proper design, the two pieces need not be precisely located relative to one-another, so that some inadvertant movement of the hopper need not effect either the crusher or the discharge conveyor.

3. Crushing forces are not imposed on the hopper feeder.

4. The two separate units, each being simpler and more accessible, are more easily maintained.

5. Separate pieces, again with proper design, may be used in a variety of arrangements (for example, in line or around a corner,) thus easing site requirements and perhaps simplifying traffic patterns.

The hopper envisioned in this discussion is a very simple device, similar to the present equipment except that the feed conveyor would be inclined to accept input at the necessary low level while discharging into the top of the crusher. With gravity feed into the crusher, and either a large inlet for the latter or a simple chute arrangement between the two, the hopper-feeder need not be fastened to, or even precisely located, relative to the crusher. This would permit easy set-up and it may provide for much simpler protection against impacts from haul vehicles. For example, Figure 18 illustrates schematically a set-up having the following features:

1. The feeder-hopper is positioned conveniently at the entrance to a heading, permitting simplified traffic patterns and better visibility.

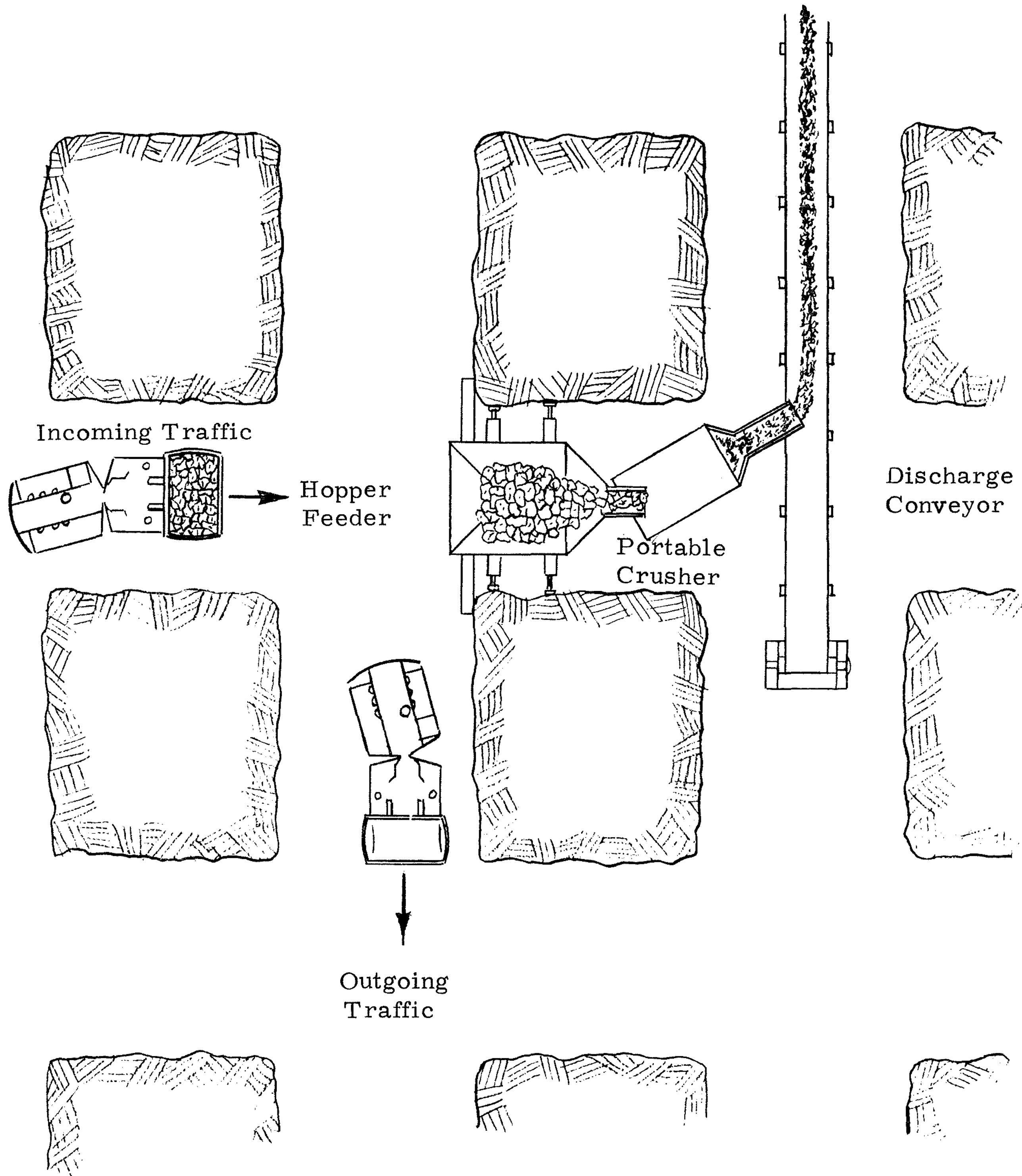
2. The feeder-hopper is secured in a position by jacking against ribs (bolting to the floor may be preferred by some operators and this is, of course, always possible).

3. The crusher is mounted under the feeder discharge at an angle to accomodate minor variations in the distance between the desired hopper position and an established discharge belt.

4. The crusher discharges onto a normal, floor- or roof-mounted discharge belt.

Actual layout of the equipment is, of course, dependent upon a variety of mining conditions. The sketch is intended to suggest one possiblity, and to illustrate the flexibility inherent in a two-piece design.

Modular assemblies, which offer interesting advantages in this simple two-piece concept, are virtually a necessity if additional crusher features are to be provided. For example, if oversize feed is to be broken on the feed conveyor, as discussed in



Modular Concept for Portable Crusher System

Figure 18

a preceding section, it is unlikely that a one piece hopper-feeder-breaker-crusher design will be either portable or maintainable. Furthermore, it has been suggested that feed scalping be employed to avoid additional crushing of already beltable material. Suitable equipment for this feature is well within the present state of the art, and development of a one-piece integrated unit is not only not necessary: it may well be undesirable.

SECTION TEN

RECOMMENDATIONS

In view of the conclusions reached in this Applications Study, presented in Section 8, and reviews of present equipment together with new concepts presented in Section 9, three recommendations are made for further design, development, and testing of a portable hard rock crusher.

10.1 Hard Rock, Low Head Room, Portable Crusher Development

It is recommended that a program be initiated to develop a hard rock, low head room, portable crusher of the rotary jaw crusher type. It is believed that this concept is the simplest available based on proven hard rock crushing principles, and therefore, it is the best concept for full development.

Although the machine should ultimately be designed within those parameters cited in Section 8, early experimental work can profitably be done on a smaller prototype of perhaps 20-inch critical inlet dimension. The purpose of this experimental phase of the development would be to establish (above ground) proper jaw shape, eccentric motion, and rotary motion to assure proper feed. Once this is assured, full scale underground prototype development could be undertaken with confidence.

10.2 Feed System Design

It has been concluded that feed scalping to avoid unnecessary crushing of beltable material would enhance the performance and capacity of any portable crusher. It is not believed that provision of this feature will require an elaborate development program: therefore, initiation of such a program at this time is not recommended. However, when a full scale prototype crusher design is undertaken, it is recommended that feed requirements be defined in suitable terms to permit procurement of a suitable feed system for use in early field tests.

10.3 Handling of Oversize

It is recommended that a program be undertaken, in parallel with crusher development, for the development of suitable means for breaking oversize feed material. This program can be divided into three major subprograms and, in view of the widespread occurance of the problem (it has been cited by others), and the variety of possible applications, it is recommended that all three sub-programs be undertaken simultaneously. They are:

1. Using existing impact actuators, explore and develop automated means to mount, aim, and control such devices for untended operation. Specific applications within the ore handling system would include use at dump pockets, or in conjunction with limited-inlet crushers.

2. Develop long stroke impact devices for better performance on loosely restrained chunks of oversize.

3. Explore the application of, and, if practical, develop other concepts, including non-impacting means, in a search for advance oversize breaking systems capable of functioning economically in realistic applications such as (1) above.

APPENDIX A

CRUSHER MANUFACTURERS

ALLIS-CHALMERS CORPORATION P. O. Box 512 Milwaukee, Wisconsin	1, 2, 5
AMERICAN PULVERIZER COMPANY 1249 Macklind Ave. St. Louis, Missouri	3, 4
BIRDSBORO CORPORATION Furnace Street Birdsboro, PA	5
EAGLE CRUSHER COMPANY Route 2, Box 72 Galion, Ohio	3, 4, 5, 6
ELMAC CORPORATION P. O. Box 1692 Huntington, West Virginia	8
EIMCO MINING MACHINERY Envirotech Corporation P. O. Box 1211 Salt Lake City, Utah	5
F M C CORPORATION Mining Equipment Div. Tenth and Belt Line Fairmont, West Virginia	8
FULLER CO., GATX 1450 Cedar Crest Blvd. Suite 104 Allentown, PA 18104	2, 5, 6
GRUENDLER CRUSHER & PULVERIZER CO. 2900 N. Market St. St. Louis, Missouri	3, 4, 5, 6, 7
T. J. GUNDLACH MACHINE CO. Div. of JMJ Industries, Inc. Box 385-T Belleville, Ill.	4, 6

HEWITT ROBBINS Div. Litton Systems Columbia, South Carolina	2, 3, 4, 5, 6
IOWA MANUFACTURING CO. 916 16th Street, N. E. Cedar Rapids, Iowa	1, 3, 4, 5, 6
JEFFREY MANUFACTURING CO. Division of Jeffrey Galion Inc. 956 N. 4th Street Columbus, Ohio	3, 4, 5, 6, 7
JOY MANUFACTURING COMPANY Denver Equipment Division 4985 Colorado Blvd. Denver, Colorado	5, 6
KENNEDY VAN SAUN CORPORATION Beaver Street Danville, Pennsylvania	1, 2, 4, 5
LONG-AIRDOX COMPANY Oak Hill, West Virginia	8
McLANAHAN CORPORATION McLanahan Bldg. Hollidaysburg, PA	5, 6
MINING PROGRESS INC. P. O. Box 3 Highland Mills, N. Y.	5, 7, 8
OWENS MANUFACTURING, INC. P. O. Box 366 Crab Orchard, West Virginia	8
PACIFIC CRUSHER SYSTEMS INC. 88 S. Linden Ave. So. San Francisco, California	1, 2, 3, 4, 5, 6
PENNSYLVANIA CRUSHER CORPORATION Box 100J Broomall, PA	3, 4, 5, 6, 7

PORTEC, INC. 3200 Como Avenue, S.E. Minneapolis, Minnesota	3, 5, 6
REXNORD, INC. Nordberg Machinery Group P.O. Box 383 Dept. TR Milwaukee, Wisconsin	1, 2, 3, 4, 5, 6
S and S MACHINERY SALES, INC. P.O. Box 897 Richlands, Virginia	8
W.R. STAMLER CORPORATION Millersburg, Kentucky	8
STRAUB MANUFACTURING CO. B383 Baldwin Street Oakland, CA	1, 2, 3, 5
TELSMITH DIV. OF BARBER-GREENE P.O. Box 723 Milwaukee, Wisconsin	1, 2, 5, 6
UNIVERSAL ENGINEERING CORPORATION Cedar Rapids, Iowa	1, 3, 4, 5, 6
WILLIAMS PATENT CRUSHER & PULVERIZER CO. 800 St. Louis Avenue. St. Louis, Missouri	3, 4, 5, 6, 7

CRUSHER CLASSIFICATION CODES

1. Cone
2. Gyratory
3. Hammermill
4. Impact
5. Jaw
6. Roll
7. Rotary
8. Feeder-Breaker

APPENDIX B

BIBLIOGRAPHY

1. Dravo Corporation. Analysis of Large Scale Non-Coal Underground Mining Methods. U.S. Department of the Interior, Bureau of Mines, January, 1974.

2. Theodore Barry and Associates. Analysis of Ore Handling Systems in Underground Metal Mines for Improved Safety and Efficiency. Phase I & II Reports. U.S. Department of the Interior, Bureau of Mines, June 1974.

3. Nicholson, D. USBM Spokane, unpublished study.

4. Cameron Engineers, Inc. A Technical and Economic Study of Candidate Underground Mining Systems for Deep, Thick Oil Shale Deposits. U.S. Department of the Interior, Bureau of Mines, July 1975.

5. Cummins, Arthur B. and Ivan A. Given. SME Mining Engineering Handbook. 1973, Vol. 2.

6. McGrew, Brownell. Crushing Practice and Theory. Allis-Chalmers, 1953.

7. Julin, Douglas E. Future Developments in Block Caving. Skillings' Mining Review, September 20, 1975, pp. 12-15.

8. Grantmyre, Innes and Ivor Hawkes. High Energy Impact Rockbreaking. The Canadian Mining and Metallurgical Bulletin, July, 1975 pp. 1-8.

9. Sarapuu, Erich. Electro-Energetic Rock Breaking Systems. Mining Congress Journal, June 1973, pp. 44-54.

10. __________. Electro-Energetic Rock Fragmentation. Electrofrac, Inc.

11. Joy Manufacturing, Cambridge, Ontario, and Denver, Colorado. Personal Communication with Alan Rivers and Carl Milner.

12. Klimke & Wright Ltd., Edmonton, Alberta, Canada. Personal Communication with Rudolph Klinke.

13. E/MJ. Alcoa Uses Portable Crushers at New Mining Site in Western Australia. Engineering and Mining Journal, August 1976.

14. Bush, Lewis P. LHD/Feeder-Breaker System Cuts Cost at International Salt Co.'s Cleveland Mine. Engineering & Mining Journal, September 1974.

15. Occidental Minerals, Grand Junction, Colorado. Personal Communication with Dick Ridley and Robert Thomason.

16. McLanahan Corp., Hollidaysburg, PA. Personal Communication

17. W.R. Stamler Corp., Millersburg, Kentucky. Personal Communication.

18. Thirumalai, K. and S.G. Demou, and R.L. Fischer. Thermomechanical Method for Secondary Breakage of Hard Rocks. U.S. Department of the Interior, Bureau of Mines 1975.

19. Mining Engineering. Update: Underground Mining in the U.S. July 1975.

20. Schroeder, William E. The Feeder Breaker as a Primary Crusher in Strip Mining Operations. Mining Congress Journal, March 1974, pp. 27-29.

21. Day, David. How to Select a Crusher. Engineering and Contract Record, March 1975, pp. 18-19.

22. Vogeno, Dr. Walter. New Low-Speed Hard Rock Impact Crusher. Chemical and Process Engineering. February 1972, page 45.

23. Mining Magazine. Continuous Crushing at Hayange. Mining Magazine. Sept. 1975, pp. 177-179.

24. Bullock, Richard Lee. Optimizing Underground, Trackless Loading and Hauling Systems. University of Missouri-Rolla. 1975, pp. 1-43.

25. Baxter, B. J., A. Gasparovic, and A. H. Bond. Primary Crusher Development. General Atomic Project 317. February 1974, pp. 1-56.

26. Ozol, M. A., and S. R. Locke. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Martin Marietta Corporation. June 1974, pp. 1-93.

27. Kellner, R. C. and K. J. Edmiston. Investigation of Crushing Parameters at Duval Sierrita Corporation. Society of Mining Engineers. December, 1975. Volume 258, pp. 345-352.

28. Mining Magazine. Strassa Mine--An Efficient Underground Iron Ore Producer. Mining Magazine. December 1974, pp. 432-445.

29. Belton, Arthur. Evaluating Underground Coal Haulage Systems. American Mining Congress. May, 1975, pp. 1-18.

FORM DI-1216
(December 1972)

UNITED STATES
DEPARTMENT OF THE INTERIOR

Date October 7, 1976

SUMMARY REPORT OF INVENTIONS AND SUBCONTRACTS

The following report must be submitted in *triplicate* as part of the interim or final report as provided for by the REPORTS and/or PATENT ARTICLE in the grant or contract.

CONTRACT DATA	
A. NAME OF CONTRACTOR Rapidex, Inc.	B. ADDRESS 18 Sargent St. /P. O. Box 520 Gloucester, MA 01930
C. IDENTIFICATION OF CONTRACT OR GRANT *(Title, number, date, and Department agency involved)* Application Study of Portable Underground Crusher, Contract No. J0265006 May 18, 1976, U. S. Bureau of Mines.	
D. DESCRIPTION OF WORK Study to determine design parameters needed for portable underground hard-rock crusher.	
E. CONTRACTOR'S PRINCIPAL INVESTIGATOR	F. GOVERNMENT TECHNICAL PROJECT MONITOR Sam Demou

(Check appropriate boxes)

1. Type of Report:

☐ Interim From ______, 19____ To ______, 19____

☒ Final.

2. Interim Report Data:

A. Invention made ☐, not made ☐, during interval of (1).

B. If invention(s) made, provide the following information:

☐ Previously fully disclosed in Invention Disclosures. Give dates submitted, and Contractor's docket numbers.

☐ Invention Disclosures attached herewith. Give Contractor's docket numbers.

(OVER)

INT: 3142-72

3. Final Report Data:

	Date Submitted	Contractor's Docket Number
A. Invention(s) previously reported—	none	
B. Invention(s) reported herewith—	Rotary Jaw Crusher	none
	Oversize Breaker	none

C. Others (explain)—

D. No inventions were made under the grant or contract. ☐

4. Patent application(s) filed and contemplated to be filed by Contractor under the terms of the grant or contract:

Application Serial No. . .	none				
Date of filing					
Contractor's Docket No. . .					

5. Subcontracts containing patent rights article:

☒ None. ☐ Listed below are subcontractors.

Name of Subcontractor	Address	Subcontract Number	Date Executed
(1)			
(2)			
(3)			
(4)			

6. Attach a copy of the patent rights article employed in each subcontract set forth in 5.

7. Contractor or Grantee certification.
I certify that this Summary Report of Inventions and Subcontracts including any attachments is correct to the best of my knowledge and belief.

Date October 7, 1976

Signature Carl R Peterson

Title President

U.S. GOVERNMENT PRINTING OFFICE : 1969—O-367-227