MINING AND ENVIRONMENTAL FACTORS IN SELECTING AN UNDERGROUND VERSUS A QUARRY MINING SYSTEM

by

Scott Gavin Haycocks

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Mining and Minerals Engineering

APPROVED:

M. Karmis, Chairman

M. Karfakis

G. Luttrell

December, 1992

Blacksburg, Virginia
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Committee Chairman: Michael Karmis
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(ABSTRACT)

Historically, the decision on whether to mine by underground or surface methods has been based on mining and economic considerations. This is rapidly changing since the environmental imperatives that have evolved over the past two decades are now a critical part of the decision process. As a result, quarry operations are increasingly considering the option of going underground. This research was carried out to identify the factors which would cause a surface quarry operator to consider the transition to underground mining.

To identify the major incentives for going underground, primary factors influencing the decision for selecting underground mining over continued quarrying were investigated. Analysis of the literature and data gathered from site visits showed that significant benefits could be gained from mining underground, with respect to selected economic factors, environmental permitting and legal compliance, and post-production site usage for continued income.

To determine mining characteristics of the typical surface quarry, data on the production phase (mining sequence) and environmental prob-
lems was collected from 18 quarries at various stages of their operating life spans. The data was obtained from sites in the Appalachian region of four states: Virginia, West Virginia, Maryland and Tennessee. Corresponding data was also gathered from successful underground operations to determine the values for a typical underground mine. Comparisons of this information indicated that the biggest differences between surface and underground operations existed in: the drilling and blasting phase, and in the haulage phase of the mining sequence; the size of the equipment; the extent of environmental concerns; and the potential for post-production income from the site.

The process of environmental risk assessment was reviewed as a supporting tool to aid in the selection of underground over surface mining. By assigning probabilities of failure to specific, independent, environmental hazards, an operator can evaluate and compare the likelihood of success or failure operating as a quarry or underground mine. A case study from the data collected was used as an example to show how the procedure can be practically implemented.
ACKNOWLEDGEMENTS

The author would like to express his gratitude to his major advisor, Dr. Michael Karmis, for his guidance and support during the course of this research, and without whom this opportunity would have never existed. Also, thanks are in order for Dr. Mario Karfakis and Dr. Gerald Luttrell, the other advisory committee members. The author also wishes to thank the secretaries and other office personnel who made his work easier. A very special thank you goes to the author’s parents who provided extremely valuable and necessary advice and support. Lastly, the author acknowledges and thanks his wife for all her encouragement and understanding.
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I. INTRODUCTION

It has been a long-held belief in the mining industry that surface mining is less expensive and therefore preferable to underground mining based on direct mining costs (Boshkov and Wright, 1973). However, new operations or existing quarries may derive significant benefits by opting for underground mining. In some of these cases the geology of the orebody may dictate a mandatory progression to underground mining. This may be due to dipping orebodies, excessively high stripping ratios, or the selective pursuit of high grade material which leads to greater depths.

Many legal, political or social problems can be avoided by underground mining in today’s environmentally conscious atmosphere, which is becoming an increasingly important influence on the mining industry. “Out of sight, out of mind” is an adage that is working well for many underground operations. Most underground mines are “good neighbors” and can more easily comply with environmental regulations and reclamation than can surface operations. The significance of preserving and conserving the environment is stressed to the mining industry in two ways. First, before mining can commence, a company must go through a long, detailed and expensive process of obtaining appropriate environmental permits. The second environmental pressure is due to the continuing regulatory compliance throughout the life of the mine. The cost of moving underground may be offset by the savings involved in regulatory compliance. Consistency of operating conditions is another advantage of mining underground. Finally, plan-
ning for the site to be used beneficially after operations have been com-
pleted may in itself be incentive enough to consider underground mining.
For example, some underground operations have been used very successful-
ly for alternative space, including warehousing, offices and farming, after
mining ceases.

The goal of this research is to quantify the reasons for and the benefits
of selecting, or converting a surface operation into an underground mining
operation. The factors which are important in this decision are varied and
often site specific, and they may not always be obvious. Benefits may be
short term, long term or both. This study will attempt to identify and quan-
tify the influencing factors, and present them in a clear and easily under-
standable format. With this information, the advantages of underground
mining can be seen and compared to surface mining alternatives. This
would permit better and faster decision making about the future of an oper-
ation with regard to operations, productivity and quarry life span.
II. LITERATURE REVIEW

When an orebody can be mined either as a surface operation or as an underground mine, the decision was historically based primarily on economics. Today, other factors, particularly environmental concerns and public opinion, are becoming more influential in this decision. Even when comparing only mining costs between surface and underground operations data would indicate that surface operations are not always the cheaper alternative. Figures 2.1 and 2.2 illustrate this point. In 2.1 underground mining is shown to be almost four times more expensive as surface mining, but 2.2 shows that quarrying costs are significantly more than either room and pillar or stope and pillar methods of underground production. From this it can be seen that the costs involved will be largely site-specific, and any operation considering surface versus underground mining must examine its conditions carefully before assuming that underground mining would simply be too expensive.

2.1 - SURFACE QUARRY CHARACTERIZATION

The materials mined in the quarries under consideration are predominantly limestone and dolomite, though some crushed stone, sand and gravel, and aggregate quarries may also be considered. Because of the bulk nature and the weight of the material being produced, it is expensive to haul
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Figure 2.2 **Cost Comparison; underground stope-and pillar less costly then quarrying** (after Hartman, 1987)
Figure 2.1 Cost Comparison; surface less expensive
(after Hartman, 1987)
over long distances. Many operations, therefore, are located near or in pop-
ulation centers, where they have the advantage of a ready market in the
form of builders and other general construction activities. Other major mar-
kets for quarry products include specific State and Federal road projects, ag-
riculture, and the mineral processing industry.

Such surface quarries are numerous and make up the vast majority of
quarry operations in the region under consideration, mainly because condi-
tions are conducive to surface mining. In the state of Virginia alone there
are 155 surface operations compared to two underground sites (Va. Division
of Minerals, 1992). Many deposits of desirable material are located at or
near the surface, which allows easy access to them. In the mountainous to-
pography of the mid-Atlantic Appalachians, much of the surface activity
consists of mining horizontally into a mountainside. In less hilly terrain,
the quarries may progress downward and laterally at the same time.

Surface quarries typically are made up of one, or sometimes two or
more large excavations or open pits (Kulczak, 1979). The pits, if more than
one, are interconnected by a system of road ways that will change as the
pits grow and develop. The office buildings, maybe mobile, are located on
site as well. In today's environmentally conscious climate, many operations
are making tremendous efforts to beautify the exposed areas of the opera-
tions as much as possible, so rows of tall trees or hedges around the perime-
ter of the quarry are becoming very common (Katz, 1987).

Every quarry is unique and specific features will vary from site to site.
Several factors exist which determine exact size and shape at each location,
though there are some common features found in most all working quarries. The first of these are benching of the pit walls. The basic elements of a bench are illustrated in Figure 2.3. Bench heights, when geologic conditions allow, should all be of uniform height and as high as possible to facilitate blasting (Armstrong, 1990). Another factor which effects pit dimensions is the overall angle of the pit slope. To maximize material extraction and to achieve minimal stripping ratios, the pit wall will be as steep as is practically possible, but it needs to be carefully planned for stability. A failed pit wall can be a major disaster for the operator because of safety hazards, lost reserves, environmental liability, damaged roads and damaged or lost equipment and the cost of cleaning up the failure. Rock strength, joints, faults, presence of water and other geologic information are key factors in the evaluation and stability of the pit wall (Hoek & Bray, 1981), as well as the stability of the haul roads into the pit.

Equipment present will vary depending upon the size of the quarry, though the basic needs are the same for all (Martin, 1982). A drill rig(s), loaders, haulage trucks and a crusher(s) are necessities for every operation. Some quarries do their blasting in-house and will also have an explosives truck. Every operation will also have a variety of maintenance, tool and utility vehicles, though these are usually large pick-up trucks, often customized at the quarry for local work (Olmedo, 1990). Figures 2.4, 2.5 and 2.6 show examples of some of the types of equipment just discussed.

Along with the equipment are the personnel required to operate and maintain it all. Small operations will often have a core of workers that can
Figure 2.3 **Bench Elements**
Elements of a slope bench
(after Armstrong, 1990).
Figure 2.4 Example of Surface Drill Rig
Figure 2.5 Typical Loader
Figure 2.6 Representative Haul Truck
do the many various jobs needed for day to day production and maintenance. The larger a quarry is or becomes, the more people are required to ensure smooth and productive operating time. In such operations the workforce is more specialized for specific tasks. The management personnel also increases in number from small to large operations, though every operation will have a general superintendent who is in charge of the entire quarry. The levels of management between the superintendent and the general laborer varies depending on the size of the quarry. Some limestone quarries will also have an in-house laboratory at the site for conducting chemical testing of the rock.

2.2 - UNDERGROUND STONE MINE CHARACTERIZATION

Underground mines of the type considered in this study are not nearly as numerous as surface quarries. Currently in the state of Virginia only two such underground mines exist (Sweet, 1989), though for this research other underground operations in other regions of the country were also considered. The two in Virginia are both lime operations, located in the southwestern part of the state in a rural area, approximately five miles apart. A number of other quarries in the region under consideration are in the process of either planning or beginning underground operations (Virginia Division of Minerals, 1992; Olmedo, 1992; and Smith, 1991). Other underground operations exist in West Virginia, Maryland, Tennessee, Kentucky and into the Midwest, though they are not all lime operations. Major prod-
ucts from these underground mines include aggregates, sand and gravel, and aglime.

The majority of limestone mines start from adits, i.e. horizontal drifts driven into the sides of hills or existing quarry walls. The typical depth for aggregate mines is 100 to 300 feet. Often, the nature of an orebody dictates that only the deeper mines can provide the stone to be calcined for lime. If a mine is to be less than 800 feet deep, a sloped entry can be used, but if it exceeds 800 feet then a shaft will be necessary (Robertson, 1983). In most underground operations the orebody will either dip downward or extend into a hillside, making the removal of overburden economically unfeasible due to the rapidly increasing stripping ratios.

The mining method employed to remove stone from underground operations is almost universally room and pillar (Barksdale, 1991). With this method, stone is removed as the mine progresses underground. As large areas, or rooms, are excavated, larger pillars of stone are left in place to support the roof. It is not uncommon in competent rock to have multiple benches in a single room resulting from multiple pass mining, which results in a stope and pillar situation (Hartman, 1987). In this case, a single pass is made across a room, then the mining progress from a side of the room as another pass is made, removing material from under the area of the first pass. Figure 2.7 diagrams the concept of stope and pillar mining resulting in multiple benches. Generally, there is no set pattern of pillar placement as there often is in coal mines. The pillars vary in height and diameter depending on the amount of material taken from a specific part of the mine,
Figure 2.7  **Multiple Pass Stope and Pillar**
Illustration of multiple pass room and pillar mining resulting in a stope and pillar situation (after Hartman, 1987).
the depth of the mining, the height of the roof and the density of the over-
burden. This concept of random pillars in an underground stone operation
is shown in Figure 2.8. In practice the pillars themselves are of no particu-
lar shape, though attempts are sometimes made to produce them with regu-
lar outlines, such as round or square (Carr, 1990). Figure 2.9 shows what
might be expected with regard to actual pillars compared to the ideal. The
importance of pillar and portal design to the success of an underground op-
eration are discussed later.

Typically, the equipment needs of an underground mine are very simi-
lar to those of a surface operation. The various maintenance vehicles are
present, but the key differences are in the sizes of equipment. As a general
rule, underground production equipment will be smaller than surface coun-
terparts (Kuhnein, 1983). Trucks and loaders are required to operate and
maneuver in confined spaces, therefore they must be smaller. The main dif-
ference in the equipment is in the drill rig. On the surface a wheeled or
tracked unit is employed as seen previously in Figure 2.4, while under-
ground a drill jumbo with single or double booms is the most common, as
seen in Figure 2.10 (Bradford, 1991).

2.3 - INITIAL PARAMETER IDENTIFICATION

The reasons for transforming a surface operation to an underground
mine are numerous and varied when studied closely. These reasons prima-
rily fall into three main categories: economics, post-mining site use and
Figure 2.8  **Random Pillar Concept**  
Random pillar placement common in underground operations (after Bullock, 1982).
Figure 2.9 **Pillar Shapes**
Figure 2.10  **Double-Boom Drill Jumbo**
compliance with environmental regulations. The geology of a site as a reason to mine underground is included within the economic factors.

2.3.1 - Economic Factors

A. General Factors

Economic factors that play a role in opting for underground mining are varied, and are most often site specific. They cover the costs associated with such things as removal of overburden, equipment maintenance, reclamation, handling water, and compliance costs. Anything that will save an operation money can be viewed as an economic incentive, though for the purpose of this research only major factors that may result in significant savings are considered. Although both surface and underground operations must deal with these various economic factors, they vary significantly for the different operations. Figure 2.11 shows the budget breakdown for various phases of all types of crushed stone mining for the East Region of the United States as well as those for the nation. Figure 2.12 shows a budget breakdown of an underground operation for comparison. Underground mines may also have the added benefits of utilizing the unused surface and the underground mine space to generate income (Drake, 1989).

It is generally accepted that to operate a mine on the surface is cheaper and more productive than an underground operation producing the same raw material (Nilsson, 1982). Figure 2.13 illustrates this point by comparing the productivity of surface mines in the United States, where such
Figure 2.11  Nation vs. East Region Budget Comparison
(after Editors, Rock Products, 1991)
Figure 2.12  Single Operation Budget
Figure 2.13  **Surface vs. Underground Productivity Comparison**

(after Nilsson, 1982)
mines are common, to the productivity of underground mines in Sweden, a country dominated by underground mining. The results of one study shows that it is approximately 26% cheaper to run a surface stone operation (Kuennnen, 1983).

B. Stripping Ratios

The decision to mine on the surface as opposed to underground is most often dictated by the stripping ratio. Stripping ratios are the primary factors in determining if the overburden is economically feasible to remove. Many surface quarries are faced with the situation of the pit being at the economic fringe of profitability simply due to of excessively high stripping ratios. This situation arises when the orebody dips steeply from the surface. When this occurs, it may be economically feasible to cease stripping and drive directly into the orebody. Figure 2.14 illustrates an example of when and how this might be done. Under these conditions the orebody must be structurally conducive to underground production, and other factors, such as water, must be taken into account (Bradford, 1991).

The basic stripping ratio is defined as the ratio of the number of tons of waste that must be removed to mine one ton of ore (Aiken & Gunnett, 1990). This ratio is extremely important to the preliminary pit design, as it will determine the amount of ore and waste to be removed from the entire operation. This ratio for the entire pit provides the average strip ratio for an operation. Pits with very low average ratios should be more efficient and thus more profitable than pits with higher ratios.
ultimate pit slope dictated by market conditions, established by breakeven ratio

(portal)

property limit

orebody

(not to scale)

Figure 2.14 Possible Underground Progression
Illustration showing possibility of continuing production underground when economics halts further lateral pit progression (after Karmis, et al, 1992).
Another important factor to be considered is the breakeven ratio. This ratio refers to the point where the ore mined covers only the cost of the overburden removed (Armstrong, 1990). This point will define the edge of the pit, but is subject to change as the market price of the product fluctuates. The breakeven ratio, BR, is defined mathematically as:

$$BR = \frac{a - b}{c}$$

where:

- $a =$ revenue per ton of ore
- $b =$ extraction cost per ton of ore
- $c =$ stripping cost per ton of waste
  (from Surface Mining)

Extraction in a particular area may cease when the breakeven point is reached, but it may continue if the price of the product rises sufficiently to cover the cost of further overburden removal. However, in situations where the breakeven ratio is anticipated to be reached very quickly or the stripping ratio becomes very large, an operation can quickly be put at a competitive disadvantage, incurring large costs of overburden removal that other operations may not have (Weaver, 1990). When this situation is encountered a serious look at the underground alternative is warranted. In areas of competent rock, quarry operators may be able to avoid the cost of high overburden removal by going underground (Drake, 1989).

C. Waste Handling

It is clear that it costs a large amount of money to handle the reject from open pit mines. This is an important part of an operation and must be taken into consideration when comparing surface to underground opera-
tions. Underground mines do not have the large waste problems associated with most surface pits, therefore that cost is assumed to be non-existent. This cost not only includes hauling and removing the waste, but the costs of creating, permitting and maintaining the waste piles is also effectively eliminated.

D. Surface Limits

Another economic situation where surface quarries may be driven underground deals with limited surface area (Smith, 1992). When the quarry reaches its pit limits, the only other option is to increase the depth of mining. This presents a problem, since as the pit depth increases, the operating costs also increase, as illustrated in Figure 2.15 (Phillipson, 1989). The major phase of the mining sequence that is depth sensitive is the truck haulage. As the haul roads are extended downwards along the pit, they may be made steeper to provide shorter distances, which can lead to safety hazards. Phillipson shows that significantly increasing the payload of the haul trucks will help in the short term. However, the number of trucks must increase substantially with depth. This in itself is a very expensive proposition, since additional trucks necessitate increases in costs for maintenance, fuel and drivers. A problem of logistics also is created. Safety considerations of operating a large fleet of large sized trucks along steep pit roads may eliminate the option of increasing pit depth long before economic considerations.

The best solution to this problem is to plan in advance for the possibility of underground mining before the pit limits are reached. The equipment
Figure 2.15 Production vs. Operating Costs
(after Phillipson, 1989)
changes can be minimal when compared to the changes needed to remain competitive and increase pit depth substantially.

E. Extraction Ratios

A unique problem for underground mines is the loss of reserves in pillars. This is expressed using the extraction ratio, which is the amount of material mined divided by the material mined plus the pillars left behind. In equation form:

$$ R = \frac{A_m}{A_m + A_p} $$

where:

- $R$ = extraction ratio
- $A_m$ = material mined
- $A_p$ = material in the pillars

This ratio is of major importance when planning underground operations, and is directly affected by the size of the pillars in relation to the excavated area. Pillar dimensions, width and height, in turn are dictated by some key factors: strength of the rock comprising the pillar, depth of the overburden, unit weight of the overburden and the distance between pillars. Planning pillar sizes can be accomplished utilizing the equation for irregular pillar shape (Hoek & Brown, 1980):

$$ \sigma_p = \gamma z \frac{A_c}{A_p} $$

where:

- $\sigma_p$ = pillar stress
\[ \gamma = \text{unit weight of the rock (overburden)} \]
\[ z = \text{depth of overburden} \]
\[ A_c = \text{column area of the rock, defined by half the distance between adjacent pillars} \]
\[ A_p = \text{pillar area} \]

This equation for pillar stress allows the determination of the minimum pillar dimensions, which in turn allows for determination of the maximum allowable extraction ratio. The extraction ratio is also affected by the depth of the overburden and the strength of the pillar rock, \( C_p \), as shown in Figure 2.16. Pillar sizing is an important consideration in planning the reserves for a given underground site.

**F. Drilling and Blasting Differences**

The methods of drilling blast holes for surface and underground operations are very different. Different equipment is necessary, and the blasting patterns are dissimilar due to the enclosed space underground. Drilling blast holes in a surface operation usually requires either a wheeled or tracked drill rig, as previously seen in Figure 2.4. Blasting utilizes the multiple free faces provided by the benches. A predetermined pattern of holes is drilled vertically down into the bench, loaded with explosives, then detonated. Figure 2.17 illustrates some common drilling patterns used for blasting in surface quarries. A key factor in planning blasts is the powder factor,
Figure 2.16 Extraction Ratio-Pillar Strength-Depth Graph
Three dimensional graph showing relationship of overburden depth, pillar strength ($C_p$), and extraction ratio ($R$).
Figure 2.17 **Surface Blast Hole Patterns**
Examples of common surface blast hole patterns (after Hartman, 1987).
or the amount of explosive used per ton of rock blasted. In open pit operations mining nonmetallic ores, the powder factor ranges from 0.05 to 0.3 pounds/ton. The overburden is typically blasted at a powder factor of 0.2 to 0.5 pounds/ton (Hartman, 1987).

The patterns of drill holes that may be necessary in an underground shot are very different from surface patterns. Commonly, underground blasts must be performed with only a single free face, which requires the differing hole patterns. The drill jumbo drill the holes horizontally into the work face. Figure 2.18 also shows typical patterns are that are utilized for underground blasting. The empty holes provide the free faces necessary for successful completion the blasts. The powder factors commonly associated with underground blasting range from 0.2 to 0.4 pounds/ton (Hartman, 1987). In underground mines that utilize multiple passes during production, the blasting patterns would be similar to the surface patterns due to the presence of the multiple faces of the benches.

The various cost components of the drill and blast phase include labor, equipment and supplies. For surface operations the cost is usually computed per ton of ore produced. Underground production blasting costs are expressed per foot of drilling or per ton of ore produced (Dowding and Aimone, 1992). Referring to Figure 2.1, it is noted that the costs of drilling and blasting are slightly more for underground than for surface mining, though with respect to underground blasting, the thicker the strata, the more inexpensive it becomes to blast, depending on site conditions (Pit & Quarry Handbook, 1981). From Figure 2.11, it can be seen that in crushed stone
Figure 2.18 Underground Blast Hole Patterns
Examples of common underground blast hole patterns (after Hartman, 1987).
mining drilling and blasting make up about 8% of an operator’s budget in the nation, while in the East it constitutes 9%.

G. Environmental Compliance Costs

Another area of high cost is in complying with the plethora of local, state and Federal mining regulations, especially environmental regulations. Recently, a study was conducted to determine the impact of the cost of environmental compliance for the entire mining industry. In this study cost implications at the project level, at the company level, at the domestic mining entry level and at the societal level were addressed. The conclusions made here point out the impacts at all levels of the increasing costs of compliance. Figure 2.19 diagrams the relative amounts of money devoted to compliance of environmental regulations over the life span of an hypothetical operation lasting 20 years. The main themes that the author of the study stresses are given in the following summary (Parrish, 1991).

- Project cash flow analyses can and should include environmental costs as distinct line items.

- Impacts on project returns caused by changes in compliance costs have corporate financial impacts.

- Declining corporate returns from mining projects will probably shrink the mining industry, and this shrinkage will be accelerated with each increase in compliance costs.

- Eventually, increased compliance costs will not come out of corporate profits, but in the form of reduced national economic
Figure 2.19 Budget Percent Devoted to Environmental Compliance
Example of percentage of total budget devoted to environmental compliance (after Parrish, 1991).
vigor.

- Environmental legislation needs to be examined in terms of its economic effect on the nation.

H. Underground Site Income

An additional economic advantage of underground mining can be seen when considering the possibilities of generating income from the site. It has been noted that underground mines have the ability to produce a triple cash flow (Kuennen, 1983) when the entire operation is considered. This cash flow can come from three different areas: income from normal production and sale of stone; income from the rental of the surface property; and income from the utilization of the underground space when mining is complete. On average, the difference between underground and surface mining cost was equivalent to eight miles of haulage of the product. As an example, an underground mine would be competitive with a surface quarry if it was located eight miles closer to the market center. This assumes that the underground mine, because of higher mining costs, would be charging more for its product than the surface operation. From the consumer’s standpoint, the money spent for hauling the stone product eight miles further from the surface operation would be equal to the amount spent purchasing the stone from the underground mine located eight miles closer. However, if the other aspects of income are considered, it becomes clear that the underground mine would be more profitable. Leasing the surface property for development, farming, or something to produce income would serve to raise
the profitability of the mine even if its costs were slightly higher. Along similar lines, the leasing or sale of the underground space would allow for income beyond the life of the mine itself. This would be especially true if the mine were located in or near an urban area where space is at a premium. The cheapest enclosed space which can be constructed is underground, that while the mine is producing stone, at the same time it is creating a building that costs only 25 to 75% of what it would cost to build it above ground (Keunnen, 1983). Therefore, in the long run it may make more economic sense for an operation to go underground.

2.3.2 - Post-Mining Site Usage

Surface quarries propose post-operational site plans into the required reclamation plans. Industry's attitude towards reclamation of surface quarries is less than focused (Carter, 1989). However, in the environmentally aware climate that currently exists, reclaiming pits and quarries is becoming more and more vital as pressure is increased on producers to develop new, creative and cost-efficient post-mining land use plans (Wassenaar, 1989). The most popular method, and perhaps the easiest and least expensive, for reclaiming the sites is to allow the pit to fill with water (Bennett, 1992). Some variations of this concept can be seen in Figure 2.20. In many areas, though, more expensive reclamation requirements may be needed, such as backhauling and recontouring the site according to requests from local governments or agencies (DeWitt, 1992).
Figure 2.20 **Surface Post-Mining Uses**
Some post-mining site alternatives for surface quarries (after Carter, 1989).
Choosing to utilize the unused surface portion of an underground mine can generate significant additional income for the operator. Upon completion of the productive life of a surface or underground mine appropriate steps must be taken in accordance with post-mining plans submitted as part of the pre-mining permitting process. The nature of the geology, geography, mining method, proximity to any communities and social impacts all are contributing factors that influence the ultimate destiny of the site. Today, as populations continue to grow, space, especially near larger metropolitan areas, can be very valuable for many reasons. Enterprising quarry companies can take advantage of this need by incorporating a post-mining, income-generating use for their site into the mine plans.

The examples of post-mining uses of underground mines cited in the literature are numerous and varied depending upon the location of the operation and the recognized needs of the community. Post-mining uses in this case include opportunities that are not available to surface mines, which is an additional consideration (Keunnen, 1983, and Barksdale, 1991). Some of these uses include:

- warehousing and storage
- underground office space
- research laboratories
- drapery making and film processing
- manufacture of precision instrumentations, facilitated by a
vibration free environment

- greeting card manufacturer
- dinner theater

One example of innovative underground space usage is in Idaho. In 1979, an underground mine was growing tree seedlings at a cost of $75 per 1,000, compared to $130 to $250 for comparable seedlings grown on the surface. This became the cheapest source for the mines' own reclamation work, as well as providing additional income from outside sales (Committee on Surface Mining and Reclamation, 1980).

This same Committee report states that 750,000 tons of ore removed would provide enough space for the storage of 100,000,000 gallons of water. If this water fills the empty space at 200° F, the stored energy would be equal to the Btu's of 6,000 tons of average bituminous coal, and could be retrieved with a heat pump system.

2.3.3 - Environmental Regulations

At the Federal level the legislation designed to protect the environment from the ill effects of mining, including the extraction of stone and aggregates, is tremendous. All major areas, water, land and air, are extensively covered. New legislation is continuously being introduced to cover perceived gaps or inefficiencies in older laws or to address new areas of concern. Outside groups, especially environmental organizations, continue to apply pres-
sure to strengthen laws and stiffen penalties against offenders. The mining industry as a whole feels that the current laws are more than adequate, often redundant and sometimes contradictory. There also exists in the public eye a misunderstanding of mining, whether it be a coal mine in West Virginia or a granite quarry in Colorado. The industry is often viewed as totally destructive and the primary source of enormous amounts of unchecked pollution (Peters, 1992). Although this may have been the case in the past, nowadays it is farthest from the truth. The very nature of the industry demands that it be environmentally conscious, as it is always in the public eye when problems arise. However, the bottom line is that modern society would cease to function without mining. Everything that is manufactured or utilized by our society is either directly or indirectly a product of the extraction of raw materials from the earth. With this in mind it is somewhat surprising to realize that less than 1% of the surface of the entire earth has been affected by mining in any way (Caterpillar, 1992).

Federal laws that govern mining in the United States include both stone quarries and underground mines. Although many of the regulations are written in a framework aimed at mining other than the stone industry, quarries are included under the laws and regulations unless specifically excluded. The quarry and mine operators comply with the environmental regulations by obtaining permits from the various federal, state and local permitting authorities. Some of the areas typically requiring permits for a mine site are as follows (after Hunt, 1992):
◆ Mine reclamation permits.
◆ Water quality and discharge permits.
◆ Air quality permits.
◆ Dam and impoundment construction permits.
◆ Waste disposal permits.
◆ Waterway encroachment permits.
◆ Water withdrawal and water rights permits.
◆ Highway encroachment permits.
◆ Mining licenses and mine safety permits and approvals.
◆ Sanitary sewage permits.
◆ Drinking water permits.

The laws described in the following sections create the necessity of these types of permits, and in some cases outline requirements for them and how they are to be implemented. In an effort to streamline this often complex and drawn out permitting procedure, several states have enacted a “one-stop” permitting process that takes care of several of the requirements at one time (Hunt, 1992).

**A. NEPA and the Environmental Impact Statement**

The National Environmental Policy Act of 1969 (NEPA), which was enacted on January 1, 1970, established the requirement of what is now
known as the Environmental Impact Statement (EIS). In determining the impact to the environment, the Federal agency preparing the EIS must emphasize possible air and water pollution, effects on vegetation and wildlife, aesthetics, and effects on the human environment. Such human impacts include anticipated social, political and economic effects to local communities.

To determine if an EIS is required, two questions must be answered. First, will there be any Federal action connected with the proposed operation, and second, if the Federal action is significantly affecting the environment (Parr, 1982). A mining operator will probably know if an EIS will be needed, but it is up to the Federal agency issuing the permits to decide. Figure 2.21 illustrates the conventional EPA permitting procedures.

In May of 1978 the Forest Service issued its guidelines for compliance with NEPA, found in Part 252 of Title 36, in the Code of Federal Regulations. These regulations are applicable to mining or millsites located within the boundaries of national forests. These regulations establish procedures and requirements for the implementation of plans for environmental protection, aimed at minimizing the disturbance to the land. A preliminary environmental assessment (EA) must be conducted to establish the basis for future plans, and from this a preliminary environmental statement is prepared. Upon completion of all activities, the required reclamation measures must be carried out in compliance with the regulations. To further this point, a bond may be required to be
Figure 2.21 EPA Permitting Procedure (Hunt, 1992).
posted before any activity can commence (Burns, 1990 & Parr, 1982).

B. Clean Air Act and Amendments

Federal air quality legislation on a large scale began in 1963 with the passage of the Clean Air Act. It has been amended several times over the past 28 years, and several supportive and specific laws have also been passed to further the cause of air quality. The most recent amendments to the Act were signed into law in November of 1990.

The EPA opted to exclude fugitive dust from any air quality impact assessment. Fugitive dust is considered to be dust that is generated from native soil and is not contaminated by one or more pollutants.

C. The Solid Waste Act, RCRA of 1976

Solid waste is a huge component of the stone industry, and managing it properly represents a huge responsibility both ethical and financial in nature.

The Solid Waste Disposal Act of 1965, amended by the Resource Recovery Act of 1970, presents guidelines for the land disposal, collection and storage of residential, commercial and institutional solid waste, but it excluded what was then termed as "hazardous mining waste". The regulations would, however, be applicable to any garbage and other refuse that a mining operation might produce.

In 1976 Congress enacted the Resource Conservation and Recovery Act (RCRA). This is currently the primary legislation designed to ad-
dress the problems of management of solid waste. The focus of this Act is to empower the EPA to aid states in developing solid waste management programs. This Act also defines hazardous solid wastes under Subtitle C (appendix B:6) and non-hazardous under Subtitle D, and authorizes programs to prohibit open dumping, regulate all phases of hazardous solid waste management, and authorizes guidelines for the transport, collection, separation and recovery of solid waste.

In December of 1978 regulations under RCRA were proposed to handle hazardous wastes, and included in this were many high-volume, low hazard wastes, which the EPA noted were from “the extraction, beneficiation and processing of ores and minerals”, in other words, mining wastes. Later, in 1980, Section 3001 of RCRA was amended by what is known as the Bevill amendment. This amendment excluded from Subtitle C the wastes from the mining industry pending a report to Congress and a regulatory determination concerning the classification of these wastes. In 1986, the EPA made the determination, saying mine wastes were to be classified under Subtitle D, and subsequently regulated as non-hazardous, stating that the metals and other potentially toxic materials had been removed and the remaining material was mostly common rock.

**D. Federal Water Pollution Control Act and NPDES**

Part of the Federal law regarding water quality that is applicable to the stone industry is the Federal Water Pollution Control Act of 1972
(PL 92-500), as amended in 1977 by the Clean Water Act. This law governs point source discharges into navigable waters, as defined in 40 CFR 401.11 [d], and requires the use, by industry, of the best available technology economically achievable (BATEA) that will make progress towards eliminating the pollution completely. The basic approach is for the EPA to authorize a state to administer its own water pollution control plans and permits, provided they meet the standards of the Federal EPA limits and are adequately and properly enforced. The mining industry is affected by this law in many areas, from quarrying and cement manufacturing to fertilizer production. Any part of the industry that will need to discharge water from what the law defines as "point sources" will come under the jurisdiction of this Act. The legal standards for effluent pollution content are laid out by the EPA in 40 CFR Subchapter N, and they are also incorporated into the National Pollution Discharge Elimination System (NPDES) permits that are set up under the Act and are required by any and all existing and new point discharges.

In November of 1991, the EPA issued its latest ruling on stormwater discharges. This ruling implements Section 405 of the Water Quality Act of 1987, and requires NPDES permits for all stormwater discharges. This part of the Act requires the development of a phased approach to the regulation of stormwater discharges, and will set up permit application requirements for industries, including the minerals industry. Both active and inactive operations will be subject to the permits. The regu-
lations do, however, contain provisions for stormwater that does not come into contact with overburden, byproduct or waste product (Stone, 1991).

E. Surface Mining Control & Reclamation Act of 1977

This Act was signed into law by President Carter on August 3rd of 1977. The underlying objective of this law is to control and minimize the adverse environmental effects resulting from surface coal mining. Therefore, its effects on the stone producing industry are minimal to nonexistent.

F. Miscellaneous Federal Laws and Regulations

F.1. Noise pollution is controlled by the EPA via the Noise Control Act of 1972 (PL 92-574). This law authorizes noise emission standards and abatement programs, which are administered through regulations in 40 CFR Subchapter G.

F.2. The Safe Drinking Water Act (PL 93-523) as amended by PL 95-190 in 1977, is designed to protect the quality of groundwater, and was originally aimed specifically at the injection of underground wastes. The Act contains a dynamic list of contaminants determined to be hazardous to drinking water supplies, but most of these are of no consequence to the mining industry. Therefore, the Act does not have a tremendous impact on the mining industry unless a site is indicated to be polluting groundwater in an area where it is used as the drinking
water.

F.3. The Endangered Species Act of 1973, implemented by the regulations in 50 CFR Part 17, is something that the mining industry, at all levels, should be aware of. Species of wildlife and plants determined to be endangered or threatened with extinction are listed in 50 CFR 17.11, including those from the Endangered Species Conservation Act of 1969. This is a dynamic list that can and does change over time. If an operation is planned or found to be in an area where animals and/or plants on this list are located, special care must be taken to avoid drawing possible negative attention and its subsequent consequences. Another important part of this legislation deals with what is known as critical habitat, listed in 50 CFR Part 17, Subpart F. As the term implies, this is habitat that is of the utmost importance to certain species on the list, and Federal agencies must take every measure to see that any permits or authorizations they give do not interfere with this habitat. Federal agencies are required to get information from the Department of the Interior as to whether or not species from the list are present in a particular area, and if so the agency must complete a biological assessment of the area in order to find out if the species really do exist in the area in question. It is plain to see how this process can delay or possibly prevent an operation from getting started.

All of the previously discussed laws come from the Federal government and are not aimed directly at the stone industry, but this does not exclude it. All the current literature reviewed expressed concern over
the current magnitude and continuing growth of regulation. The Federal laws serve mostly as guidelines lower levels of government. As one author notes, miners can never completely avoid Federal regulations, and in addition, must routinely deal with state and municipal agencies for mining or conditional-use permits, zoning decisions, and reclamation-plan approval (Carter, 1989). The area of reclamation is one of growing importance to the stone industry in light of the new regulations. Carter also notes that successful companies treat reclamation as they would any other part of their operations, simply a part of doing business. He goes on by adding that the ultimate value of the reclaimed land is a key factor in planning budgets for restoration and possible further development, either by the mining company or the landowner. Making the land suitable for agriculture or commercial endeavors must certainly be planned for and the future value of the land considered.

2.3.4 - Environmental Considerations

The general population in a given area, including employees at quarry and mine sites, want to see their environment protected and conserved, and to better handle the varied environmental concerns many companies go far beyond the legal protection requirements in conducting business. The main goal of these activities is to protect and conserve natural resources, and to generate greater community acceptance. Zoning, property use, mining and air and water permits are required for
any site, and in most cases public hearings are the pathway to gaining them. With an operation that is non-offensive, accepted by the community, and viewed as conducting strong and sound environmental practices, the permits are much more likely to be obtained (Barksdale, 1991). Underground mining, in this regard, may be considered as an example of conservation at its best, provided that the space is later utilized (Committee on Surface Mining and Reclamation, 1980).

As mentioned in a previous section, aesthetics is an area of environmental concern based mainly on generating public acceptance, and to this end beautification of sites through landscaping is common. For this study, environmentally related problems that quarries and mines may experience have been divided into four main areas: water, air, noise and reclamation. The first three areas concern an operation during its life, while reclamation is concerned primarily with a site after production is complete, though it is often implemented concurrent with production.

(i) Water Problems

One potential adverse environmental impact exists with the effects a site may have on the local water supply, both surface water and groundwater. With respect to the stone industry, areas of possible water contamination include:

- Accidental spills of chemicals (fuels, solvents, e.g.)
- Leaking underground storage tanks
- Solid waste and hazardous waste landfills
- Leaking equipment
- Sediment in runoff and discharge

Runoff control from waste piles of overburden and exposed slopes is one of the major problems, mainly with surface quarries due to their exposed areas. Methods to handle this problem are mainly revegetation, drainage ditches and sediment settling ponds. These methods are based on some key concepts of erosion control (Smith, 1991):

- Fit site development to existing conditions
- Minimize the extent and duration of exposure
- Protect areas to be disturbed from stormwater runoff
- Stabilize disturbed areas
- Keep runoff velocities low
- Keep the sediment on site
- Inspect and maintain control measures

Figures 2.22 and 2.23 illustrate the practical implementation of some erosion control and revegetation techniques.

Efforts to control water contamination are required by law to be written into the pre-operational permits for approval. Ongoing monitoring of discharge points for pollution beyond the legal parameters is also required. Recirculating process water is also a measure to reduce pollution and conserve the resource. Groundwater is typically monitored through a system of groundwater monitoring wells. These wells measure the quality of the water and the fluctuations in the water table.
Figure 2.22 *Erosion Control Techniques*, sediment settling pond (top), runoff ditch (bottom).
Figure 2.23 **Revegetation Techniques**, revegetation of waste pile (top), revegetation and settling pond (bottom).
(ii) Air Problems

The primary air pollutant from a quarry site is dust. Dust can arise from blasting, the pit, roadways, stockpiles and the primary crusher. Dust emissions, including fugitive dust, are regulated on a visible emissions measurement based on opacity. Most dust from pits is large enough that it settles on the site, in the range of 0.1 micron to better than 300 microns in diameter (Barksdale, 1991). Figure 2.24 shows the rapid settling of dust as a function of distance from the primary plant. The erosion control methods previously listed that cover exposed areas of dirt, such as revegetation, are also effective in controlling dust. Other methods include regular watering of exposed dirt areas, putting down gravel or paving roads, exhaust collection, filter screens (baghouses) and wet dust suppression methods in the crushers, natural and artificial windbreaks, and on-site speed limits (Bennett, 1991).

(iii) Noise Problems

Noise is another area of concern for quarry and mine sites, and its source is often blasting, haul trucks and crushers. Noise from the latter two sources must be kept under local limits. The environmental impact of blasting vibration and other blasting-related problems are another source of concern for operators, especially at sites near urban or commercial zones. However, the fundamental problem is with complaints, not compliance, since
Figure 2.24 **Dust Settling Graph**
Settling rates of dust particles as a function of distance from primary plant (after Barksdale, 1991).
most blasting is done within the legal restrictions to not cause damage (Petro and Anderson, 1987). This can happen because blasting within the regulations does not always preclude annoyance to neighbors, and such annoyance may lead to public relations problems and even litigation.

(iv) Reclamation

Reclamation in the stone industry is an area of growing concern (Carter, 1989). By definition, reclamation means to put the disturbed land back to a state that is at least as good as it was before it was mined. In many locations the mine site is allowed to fill with water, thus creating a pond or lake, possibly for recreational use. In other areas the site may be designed and mined with a specific end use in mind, such as a park, building site, farm land or commercial zone. The nature of reclamation is extremely site-specific, depending upon the area the pit is situated in. This is evidenced by the number of factors that must be considered when planning, for example, for the handling of waste. Waste handling represents a single aspect of reclamation planning, and it is sensitive to many factors, including (Bohnet and Kunze, 1990):

- Government regulations
- Prior land use
- Proximity to population centers
- Desired aesthetic value and visibility
- Local vegetation types and densities
- Climatic conditions
- Cost and effect on mine development
- Prior reclamation attempts in the area
- Dump configuration
- Availability of water and water table
- Company policy

This list can be extended, and it serves to reinforce the site-specificity of reclamation requirements.

Reclamation plans must be included in all pre-mining plans, though they may be modified later. Local communities, together with the operator, may decide what would be best as the site nears its completion. One particular type of reclamation practice conducted concurrently with production involves blasting overburden into the mined-out pit, as shown in Figure 2.25.

An important note here is that underground mines do not have the same reclamation concerns that surface quarries do. Reclaiming disturbed surface areas around the site is minimal when compared to dealing with an open pit that may cover tens or hundreds of acres. This point is graphically illustrated when comparing Figures 2.26 and 2.27. Figure 2.26 shows a limestone quarry in the region under study. The reclamation of this site would be many times more intensive than the reclamation that would occur at the site in Figure 2.27, which shows the entrance to an underground limestone mine.
Figure 2.25 **Blasting Reclamation**
Principles of Blasting Reclamation with Production: stone hauled in direction of thick arrows, overburden A blasted into mined-out pit in direction of dashed arrows after stone B is removed, overburden bench C stockpiled into waste piles D prior to bench removal. Final contour achieved with dozers. The overall effect is to minimize haulage of material away from and back to the site (after Postupack, 1988).
Figure 2.26  **Surface Quarry in Region of Study**
Figure 2.27 Underground Mine Entrance
III. DATA PRESENTATION AND ANALYSIS

Data was collected from visits to 20 sites ranging over the area indicated in Figure 3.1, and included 18 surface quarries and two underground mines. The shortage of data for underground operations reflected the limited number of such mines in the Appalachian region of the country under study. The majority of underground stone mines are located in the Midwest, with a large concentration in and around Kansas City, Missouri. Variables collected include:

- number of drill rigs at each site
- diameter of drill holes
- blasting frequency
- number of haul trucks used
- payload of haul trucks used
- one-way haul distance
- number of loaders used
- personnel at each site, from the superintendent down
- number of shifts per day worked
- length of shifts
- scheduled days per week worked
- site reserves (life of the operation)

Table 3.1 is a listing of the field data collected, and Table 3.2 presents the results of the statistical analysis by displaying the relevant parameters, those being the mean, standard deviation, count, minimum, maximum,
Figure 3.1 **Study Region Map**, covering the Appalachians in Virginia, West Virginia, Maryland, Tennessee and North Carolina (VPI & SU Geology Library, 1992).
### Table 3.1 Initial Data Presentation

<table>
<thead>
<tr>
<th>Surface</th>
<th>drills/hole</th>
<th>blast freq.</th>
<th>trucks</th>
<th>* haul dist.</th>
<th>loaders</th>
<th>crushers</th>
<th>personnel</th>
<th>shifts</th>
<th>work days</th>
<th>reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-4.5&quot;</td>
<td>1/wk</td>
<td>2-30 ton, 2-25 ton</td>
<td>2000 ft.</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1-9 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>2</td>
<td>1-4.5&quot;, 6&quot;</td>
<td>1/wk</td>
<td>2-35-ton</td>
<td>3500 ft.</td>
<td>2</td>
<td>1</td>
<td>12</td>
<td>1-10 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>3</td>
<td>1-4&quot;</td>
<td>2/wk</td>
<td>3-60 ton, 3-35 ton</td>
<td>2700 ft.</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>1-9 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>4</td>
<td>1-7&quot;</td>
<td>1/wk</td>
<td>3-25 ton, 3-25 ton</td>
<td>3300 ft.</td>
<td>2</td>
<td>1</td>
<td>14</td>
<td>1-10 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>5</td>
<td>1-7&quot;</td>
<td>1/wk</td>
<td>3-25 ton, 3-25 ton</td>
<td>4000 ft.</td>
<td>2</td>
<td>1</td>
<td>16</td>
<td>1-10 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>6</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>3-50 ton, 3-35 ton</td>
<td>3000 ft.</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>7</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>2100 ft.</td>
<td>2</td>
<td>1</td>
<td>12</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>8</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-50 ton, 2-50 ton</td>
<td>1500 ft.</td>
<td>2</td>
<td>1</td>
<td>12</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>9</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>2200 ft.</td>
<td>2</td>
<td>1</td>
<td>14</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>10</td>
<td>1-7.63&quot;</td>
<td>2/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>900 ft.</td>
<td>3</td>
<td>1</td>
<td>14</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>11</td>
<td>1-6.5&quot;</td>
<td>3/wk</td>
<td>4-50 ton, 4-50 ton</td>
<td>1400 ft.</td>
<td>3</td>
<td>3</td>
<td>15</td>
<td>1-8 hr</td>
<td>6/wk</td>
<td>life</td>
</tr>
<tr>
<td>12</td>
<td>1-7.63&quot;</td>
<td>5/wk</td>
<td>4-50 ton, 4-50 ton</td>
<td>2000 ft.</td>
<td>4</td>
<td>1</td>
<td>25</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>13</td>
<td>1-7.63&quot;</td>
<td>2/wk</td>
<td>4-50 ton, 4-50 ton</td>
<td>1300 ft.</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>14</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-50 ton, 2-50 ton</td>
<td>2000 ft.</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>15</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-50 ton, 2-50 ton</td>
<td>1600 ft.</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>16</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>3100 ft.</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>30-40 yrs.</td>
</tr>
<tr>
<td>17</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>3-50 ton, 3-50 ton</td>
<td>1500 ft.</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>30-40 yrs.</td>
</tr>
<tr>
<td>18</td>
<td>1-6.5&quot;</td>
<td>1/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>1000 ft.</td>
<td>2</td>
<td>1</td>
<td>11</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
</tr>
<tr>
<td>Underground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2/wk</td>
<td>2-30 ton, 2-30 ton</td>
<td>4000 ft.</td>
<td>1</td>
<td>1</td>
<td>32</td>
<td>1-8 hr</td>
<td>5/wk</td>
<td>life</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1/wk</td>
<td>2-35 ton, 2-35 ton</td>
<td>3800 ft.</td>
<td>1</td>
<td>1</td>
<td>40</td>
<td>2-8 hr</td>
<td>6/wk</td>
<td>life</td>
<td></td>
</tr>
</tbody>
</table>

*All blast with ANFO except one of the underground mines when they have excess water present, then gels are used.*  
**" denotes data either not supplied or unknown. *Haul distances are one-way."
Table 3.2 Statistical Analysis of Surface Quarry Data

<table>
<thead>
<tr>
<th>row</th>
<th>variable</th>
<th>count</th>
<th>mean</th>
<th>std. dev.</th>
<th>mode</th>
<th>minimum</th>
<th>maximum</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>drill holes, inches</td>
<td>17</td>
<td>6.29</td>
<td>1.05</td>
<td>6.5</td>
<td>4.0</td>
<td>7.63</td>
<td>3.63</td>
</tr>
<tr>
<td>2</td>
<td>shots/week</td>
<td>18</td>
<td>1.5</td>
<td>1.04</td>
<td>1.0</td>
<td>1.0</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>3</td>
<td># loaders</td>
<td>18</td>
<td>2.22</td>
<td>0.55</td>
<td>2.0</td>
<td>2.0</td>
<td>4.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td># haul trucks</td>
<td>18</td>
<td>2.89</td>
<td>1.08</td>
<td>2.0</td>
<td>2.0</td>
<td>6.0</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>truck payloads, tons</td>
<td>52</td>
<td>40.67</td>
<td>11.2</td>
<td>50</td>
<td>20.0</td>
<td>60.0</td>
<td>40.0</td>
</tr>
<tr>
<td>6</td>
<td>one-way haul dist.</td>
<td>18</td>
<td>2047.22</td>
<td>1026.2</td>
<td>1500</td>
<td>600</td>
<td>4000</td>
<td>3400</td>
</tr>
<tr>
<td>7</td>
<td>personnel</td>
<td>18</td>
<td>16</td>
<td>11.72</td>
<td>12</td>
<td>5</td>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>*personnel</td>
<td>17</td>
<td>13.41</td>
<td>4.23</td>
<td>12</td>
<td>5</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>hours/shift</td>
<td>18</td>
<td>8.44</td>
<td>0.78</td>
<td>8.0</td>
<td>8.0</td>
<td>10.0</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>days/week</td>
<td>18</td>
<td>5.22</td>
<td>0.43</td>
<td>5.0</td>
<td>5.0</td>
<td>6.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*adjusted personnel data
range and mode.

The goal of the analysis was to accurately derive "typical" values for surface and underground operations. These values should represent what an average surface quarry and an average underground mine would consist of, with the values representing, for example, aspects such as number of personnel and the days per week worked.

Once the typical surface and underground operations have been defined they will be compared and analyzed with respect to each other. Similarities and differences are discussed in an attempt to identify the particular needs of a surface quarry that is considering the move to underground operations.

Cost data was not obtained during the data collection. Due to the competitive nature of the stone industry the vast majority of the quarry operators interviewed refused to relinquish any precise cost figures regarding their respective operations. The best estimate was an approximate cost per ton to produce material. Similarly, the selling prices of the products are also very general. For this reason, cost differences between surface and underground operations in the region of study cannot be accurately determined and compared. Therefore, the data focuses on the technical differences, represented by the data variables collected.

3.1 - SURFACE Quarries

The following is a discussion of the data collected. After each set of data is analyzed, a value for the variable is presented and used as expected
the value, representative of surface quarries in the area of study.

3.1.1 - Drilling

As indicated in Table 3.2, each of the surface quarries utilized a single drill rig. Of the 18 sites sampled, all 18 used a tracked drill. Some of the sites are owned by the same company, and among these a single drill serviced all the sites, or a single drill was used by some of the sites. For example, if company X operated four sites, they might have one drill rig that worked for all sites or two drill rigs that each worked for two quarries. In these cases a single rig was counted for each site, since an operation never has more than one rig at any time.

The mean of the sample representing the number of drill rigs at each site is one for the reasons just discussed. Because all values are one there is no need for further analysis of this sample.

Table 3.2 shows the results of the analysis of the drill hole diameter data. The mean here shows a diameter of 6.92 inches with a standard deviation of 1.05 inches. This size drill bit is not an industry standard, but it fairly represents the approximate diameter of most drill holes used by surface quarries. The count is 18, therefore 18 sites supplied this data and consequently comprised the sample. The smallest diameter used was three inches and the largest was 7.63 inches, or seven and five eighths inches, with a range of diameters of 3.63 inches. Perhaps the most important datum from this sample is the mode, 6.5 inches. The histogram in Figure
3.2 shows the frequency of each of the diameters in the sample. From this it is concluded that the most commonly used drill hole diameter is 6.5 inches.

3.1.2 - Blasting Frequency

From the histogram in Figure 3.3, it can be seen that by far the majority of the quarries sampled schedule shots an average of once each week. Table 3.3 provides further validation by showing that the one shot per week was carried out by 77.22 %, or 13 out of 18, of the sites, with the next closest frequency being two shots per week in 16.67%, or three out of 18, of the sites. The major exception to this is the one site that shot five per week, which was the maximum number for any site. As it was explained by the area manager of that site, this occurred during a period of rapid growth for that operation. The quality of its product was very good and in great demand, and every effort was made to produce as much as possible. Since this was happening during the time of the field investigations, it was included in the data. However, the superintendent disclosed that more recently this operation has slowed production to the point of shooting two to three times per week.

All of the quarries investigated did not handle blasting the same way. There was a near even split between blasting done in-house and contract blasting. The common denominator to all the sites is the explosive used. All 18 sites shot with ammonium nitrate fuel oil, or ANFO.
Figure 3.2  Surface Drill Hole Diameter Frequency
### Table 3.3 Analyses of Selected Surface Data

<table>
<thead>
<tr>
<th>shots/week: no./week</th>
<th>count frequency</th>
<th>percentage frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>loaders: number</th>
<th>count frequency</th>
<th>percentage frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>83.33%</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>11.11%</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>5.56%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>truck payloads: payload (tons)</th>
<th>count frequency</th>
<th>percentage frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2</td>
<td>3.85%</td>
</tr>
<tr>
<td>25</td>
<td>8</td>
<td>15.38%</td>
</tr>
<tr>
<td>30</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>35</td>
<td>17</td>
<td>32.69%</td>
</tr>
<tr>
<td>40</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>45</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>50</td>
<td>22</td>
<td>42.31%</td>
</tr>
<tr>
<td>55</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>60</td>
<td>3</td>
<td>5.77%</td>
</tr>
</tbody>
</table>
Figure 3.3  Surface Blasts Per Week
Therefore, from this data it is apparent that the standard number of blasts per week conducted in surface quarries in the region under study is one per week, and the shot is done with ANFO. However, there would be an even chance that a particular site would shoot in-house or contract out, depending on company policy.

### 3.1.3 - Loaders

The most notable evidence to appear in this data set is that no quarry uses only a single front-end loader. Table 3.2 shows the set has a mean of 2.2, with a standard deviation of .55. This would indicate that the majority of sites use only two loaders, and in Table 3.3 it can be seen that this is true, where 83.33%, or 15 out of 18 sites use two loaders, which is the mode of this data set. The range of loaders used went from two to four. Only two sites use three and a single operation uses four. The important thing to remember is that not all of the loaders are used for direct production purposes. Some are put to work clearing roads, keeping stock piles neat, and other miscellaneous tasks. The sites that have two loaders must also use them for these tasks, which means they spend less time in production unless time is scheduled specifically for such nonproduction tasks, perhaps if trucks are down or the crusher is being repaired or inspected.

### 3.1.4 - Haul Trucks

This particular topic includes three separate variables: the number of
trucks used at each site, the payload of the trucks, and the one-way haul
distances of the trucks at each site. Each of these variables was analyzed
and discussed separately.

A. Number of Trucks

Table 3.2 and Figure 3.4 both display the statistical analysis of the
data on the number of haul trucks used at each site. The mean of the data
is 2.89, or just less than three trucks per site with a standard deviation of
1.08. The mode of the set is two trucks per site, with eight out of a count of
18 sites reporting this number. The largest number of trucks any quarry
used was six, but this only occurred at one site. No quarry used a single
truck, all had at least two, and six of the 18 used three while four sites used
three trucks.

Despite the fact that the mode was two trucks, the data does not sug-
gest that this can be selected as the typical value. For this reason the mean
of the data, 2.89 rounded to three, more accurately represents the actual
number of trucks at each site.

B. Payloads

Table 3.2 shows the breakdown of the haul truck payloads for all 18
sites. The count of the trucks for all 18 sites was 52, with a mean payload of
40.67 tons and a standard deviation of 11.2 tons. Figure 3.5 shows the fre-
quencies of the payloads. What all this is saying is that most haul trucks
used are rated at payloads between 30 and 50 tons. The minimum payload
Figure 3.4  **Surface Haul Truck Number Frequency**
Figure 3.5 Surface Haul Truck Payload Frequency
was 20 tons and the maximum was 60 tons. The mode was a 50 ton truck, so it was used more than any other size, a total of 22 out of 52 or 42.3%. Table 3.3 shows that 35 ton trucks were the next most commonly utilized, 32.7% of the time, then 25 ton trucks, which were used 15.4% of the time. To make a definite conclusion about the typical size of haul trucks used is difficult, but it is probably safe to say that the preferred size is a 50 ton truck. This can be assumed because several quarry operators indicated they would like to use nothing but 50 ton trucks if they could.

C. One-Way Haul Distances

Figure 3.6 and Table 3.2 both provide information on one-way haul distance frequencies. The range of data varies considerably, 3400 feet, with the minimum being 600 feet and the maximum being 4000 feet. The mode was a distance of between 1280 feet and 1620 feet, but this only happened in four out of a total count of 18 sites. Three distances were between 600 and 940 feet, and three were between 2300 and 2640 feet. The data in Table 3.2 shows a mean of 2047.22 feet with a standard deviation of 1026.2 feet, which is indicative of the spread in the values.

The general trend of the data seems to be toward the range of around 600 to 2600 feet. This still leaves a range of 2000 feet, which is substantial. However, if a closer look is taken at the data in Figure 3.6, it can be seen that within this 2000 foot range 13 of the 18 data points are present. The midpoint of this range is 1600 feet, with seven of the thirteen points below it and six above it, which is fairly evenly distributed. Therefore, because most
Figure 3.6  *Surface One-Way Haul Distance Frequency*
of the data is grouped here, it can be stated that the typical one-way haul
distance for surface quarries is approximately the same as the mode of the
entire set, which is 1500 feet, though plus or minus 500 feet would not be
unexpected.

3.1.5 - Crushers

All 18 sites utilized a single crushing plant. Some operations periodically
will adjust the location in order to keep haul distances within an optimum
range, or to make room for expansion of the pit. There were no multiple-crusher
operations visited or discussed in any detail. It was the general
consensus that a single plant was enough of a worry to keep running and in
line with the periodic state and federal inspections. The logistics of coordi-
nating the efforts of multiple plants would cause major changes to occur in
the normal run of business, and would require more personnel at most lev-
els to run smoothly. Therefore, a second plant would be feasible only in an
operation of tremendous size and production potential.

3.1.6 - Personnel

Table 3.2, row 7 and row 8 show the statistics of the personnel data
breakdown in two slightly different ways. Row 7 shows the complete data
set as it was collected, and row 8 shows the set without the outlying value of
60 workers. This particular site is an anomaly in that it consisted of a sur-
face operation and an underground mine. Both phases of this operation utilized the same resources for administration, maintenance, etc. The total personnel at this site numbered 120, and production was split roughly 50-50 between the surface and underground aspects. For this reason the datum entered for the site was 60 people, as it was for the underground operation. However, because this operation is rather unique when compared to all the others, this data set was also analyzed excluding the anomalous datum. These results are seen in Table 3.2. First the complete set is discussed, then the amended set is discussed, and finally the two are compared and the conclusions made.

The all-inclusive data set exhibits a mean of 16 workers per site with a standard deviation of 11.72. The minimum is five and the maximum is 60, as previously discussed. The mode of the set is 12, which is substantially below the mean. Figure 3.7 graphically displays the data, and it can be seen that there is a concentration of data in the 10 to 16 range where 14 out of the count of 18 values fall, or 78%. The mean of this data set falls on the upper edge of this cluster and can’t be considered an accurate representation due to the influence of the very large outlying value. Also, the mode of the set, 12, is four units away from the mean of 16, which further serves to invalidate this particular analysis.

Next is the analysis of the set excluding the outlying value. The mean drops from 16 to 13.41, or 13 since actual full-time people are involved and can not exist as fractions. The standard deviation drops from 11.72 to 4.23, which is a significant drop. This allows the entire cluster of data, as just de-
Figure 3.7  Workforce Size Frequency

Number of personnel at each site
scribed and shown in Figure 3.7, to fall within one standard deviation of the mean. The mode stays at 12, only one person away from the mean. Clearly this data analysis is superior to the previous one and is a more fair representation of what would be expected at an actual site. Therefore, the number of personnel working at a particular site in the region under consideration, from the superintendent all the way to any secretaries or maintenance workers, would be fairly assumed to the mean of the data set in the second analysis, or 13 people.

3.1.7 - Work Week

The information in this section covers the scheduled work at each site during the course of an uninterrupted work week. Three different aspects of the work week are covered: the hours per shift, the shifts per day and the days worked per week. An overview of the values reported for these variables can be seen in Table 3.1.

The first of these variables is the hours per shift, and the analysis is in Table 3.2. All 18 sites reported values, and there was some variation, but not much. The mean is 8.44 hours per shift with a standard deviation of .78 hours or roughly 47 minutes, and the mode is an eight hour shift. The limited variation can be seen in the range of values, only two hours, with eight being the minimum and 10 the maximum. Only a five of the 18 sites actually worked shifts of more than eight hours, so it is accurate to assume that the typical shift worked is eight hours long.
The second of the variables is the number of shifts worked per day. As seen in Table 3.1, all sites reported working a single shift per day.

The next data studied are the number of days worked per week, shown in Table 3.2. Only four of the 18 operations worked more than five days each week, and they worked 6 days per week. A side-by-side comparison of this information is displayed in Figure 3.8. The mean here is 5.22, standard deviation is .43, and the mode is five. With all this in mind, it can be stated that the average work week lasts five days.

An important note here is that many of the superintendents commented that the current state of the economy has caused them to cut back in either the hours worked each day, the days worked in a week, or both. However, they also stated that they have been on their current schedules for over a year, many longer than that, and they were going to remain on these shorter schedules into the foreseeable future.

In addition, all sites observed all the major holidays with almost the same amount of time off given to the workers. A few of the sites received one or two extra days off if the parent company chose to observe some of the lesser holidays, but this was by far the exception not the rule. Therefore, it can be stated that all the operations were in active for the same amount of time over a year.

3.1.8 - Reserves

The data gathered on reserves is sketchy at best. When interviewing
Figure 3.8  Work Week Frequency
quarry operators or superintendents it quickly became clear that this information, in any detail, would be impossible to obtain. Reasons for this are based on competition within the industry. When operators understood the scope of this work, they agreed to relinquish general information regarding the life expectancy of the operations. Therefore, it was agreed to treat all such information as strictly confidential.

In lieu of information on reserve estimates, the best data gathered is displayed in Table 3.1. Despite their reluctance to report numbers, operators did give general indications on the quarry in terms of their own careers. This was agreed upon by all interviewed, and they freely admitted this information. In the Table the reserves at 16 of the 18 sites were said to last beyond the life of the operator. The two quarries that reported more precise estimates of the life of the quarry did not disclose any tonnage numbers, but did report life expectancies in the range of 30 to 40 years, depending on market conditions.

This data can not say anything on the reserves of the quarries with respect to tonnages, but a general conclusion can be drawn from it. That is, the tonnages in reserve at a quarry in the region under study are sufficient to last beyond the life of the operator or superintendent, and for that matter, beyond any currently living life span as well. This would indicate that the quarries have reserves sufficient to last in the neighborhood of at least 30 years, as this was the estimated remaining life span of the oldest interviewee.
3.2 - UNDERGROUND MINES

The data collected for this section is very limited at best, and self-explanatory when seen in Table 3.4. This is due solely to the fact that relatively few underground operations exist in the part of the country covered by the research, which includes Virginia, West Virginia, Maryland and Tennessee. For this reason the averages of the two operations will be used to represent typical values to be expected for underground mines.

The biggest differences between the two operations are in haul distance and in the number of personnel at each site. One-way haul distances at the sites are both very great, with a difference of 2200 feet and an average of 4900 feet. The number of people working at the sites is also large, with a range of 28 between the two, and a maximum of 60 people.

As explained in the personnel section of surface quarries, one site consisted of both a surface and an extensive underground mine. The datum of 60 people comes from this same site.

3.3 - ENVIRONMENTAL PROBLEMS

Surface quarries are faced with some environmental problems that underground mines do not have to face. These are primarily in the areas of runoff control, stream diversion, noise, aesthetics, and to a lesser extent dust control. These concerns vary in importance between sites depending
<table>
<thead>
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<th></th>
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<th>mine 2</th>
<th>average</th>
</tr>
</thead>
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</tr>
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</tr>
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<td>2</td>
</tr>
<tr>
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<td>32.5</td>
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<td>4900</td>
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</tr>
<tr>
<td>crushers</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>personnel</td>
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<td>60</td>
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</tr>
<tr>
<td>hours per shift</td>
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</tr>
<tr>
<td># shifts</td>
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<td>6</td>
</tr>
<tr>
<td>reserves</td>
<td>life</td>
<td>life</td>
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</tr>
</tbody>
</table>
upon proximity to urban centers. More rural quarries have greater problems with water and areas designated as wetlands, while more urban quarries place a greater importance on noise control, dust control and general aesthetics.

One of the biggest areas of concern in the surface quarries is in public relations. Operators at all of the sites investigated report that the idea of being a "good neighbor" is being taken as literally as possible by listening to complaints and suggestions from the public with regard to the local environment and the quarry's perceived effects on it. A consistent complaint is one of blasting vibration and noise, and every effort is made according to the laws to keep problems to a minimum.

Other problems surface quarries have deal mainly with water and discharging it into local waterways. This can be a problem especially during a rainy period when significant runoff from the site takes place. Legal limits exist on the amount of sediment that an operation can let go. Every site has numerous settling and catchment ponds to allow the silt to settle out before the water is discharged. Also, to help prevent runoff from getting out of hand, many stockpiles, roadside ditches and other exposed areas are temporarily reseeded to contain the sediment. One particular operation went so far as to construct large grassy berms on the perimeter of the quarry property, not only to contain runoff water and sediment loss, but to make the site more invisible from the outside. Another point to make here is the quality of the water is more often than not better than the waterway into which it being discharged. This is because most of the operations are in
limestone, which neutralizes any ill effects the water may have.

Yet another area of concern expressed by several of the operators deals with the spillage of oil and fuel, and storing it in underground tanks. This is not a problem unique to the quarry industry, but it is very important. The contamination of local water supplies from oil or fuel, or a leaky storage tank does occur, and it can cause the quarry a tremendous amount of grief. This is an area watched closely by the operators themselves and by the state and federal inspectors. A superintendent at one surface quarry is so worried about this problem that he has his heavy equipment park in different places at the end of each work day so as not to have any one place build up a concentrated amount of oil leaking from the vehicles.

A final environmental concern is in the area of site reclamation. Most sites practice their reclamation concurrently with the extraction phase of the operation. This involves contouring the land to acceptable grades and reseeding it the moment it is taken out of production. If the pit is progressing deeper, then the waste is shaped and seeded, and the pit will eventually be left to fill with water. This ultimate reclamation solution to large pits is by far and away the most frequent in the sites visited.

Underground mines do not have near the environmental problems associated with surface quarries. However, the ones they do have are not minor. The discharge of water is generally not a problem because of the resulting cleanliness of the effluent, but if the mine causes changes to the local water supply by tapping into an aquifer then problems can result. Blasting vibration is apparently not a problem with underground mines ei-
ther because they are far enough under the surface to dampen the noise and vibration that comes with blasting.

The largest environmental problem associated with underground mines is subsidence. Because most of mines are limestone operations, they are subject to sinkholes, and in a populated area this will be a major environmental and safety concern. Such sinkholes can possibly divert waterways from their natural course or cause property damage. One of the underground operations did report the existence of a sinkhole probably, though not definitely, due to the mine. However, this sinkhole is located well within the property limit of the mine, and did not produce any noticeable effects on the local water system.
IV. COMPARISON OF SURFACE AND UNDERGROUND OPERATIONS

Figure 4.1 illustrates four possibilities of the mining sequence when comparing surface to underground operations. The analysis of the data collected will clarify which of the possibilities, is any, is the correct one. The values established as being representative of a “typical” surface quarry or underground mine are listed in Table 4.1. These parameters are to serve as guidelines for the sake of comparative analysis, and are not in any way suggesting that all operations fall within the range of the data. Every attempt was made to collect as large and as comprehensive a data base as possible in establishing these figures in order to create a realistic situation. Because the numbers are used for comparison, they are more useful when viewed in terms of percentage differences between surface and underground operations. Figure 4.2 shows this comparison. The areas in which differences are evident between the two methods are numerous. The following discussion analyzes the differences and suggests possible reasons for them.

4.1 - BLASTING

The first variable that is different between the operations is the number of shots per week. The underground operations tend to shoot more often on a per week basis than do surface quarries. The underground operators suggest this is so because their shots are smaller and more confined. This in
Figure 4.1 **Mining Sequence Comparison**  
Comparison of alternative mining sequences, highlighting the possible similarities and differences in the unit operations between surface and underground operations (after Hartman, 1992).
Table 4.1 Averages for Surface and Underground Operations

<table>
<thead>
<tr>
<th></th>
<th>surface</th>
<th>underground</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
</tr>
<tr>
<td>hole diameter</td>
<td>6.5</td>
<td>variable with drill pattern</td>
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<tr>
<td>shot frequency</td>
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<td>1.5</td>
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<tr>
<td># haul trucks</td>
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<tr>
<td>truck payload</td>
<td>50</td>
<td>32.5</td>
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<tr>
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<td># loaders</td>
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<td>crushers</td>
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<td>1</td>
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<td>personnel</td>
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<td>hours per shift</td>
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<td>6</td>
</tr>
<tr>
<td>reserves</td>
<td>life</td>
<td>life</td>
</tr>
</tbody>
</table>
Figure 4.2  Surface vs. Underground Differences, (%)
turn allows the material to be loaded and cleaned out in a shorter amount of
time. Surface blasts are larger and take much longer to load. Also, in sur-
face blasting there often is a large percentage of waste material to be selec-
tively loaded and discarded.

In a similar vein, the underground shots take less time to prep for. The
drilling phase is completed more quickly underground because fewer and
shallower holes need to be drilled, which saves time when compared to the
same phase on the surface.

4.2 - LOADERS

The data shows that surface operations will use more loaders than will
underground operations. The reasons for this are varied. Many surface
quarry's used more than one loader not only in production but to perform
other maintenance activities at the site. With the entire operation exposed
to the weather, there is faster breakdown of roadways which need to be re-
paired. Other jobs for the extra loaders include work around the stockpiles
and other construction or maintenance work. The underground mines oper-
ate in a constant environment, and road work is minimal due to this and
the fact that the roads themselves are mostly on solid rock, and therefore do
not degrade at the rate of an ordinary dirt haul road. Also, the under-
ground mines only consisted of a single work face in a confined space, so
only one loader was needed and could be practically utilized.
4.3 - HAUL TRUCKS

Surface operations will utilize more trucks for hauling material than underground mines will. The main reason for this is simply one of logistics. Trucks hauling stone in and out of an underground mine do not have the room necessary to maneuver around each other on a haul road. While one truck is being loaded at the work face, the other is in transit to or from the dump site. Having more than two trucks driving on the same road underground would undoubtedly cause much longer wait times for the drivers, and the risk of accidents and injuries would probably rise, too.

Not only do surface quarries use more trucks, but the ones they use are significantly larger than the underground trucks. The surface trucks were generally 50 ton vehicles, which is 54% greater in payload capacity than the underground trucks. Table 4.1 shows trucks of 32.5 tons, though in reality they are either 30 or 35 ton haulers. In either case, they are quite a bit smaller than their surface counterparts.

The underground trucks are smaller for two primary reasons. The first is similar to the reason for fewer numbers of trucks underground, the limited space. The area to maneuver underground is not conducive for the use of the larger trucks. They would be very difficult, if not impossible to turn around, or drive through narrow tunnels at a reasonable and safe speed. The second reason that underground trucks are smaller is that trucks used in surface quarries are just much larger in comparison. They have ample room to maneuver in, and are required to haul material from much larger
blasts. It is more efficient to use the larger vehicles to carry the stone in larger amounts.

Haul distances are one aspect of the two methods that exhibited an extremely large discrepancy. Figure 4.2 shows a difference of 227%, with the one-way distance in underground mines being that much longer. This situation exists as a result of the natural progression of the mine with advancement of the working face. Surface pits are a set distance from the crusher, and this distance will increase, or possibly decrease, very slowly over time. The crusher can even be translocated in an effort to keep the haul distance at an optimum. But in underground mines the face will get farther from the crusher as production progresses. As the face moves farther underground, the distance to the crusher becomes greater, thus accounting for the radical difference in haul distances between underground and surface operations.

4.4 - PERSONNEL AND WORK SCHEDULES

The number of people working at underground mines is a significant amount more than in surface operations. Figure 4.2 shows a discrepancy of 253% in favor of the underground operation. The reason for this becomes apparent when the differences between the number of shifts worked and the days per week worked are examined. While both methods employ shifts of the same duration, the underground mine works two shifts per day for six days per week. This additional shift at one of the underground mines included not only production workers but a maintenance crew as well. This
additional amount of work each week accounts for the needed personnel. The underground mines opt for this work schedule for two important reasons.

The first is due to the output rate of material. Because underground mines utilize fewer loaders and fewer and smaller haul trucks, the output rate is not equal to that of the surface quarries. In order to stay competitive, and because the working conditions easily permit it, underground work can be continued in any weather and at any time of day or night.

The second reason more shifts are worked during the week is a result of the slower output and the mining conditions. The underground operation allows for more selective mining, following higher quality stone throughout the deposit. In order to meet the demand for this stone, the mine must operate for longer periods of time. The high quality material sells for a higher price, and the revenue generated from the longer work time easily supports the additional costs incurred with the schedule.
V. ENVIRONMENTAL RISK ASSESSMENT IN STONE PRODUCING OPERATIONS

Every surface operation investigated for this study had environmental impacts associated with them which often involved the evaluation and management of risks. Underground stone mining operations also have environmental risk assessment problems. Some of these are shared by surface operations, and some are unique to the underground situation. When a company is faced with the choice of quarrying on the surface or mining underground, comparing the environmental risks associated with both types of production may cause a decision to be made in favor of one method over the other, or at least aid in the decision-making process regarding which method to undertake.

When a situation arises where an operation must decide whether or not to pursue mining underground, careful consideration must be given to the environmental risks associated with each method. Failure to foresee the potential environmental hazards accompanying a particular extraction method can and has halted many proposed operations (Haycocks, et al, 1992). Risk assessment and analysis is a valuable tool for evaluating the environmental risk factors involved with surface and underground sites and can be the decisive factor in choosing one of them as a mining method (Kates, 1978, Zeigler, et al, 1983). In summary, risk analysis involves studying the risks involved with a situation, the technology used to deal with them, and the social response to the potential problems and solutions.
In the current environmentally aware climate it is to the company's benefit to be very careful in opting to either remain on the surface or move to underground extraction. This is evident in the "good neighbor" policy of operations within their communities, and thus far this attitude has been much less troublesome and significantly less expensive than court challenges (Rukavina, 1987).

The process of risk assessment and analysis can be broken down into three major steps. The first of these is the information gathering phase. This involves collecting data on the ecosystem to be affected by the site. The first step is to conduct an environmental audit to establish an inventory of the flora and fauna, and the water system in the area. Based on this preliminary report the area may be deemed critical, then an environmental impact statement will probably be required. In the case of a surface quarry going underground, similar steps must be followed to determine the effects of the underground operation on the environment. Also part of the first phase is the gathering of information from the community, regulatory boards, governmental agencies and special interest groups on the operation. Most environmental problems can be handled with a high degree of certainty, but the more human elements can and frequently do introduce a tremendous amount of uncertainty, and therefore risk. Many operations are terminated due to political pressures from the opposition to mining and quarrying operations (Haycocks, et al, 1992; Carter, 1989). The newspaper article in Figure 5.1 describes how an operation in the region under study was halted by local opposition before it was ever started. This example illus-
Controversial quarry quashed

By LON WAGNER

Instead of preparing for its next battle over a proposed rock quarry, Salem Stone Inc. is concluding its withdrawal of its application for the quarry.

Salem Stone pulled out of the process last Monday, the company's decision to withdraw coming after a unanimous recommendation against the quarry by the county Planning Commission on Nov. 3.

Planning Director John Wallace said, "I guess before they even got the fax to me, word got out. The fireworks were going off here."

The Salem-based quarry operator saw potential in the band of granite that runs southwest to northeast through Pittsylvania County. The extremely hard rock is especially valuable in highway construction.

"In our comprehensive plan, we call out this resource and very strongly suggest it should be utilized," Wallace said.

But Salem Stone had secured rights to 180 acres in the midst of a booming residential area of the county. Danville's northern suburbs. The property was three-quarters of a mile from an old quarry that had been used as a hazardous materials landfill.

Residents were concerned that drilling from Salem Stone's proposed quarry would reopen fissures in the hazardous materials landfill and allow toxic runoff into the community's drinking water.

The residents fought the application with a public relations campaign, information provided by the Environmental Protection Agency's study of the old quarry, and using the county's zoning laws adopted in January 1991.

Lee Ann Baker, who lives within half a mile of both the EPA Superfund site and the property Salem Stone wanted to use, said the residents' victory was a classic example of the proper use of zoning. Because of the county's new zoning ordinance, the residents had a chance to present their opposition.

Salem Stone President Leonard Hill was not available for comment. Barker said she had heard that the company might want to mine granite in the county.

"If they do apply again," she said, "I hope they apply somewhere where it wouldn't have as much impact on the community as over here."

Wallace said the scars of granite mining would likely remain for decades, but it was not close enough to the surface to mine everywhere.

Figure 5.1 Newspaper Article

Article describing the termination of the plans for a stone quarry in the region of study due to local social and political pressure (Roanoke Times & World News, 1992).
trates how important thorough and careful planning for a site is, and the significance of managing of potential environmental hazards, even before they become reality.

The second major step is the evaluation phase. This involves analyzing the information gathered in the first step and measuring the various options to environmental risks against their corresponding social consequences. This step gives the site operator an idea of what the public perceives as major environmental hazards and what are legally considered hazards that they would be liable for. Careful and thorough evaluation will also allow the operator to predict possible risks far into the future which must also be considered. This can sometimes be difficult, for what may not be a risk or hazard in the present may become one in the future, resulting in more liability and public opinion problems.

Finally, the third and last step is the management phase. During this phase attempts are made to reduce environmental risks to acceptable levels by utilizing available technology and resources. The management phase must deal with risks that are both human-caused and natural. The human-caused problems can be controlled to a much greater extent than the natural ones. The naturally occurring hazards are more likely to be avoided through careful management and smart decisions than to be controlled. In the context of quarry and underground sites, the majority of environmental risks will be human-caused (Haycocks, et al, 1992). An overview of the risk assessment process utilized here is illustrated in flowchart form, seen in Figure 5.2.
Figure 5.2. **Environmental Risk Assessment Flowchart**
The types of environmental problems and risks associated with the stone industry, for both surface and underground production, can be looked at in several different ways. For the purposes of this work the potential areas of risk have been divided and categorized into two major groups for both surface and underground operations, displayed in Table 5.1. As the table shows, the areas of risk have been separated into those associated with the production phase of the operation, and those associated with the post-production phase. The pre-production aspect of risk analysis involves the permitting process, which can be viewed as the most important step in the entire environmental risk assessment process. If all possible contingencies are not accounted for, the operation likely will never get under way. To gain a perspective on the lengthy and often difficult task of permitting a site, the procedure for obtaining permits in the state of Virginia is outlined in Figure 5.3. However, this research is focusing primarily on those operations which already exist as surface quarries and are faced with the option of going underground, though this does not exclude the environmental risks associated with the continual and ongoing permitting process, whether they be for simple sediment ponds or for expansion onto new property.

After the first phase of identifying the possible environmental hazards for a specific site, it becomes necessary to compare all the possibilities (second phase) and make decisions regarding the various environmental risks involved in order for the operator to determine if going underground would be beneficial (third phase). By quantifying the risks identified, this decision process can be made much simpler. The first step is to define risk in quanti-
Table 5.1 Risk Factors for Surface and Underground Operations

<table>
<thead>
<tr>
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<th>Unique Surface Risks</th>
<th>Risks Common to Both</th>
<th>Unique Underground Risks</th>
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<td>sinkholes</td>
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<td>dust control</td>
<td>water table</td>
<td>vent. fan noise</td>
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<td>blasting vibration</td>
<td>habitat disruption</td>
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<td>runoff</td>
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<tr>
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<td>highwall stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>noise</td>
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<td></td>
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<tr>
<td>Post-Production</td>
<td>highwall stability</td>
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<td>sinkholes</td>
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<td>revegetation</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>runoff</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>reclamation</td>
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</tr>
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</table>
Figure 5.3 Virginia Division of Minerals Permitting Flowchart, 1992.
tative terms that make it an easily understood and useful tool. Therefore, for the purposes of this research, risk is defined according to the following equation:

\[
\text{Risk} = 1 - \text{Probability of Success (\%)}
\]

The probability of successfully handling or permitting for each risk identified can be assigned as \( p_1 \). The probability of failure for the entire switch to underground mining, \( P_f \), becomes:

\[
P_f = 1 - (p_1 \times p_2 \times \ldots \times p_n)
\]

(eq. 5.1)

In reality, an operator probably would only have two, three or maybe four elements in this equation. Any more than this and the operation is probably not feasible. Because no two sites are the same, determining what the probability is for each environmental hazard must be site specific and is often very difficult, especially when dealing with risks that are man-caused because of the degree of uncertainty that is associated with human actions. Each of the hazard areas identified must be independent of each other for the equation to work properly. Each hazard must also be considered a potential "stopper" to the entire operation. As previously mentioned, natural processes can be predicted with much more regularity when compared to human-caused risks. Table 5.2 lists some possible environmental hazards
Table 5.2  Suggested Failure Probabilities: \( (1-p_n) \)

Validity for equation maintained only when hazards are independent from each other.

<table>
<thead>
<tr>
<th>potential environmental risks/hazards</th>
<th>surface value ( (1-p_n) )</th>
<th>underground value ( (1-p_n) )</th>
<th>comments</th>
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</thead>
<tbody>
<tr>
<td>reclamation plans</td>
<td>0.0 - 0.15</td>
<td>0.0 - 0.01</td>
<td>easier for underground</td>
</tr>
<tr>
<td>water permits</td>
<td>0.0 - 0.25</td>
<td>0.0 - 0.1</td>
<td></td>
</tr>
<tr>
<td>air pollution permits</td>
<td>0.05 - 0.35</td>
<td>0.05 - 0.15</td>
<td>surface sources include pit</td>
</tr>
<tr>
<td>blasting permits</td>
<td>0.1 - 0.5</td>
<td>0.0 - 0.15</td>
<td>depends largely upon location</td>
</tr>
<tr>
<td>special use permits</td>
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<td>0.0 - 0.15</td>
<td></td>
</tr>
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<td>excess noise/vibration</td>
<td>0.05 - 0.25</td>
<td>0.05 - 0.1</td>
<td>mainly from mobile equipment and crushers</td>
</tr>
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<td>highwall stability</td>
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<td>0.0</td>
<td>absent in underground mines</td>
</tr>
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<td>public acceptance</td>
<td>0.1 - 0.5</td>
<td>0.0 - 0.2</td>
<td>out of sight, out of mind</td>
</tr>
<tr>
<td>special interest groups</td>
<td>0.15 - 0.6</td>
<td>0.05 - 0.25</td>
<td>human factor very unpredictable</td>
</tr>
<tr>
<td>environmental monitoring/control</td>
<td>0.01 - 0.2</td>
<td>0.0 - 0.15</td>
<td></td>
</tr>
<tr>
<td>environmental impact statement</td>
<td>0.05 - 0.3</td>
<td>0.01 - 0.15</td>
<td>reflects corresponding levels of disturbance</td>
</tr>
<tr>
<td>aesthetics</td>
<td>0.1 - 0.4</td>
<td>0.0 - 0.15</td>
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<td>subsidence</td>
<td>0.0</td>
<td>0.5 - 0.25</td>
<td>only a surface problem</td>
</tr>
<tr>
<td>flyrock</td>
<td>0.05 - 0.3</td>
<td>0.0</td>
<td>only a surface problem</td>
</tr>
<tr>
<td>contamination of water supply</td>
<td>0.05 - 0.3</td>
<td>0.0 - 0.1</td>
<td>contamination includes runoff from surface pit &amp; piles</td>
</tr>
<tr>
<td>revegetation</td>
<td>0.0 - 0.2</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>subsidence (sinkholes)</td>
<td>0.0</td>
<td>0.0 - 0.2</td>
<td>major underground concern</td>
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<tr>
<td>habitat disruption</td>
<td>0.1 - 0.4</td>
<td>0.0 - 0.1</td>
<td>reflects corresponding levels of disturbance</td>
</tr>
</tbody>
</table>
with suggested ranges for probabilities of failure, defined as $1 - p_n$, inferred from literature and interviews. These values may be very different for actual sites due to the site specific nature of the industry. The following is an example, from amongst the sites visited for this research, of how this entire process may be used to aid in the decision to progress underground.

The quarry under discussion is a surface limestone operation in Southwest Virginia. It has been in operation for many years supplying stone for road projects and contractors. Until recently, the largest environmental problems were runoff from exposed areas into a large river adjacent to the operation's property and the diversion of a stream utilized by local farmers. The runoff control problems include revegetation and other techniques, which are not always successful, especially during a very heavy rain when the river becomes noticeably silted from soil out of the operation. The likelihood of handling these problems, as independent events which may cause closure of the operation or large amounts of capital investment to better control them, can be assigned success probabilities of 0.85 for the stream diversion ($p_s$) and 0.7 for the runoff problems ($p_r$). Inserting these values into equation 5.1, the result is:

$$ P_f = 1 - \left( p_s \times p_r \right) $$  \hspace{1cm} (eq. 5.2)

\begin{align*}
&= 1 - (0.85 \times 0.7) \\
&= 1 - 0.595 \\
&= 0.405
\end{align*}
Thus, the probability of unsuccessfully dealing with the problems is 40.5%, or a 59.5% probability of being successful. With a probability of success this high, the operation has not had to consider going underground. However, recently this operation experienced problems that were not originally anticipated, which have resulted in the progression into underground mining. The difficulties arose when large, naturally occurring caves were found behind the working face. This created the choice of staying on the surface and operating in potentially unsafe conditions, or mining underground. Caves behind the working face are a tremendous concern, and this handling event \( p_c \) could receive a success value of as little as 0 to 10%. For this example, it will be given a success value of 5%, or 0.05. Putting it into equation 5.2 the result is:

\[
P_f \approx 1 - (p_s \times p_r \times p_c)
\]

\[
= 1 - (0.85 \times 0.7 \times 0.05)
\]

\[
= 1 - 0.02975
\]

\[
= .97025
\]

This shows the probability of the operation being unsuccessful while remaining on the surface as 97.025%, or the success probability as 2.98%. Subsequently, the operation proceeded underground. Had the operator known of the caves, this environmental assessment process could have been performed and the slim chance of success as a continued surface operation recognized. This could have prevented the expenditure of large sums of
money to handle the resulting dilemma the caves caused. The operator also had to have some environmental audit work done on the caves because they were disturbed, which cost time and money and which could also have been avoided.

With this kind of information, an operator can explore various pathways to achieving a successful move to underground mining, and also gain insight into the environmental risks that would be associated with the mine. From this point the ultimate decision to pursue underground production can be made more easily, while demonstrating care and concern for the environment and trying to minimize any negative pressures the operation may introduce.
VI. CONCLUSIONS and RECOMMENDATIONS

The conclusions of this research are drawn from the analyses of the data collected and interviews with personnel in working in the stone industry, and are supported by the literature reviewed.

6.1 Factors Influencing the Underground Decision

Based on the research conducted, several conclusions can be drawn regarding the factors that may cause a quarry to progress to underground production. These reasons are summarized in the following section.

1) High stripping ratios - if the orebody, or the grade of material desired, dips downward and the overburden becomes economically unfeasible to remove and still realize a profit. Experience from most people interviewed indicates that the cutoff for overburden depth is approximately 60 to 80 feet. This depth is a function of the amount and value of the stone being mined.

2) Post-mining site uses can generate continuous income for the company.

3) Leasing of surface property can generate income during and after the life of the operation.

4) Greater selective mining capabilities than in a surface operation.

5) Constant, year-round working environment allows for production to
continue during inclement weather.

6) Easier environmental permitting.

7) Environmental hazards, such as sedimentation from runoff and dust, are minimized, resulting in possible reduced compliance costs.

8) Reduced blasting vibration on the surface.

9) Problems with flyrock are eliminated.

10) Blasting in an underground mine produces smaller rock pieces, thus saving crusher runs and making the crushing phase more efficient. One interview suggested up to 30% more efficient than crushing stone from surface blasts.

11) Limited handling of waste material due to the fact that it does not exist.

12) Limited reclamation concerns compared to surface (e.g. revegetation during the operation is unnecessary, highwall stability problems are eliminated).

13) Generally greater acceptance by local communities, special interest and environmental groups because of the “out of sight, out of mind” concept.

14) Property limits of a surface operation are reached.

15) Correctly handling specific, independent environmental hazards may be assigned probabilities of success, and multiplied together to determine the likelihood of success or failure for an operation to stay on the surface or progress underground. If the overall probability of failure is not acceptable to a surface operator, then steps toward underground production may begin.

Based on experience from people interviewed, it is recommended that the
probability of failure be less than 25%.

6.2 Expected Differences Between Surface and Underground Operations

The conclusions of this section represent the differences that would be expected if an operator were to change from a quarry to an underground mine.

1) The drilling and blasting phase of surface and underground operations are radically different, illustrated in Figure 6.1.

2) Haul distances in underground mines will become significantly longer than in surface quarries as mining advances (see Figure 6.1).

3) Underground mines will have more personnel in the workforce.

4) Mining underground allows for multiple shifts to be worked each day, allowing greater hours spent in production.

5) The haul trucks used in an underground mine are smaller than those in a surface quarry and fewer in number, due primarily to space limitations.

6) Underground mines blast more often due to the smaller area involved.

The goal of this research was to quantify the factors that influence the decision for a surface quarry to transform into an underground operation, and to present the differences of equipment, personnel and other physical factors that exist between the two types of operations. Although these fac-
Figure 6.1  *Actual Mining Sequence Differences*  
Mining sequence representing the actual differences between surface and underground production phases, based on the collected data.
tors will vary due to the site-specific nature of the industry, but the data collected in this study provides valuable guidelines for typical operations that would be expected in the region of study.

It is recommended that future work in this area should concentrate on three topics. The first of these concerns the actual costs involved with the transition from surface to underground production. Comparing the approximate costs involved with the change to underground mining to the possible long-term profits of underground mining would benefit an operator for both short and long-term planning. Ideally, this would be accomplished utilizing an actual case study where a surface operation is or has proceeded underground.

The second topic concerns the human factors involved in the alteration of a quarry to underground mining. The sentiments of the local communities involved, for both rural and urban settings and including the general public along with local authorities, should be evaluated and studied to determine anticipated reactionary guidelines for current quarry operators.

The final recommended topic for study is in the determination of accurate probabilities for environmental hazards. This information may be quantified on the basis of regions. In this way an operator in a specific region may have an idea of what the probabilities of success or failure would be for environmental hazards likely to be encountered.
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VIII. VITA

Scott Gavin Haycocks was born on November 29, 1964, in Oklahoma City, Oklahoma. In 1969, his parents moved to Blacksburg, Virginia, where he graduated from Blacksburg High School in 1983. He spent the next four years attending the University of Virginia in Charlottesville, Virginia, graduating in 1987 with a B.A. in Environmental Science. In the fall of 1987, he was enrolled in Radford University in Radford, Virginia, to obtain his high school teaching credentials. In July of 1988 he married, completed his teaching certificate requirements, and moved to Chapel Hill, North Carolina. After working in North Carolina for over 2 years, he returned to Blacksburg where he was enrolled in the Master's Degree program in the Mining and Minerals Engineering Department of Virginia Polytechnic Institute and State University. He will complete all requirements for the Master of Science Degree in Mining Engineering during the fall semester of 1992.