RI 9404

REPORT OF INVESTIGATIONS/1992

Geotechnical Aspects of Roof and Pillar Stability in a Georgia Talc Mine

By Noel N. Moebs and Gary P. Sames

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Report of Investigations 9404

Geotechnical Aspects of Roof and Pillar Stability in a Georgia Talc Mine

By Noel N. Moebs and Gary P. Sames

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Moebs, Noel N.
Geotechnical aspects of roof and pillar stability in a Georgia Talc Mine / by Noel N. Moebs and Gary P. Sames.

p. cm. — (Report of investigations; 9404)

Includes bibliographical references (p. 28).

Supt. of Docs. no.: I 28.23:9404.

1. Talc—Georgia. 2. Mine roof control. I. Sames, Gary P. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9404.

TN23.U43 [TN948.T2] 622 s—dc20 [622'.3676] 91-23341 CIP

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS—Continued

TABLE

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

deg	degree	μm	micrometer
ft	foot	pct	percent
in	inch	psi	pound per square inch
lb	pound		

GEOTECHNICAL ASPECTS OF ROOF AND PILLAR STABILITY IN A GEORGIA TALC MINE

By Noel N. Moebs[1] and Gary P. Sames[1]

ABSTRACT

This report summarizes a U.S. Bureau of Mines study on the application of geotechnology to identify and minimize ground control hazards in talc mining operations in northwest Georgia. The major ground control hazard is pillar sloughing attributed to the steeply dipping orientation of a pronounced foliation in the talc ore body. The sloughing problem, which gradually reduces the effective support area of a pillar through attrition, can be minimized by appropriate artificial support, as determined by a rock classification system, and by a more uniform pillar design. A boundary element model confirmed the advantages of using a uniform pillar design to avoid excessive loads on portions of irregular pillars. Instrumentation to measure roof convergence and pillar loading was installed at selected locations in an active talc mine but failed to detect any significant changes, suggesting that the gneiss hanging wall constitutes a strong roof that probably can support large spans between pillars and permit high extraction ratios. This interpretation also is supported by a rock classification of the hanging wall gneiss.

[1]Geologist, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Talc is used by many branches of industry whose number is steadily increasing. It has many advantageous properties: softness and high coating ability; a high melting point; chemical inertness; low electric conductivity; a high absorption capacity for fat, colors, oils, and resins; a very low hygroscopicity; and a pure white color.

In the United States in 1987, talc was produced from 34 open pit and 4 underground mines in 9 States (*1*).[2] This production included soapstone, a massive variety of talc. Ten of these mines, operating in California, Montana, New York, Texas, and Vermont, accounted for 71 pct of all domestic talc production. Montana led all States in the tonnage and value of talc produced, followed by Texas and Vermont. Over 90 pct of production in the United States came from open pit operations.

By 1989, of 23 producing talc mines in 10 states (fig. 1), 8 were active underground operations (*2*). Three of the eight underground talc mines were located in Georgia. Depending on the geologic setting, underground mining is an option that is becoming increasingly popular with producers of stone products (*3*), although many factors must be investigated before planning underground talc mining. The application of continuous mining machines such as the Dosco Mark II[3] or the Alpine F-6-A to underground talc mining has facilitated selective mining, reduced the damage to hanging walls and foot walls by blasting, minimized support requirements, and provided an essentially precrushed ore to the mills (*4*). Thus, underground mining of talc may experience broader application as soon as some of its advantages are evaluated.

Talc has been produced from the talc deposits of Murray County, GA, since 1872 (*5*). Large reserves of commercial-grade talc sufficient for years to come probably remain. The main talc-producing area is situated a few miles east of Chatsworth in Murray County and extends

[2]Italic numbers in parentheses refer to items in the list of references preceding the appendix.

[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

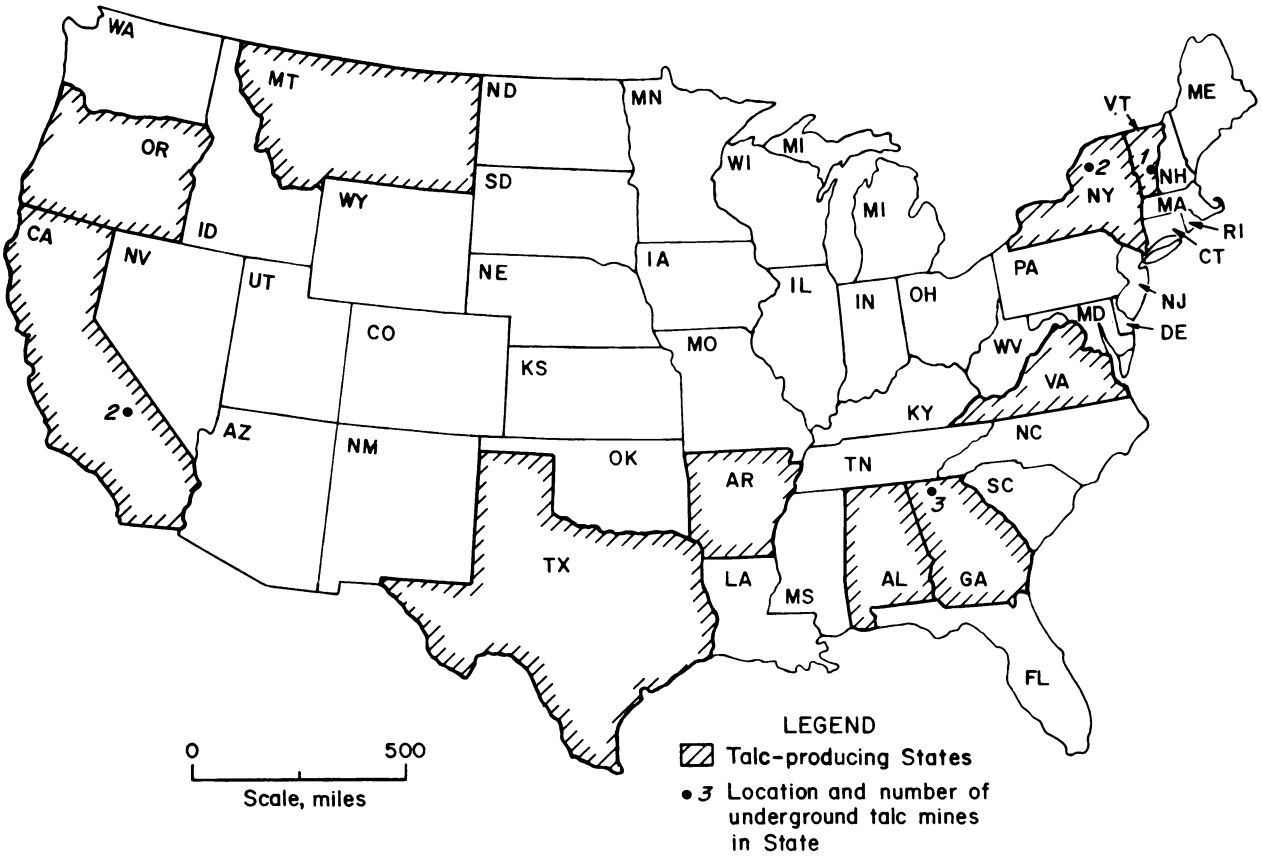


Figure 1.—Talc-producing States.

for about 6 miles along a north-south trending belt of metamorphic rocks. Production from this district was relatively small until the 1930's, when it began to increase significantly. Four active underground talc mines were reported in 1947, along with 11 prospects or intermittently operated mines. In 1989, three underground mines were being operated with modernized facilities. One of these mines, the Earnest Mine, is the subject of this report.

As with most mines that are opened from outcrop by a drift or adit, some artificial support is required in the portal area, because weathering, water, and fractures commonly weaken the roof or hanging wall rock. These conditions prevail even in the resistant gneiss usually encountered in the early development of Murray County talc mines. As mining progresses farther underground, conditions generally improve. However, in 1932 at least one of the talc mines reportedly was abandoned because of so-called heavy ground conditions. These conditions could have resulted for a variety of reasons, including highly foliated and slickensided rock, poor scaling practices, absence of artificial support such as rock bolts, or deterioration of the pillars and roof because of excess roof span and inadequate pillar support. In that early era of mining, especially in smaller mines that attempted selective mining, little attention was given to systematic mine development or pillar design. Numerous studies in the last several decades have led to a much improved understanding of mine design principles, the distribution and magnitude of rock stresses, and the role of geologic structures in assessing roof and pillar stability. Unfortunately, studies of ground control in underground talc mines are virtually nonexistent. Because of this lack, the unusual physical properties of talc ore, and the contrasts between the ore and the hanging wall or footwall, any attempt to assess potential instabilities and hazards must involve much preliminary work to establish some background information.

In addition to meeting safety standards mandated by Federal and State regulatory agencies, a modern mining operation must practice a high level of ore extraction to operate efficiently and profitably, preserve diminishing resources of high-grade ore, and remain competitive in the world market.

Until recently, the talc mining industry had received little attention because priorities and national interests had turned to the state of the economy, strategic minerals in time of war, environmental protection, and other issues. The United States, however, has continued import duties on talc minerals and at the same time has maintained a small stockpile of both lump and ground talc for national emergencies.

Recently there has been a renewed interest in promoting health and safety technology in the mining industry through research. The U.S. Bureau of Mines, which is responsible for a broad spectrum of programs for improving mining technology, recognized that the talc industry was in need of up-to-date safety technology and production methods, particularly methods dealing with mine design and hazard avoidance.

In response, the Bureau conducted a reconnaissance of the talc mining operations in Georgia and selected the Southern Talc Co.'s Earnest Mine in Murray County as an appropriate site at which to attempt a geotechnical assessment of potential pillar and roof instability.

BACKGROUND

COMPOSITION AND PROCESSING OF TALC ORE

The mineral talc, a soft, hydrous magnesium silicate, is formed through hydrothermal alteration of ultrabasic rocks or the low-grade metamorphism of siliceous dolomite. Talc ore generally consists of a mixture of minerals, including talc, chlorite, dolomite, and serpentine. A large number of accessory minerals in small to minute quantities usually accompany the talc ore. These include antigorite, chrysolite, picrolite, amphibole, actinolite, magnetite, chromite, quartz, zircon, and various feldspars. A high-grade talc ore should consist of at least 80 pct talc.

The mineral content of talc ore is very important because it usually dictates the end use. The following categories of talc are determined by the mineral content and the amount of processing required before marketing:

Ceramic	Less than 325 mesh; low iron, manganese, aluminum, and calcium content; no discoloration during firing.
Cosmetic ...	Less than 200 mesh, free of gritty material, less than 6 pct acid-soluble minerals, no amphiboles, consistent color.
Insecticide ..	Specifications vary.
Paint	Relatively fine particle size of 98.5 to 99.5 pct through a 325-mesh screen generally required.
Paper	White, nonabrasive, chemically inert, ultrafine particle size.
Plastic	Specifications vary.
Roofing	Minus 80 mesh, high absorbency.
Rubber	Particle size less than 45 μm, no abrasives.
Sculpturing and crayon.	Less than 1 pct impure, free of cracks, apple-green color preferred.

After mill-run ore is reduced in a jaw crusher, roller mills commonly are used to produce the next stage of the product. Subsequent use of air classifiers yields a particle size of 5 to 10 μm, or 0.00004 in. If extreme white color is desired, ceramic grinding media are used to avoid contamination by metals. Some of the newer talc mills use froth flotation, sedimentation, hydrocycloning, dry and wet magnetic separation, centrifugal sizing, and spray drying. One of the earliest examples of froth flotation processing in the talc industry was a result of Bureau studies (*6*). A commercial processing plant using froth flotation was developed in 1938 and installed at a talc mining operation in Vermont. In some talc processing, shaking tables are used to remove high-gravity products containing nickel, iron, and cobalt.

TALC MINE DEVELOPMENT IN MURRAY COUNTY, GA

Talc in Murray County, GA, was first discovered and mined in the late 19th century. Only crayon talc was sought after. Early mining was confined to shallow pits along outcrop, and the ore was of poor grade.

Beginning around the turn of the century, underground mining was practiced to obtain a better grade and less weathered ore. Generally, in underground mining, an adit is driven into the footwall of the talc lens (fig. 2) so that the ore body is encountered well below the weathered and stained zone. These nearly horizontal adits generally are driven in a footwall of granite gneiss. After the talc ore body has been encountered, a main inclined haulage or slope is driven down into the ore body at varying grades, depending on the method of haulage.

Formerly, levels were driven from the slope from which overheading stoping was practiced, principally for selectively mining crayon-grade talc. The thickness of the ore bodies and thus the height of the stopes range from 5 to 25 ft. In 1946 the Georgia Department of Mines, Mining, and Geology conducted a study of the Murray County talc industry (*7*) in which the geology of the talc deposits was emphasized as a means of improving the efficiency of the mines and mining in a more systematic manner. Recent mining methods include enlarged entries to accommodate diesel trucks and loaders and drilling and blasting an entire entry face or bench. Rapid analysis of bulk samples from each round permits blending of ore during loading and provides a basis for limited selective mining.

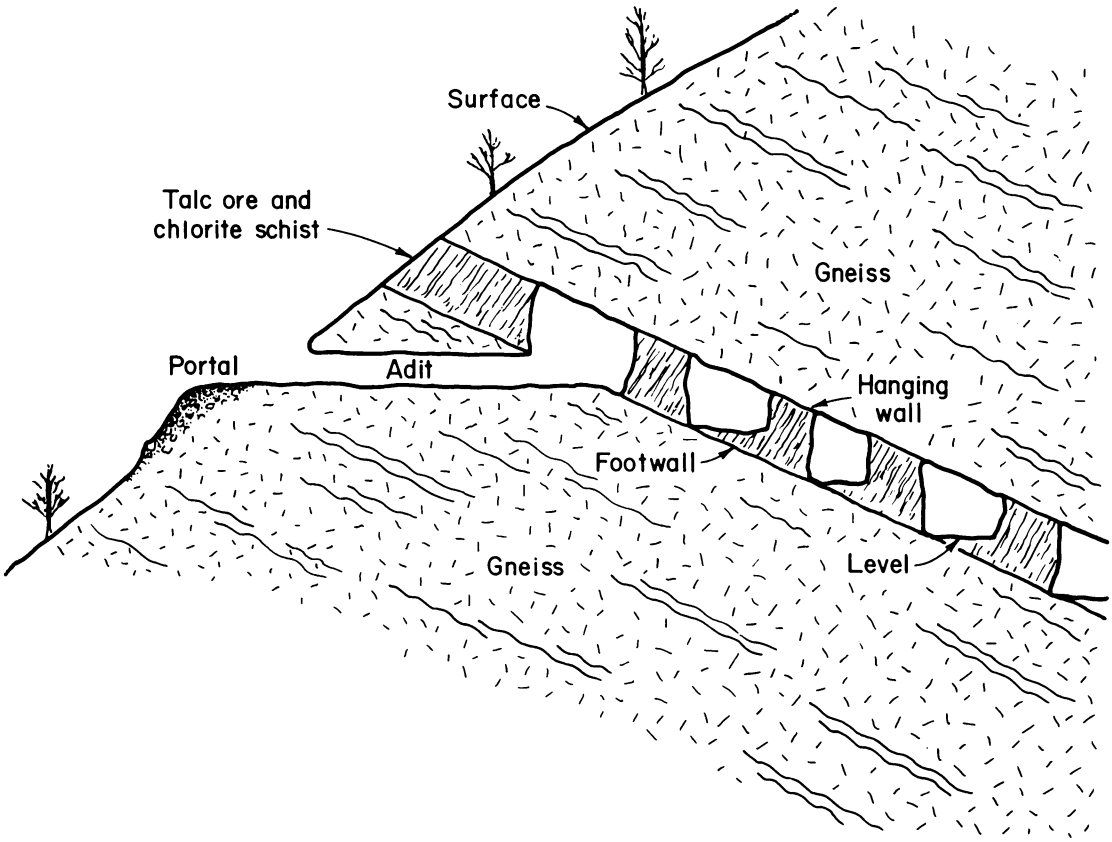


Figure 2.—Typical method of developing an underground talc mine in northwest Georgia.

Mines are developed in a somewhat random manner in that no uniform pillar plan is followed. This method of extraction can best be termed either "room-and-pillar" or "open stope" mining. Generally, oversized pillars containing good grade ore are later split or reduced in size.

Since most mine adits are initially in the granite gneiss footwall of the ore body, the rock requires little artificial support except at the portal. On encountering the talc ore body, conditions change abruptly because of the highly foliated, soft, and distorted character of the ore. Scaling of roof and ribs is essential in preventing falls of rock. Despite this precaution, wedges of rock occasionally become dislodged and fall from the roof or pillars without warning, even though they appear sound when the roof is scaled. Needham and Hurst (*8*) cite at least two Murray County talc mines that were abandoned because of heavy ground and hazardous working conditions. Major rock falls occur chiefly when large wedges or slabs of talc ore remaining in the gneiss roof become detached or when rock works loose from the pillars, generally along planes of foliation (fig. 3). These falls of rock are attributed to blasting vibration, mining-induced stresses, or atmospheric moisture effects on slickenside surfaces. A roof bolting plan is not a standard practice in the talc mines, but spot bolting along haulageways is used as needed.

EARNEST MINE DEVELOPMENT

The Earnest Mine is an extension of some older workings in the talc-rich portion of the Cohutta schist occurring on the northwest slope of the Fort Mountain. There is some evidence to suggest that before 1900 some talc was mined at this site by means of shallow pits on the surface. Beginning in 1939 or possibly earlier and continuing until 1946, an exploration adit was driven into the talc ore body and some crayon talc for use in the shipbuilding industry was mined. These workings were named the "Fort Mine" or "Fort Mountain Mine." Some development and production was continued sporadically from 1946 to 1950. The mine was inactive from 1950 to 1957.

A new portal was opened in 1962 adjacent to the Fort Mine. These new workings were named the "Earnest Mine" and connected with the old Fort Mine, although at a somewhat lower level, in the same lens of talc. The

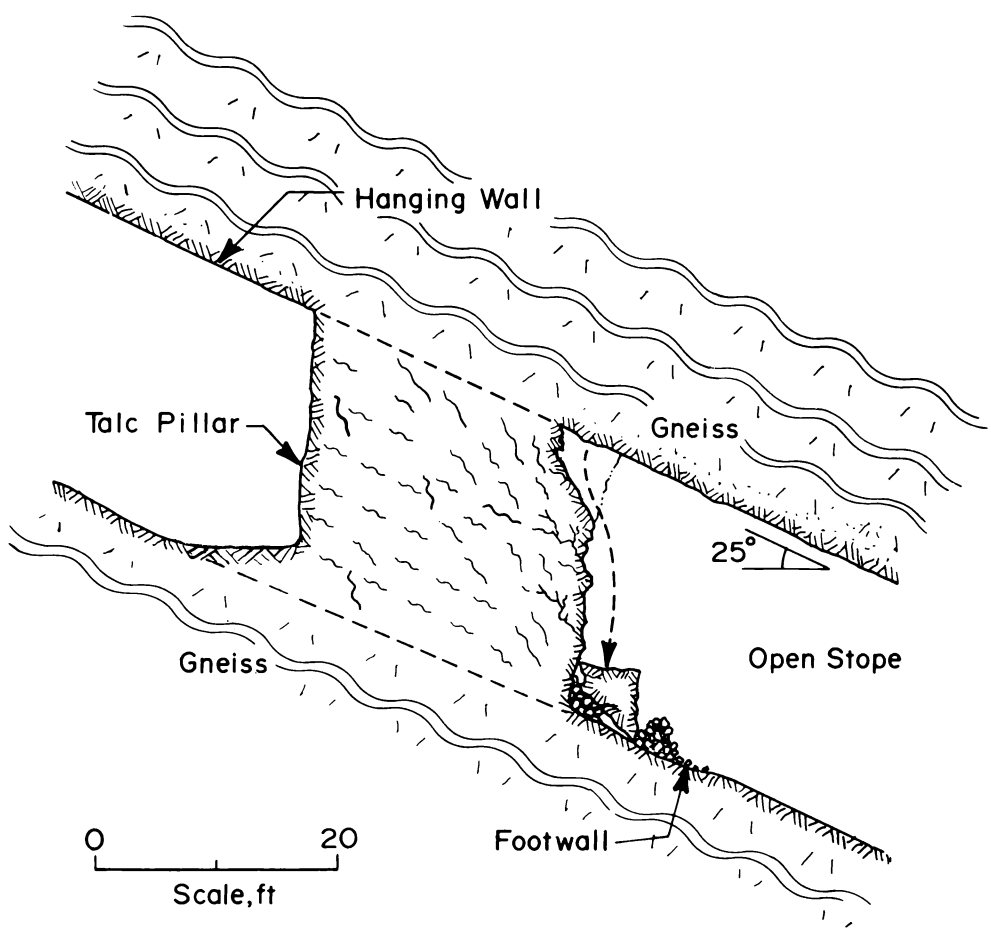


Figure 3.—Schematic of incipient pillar failure.

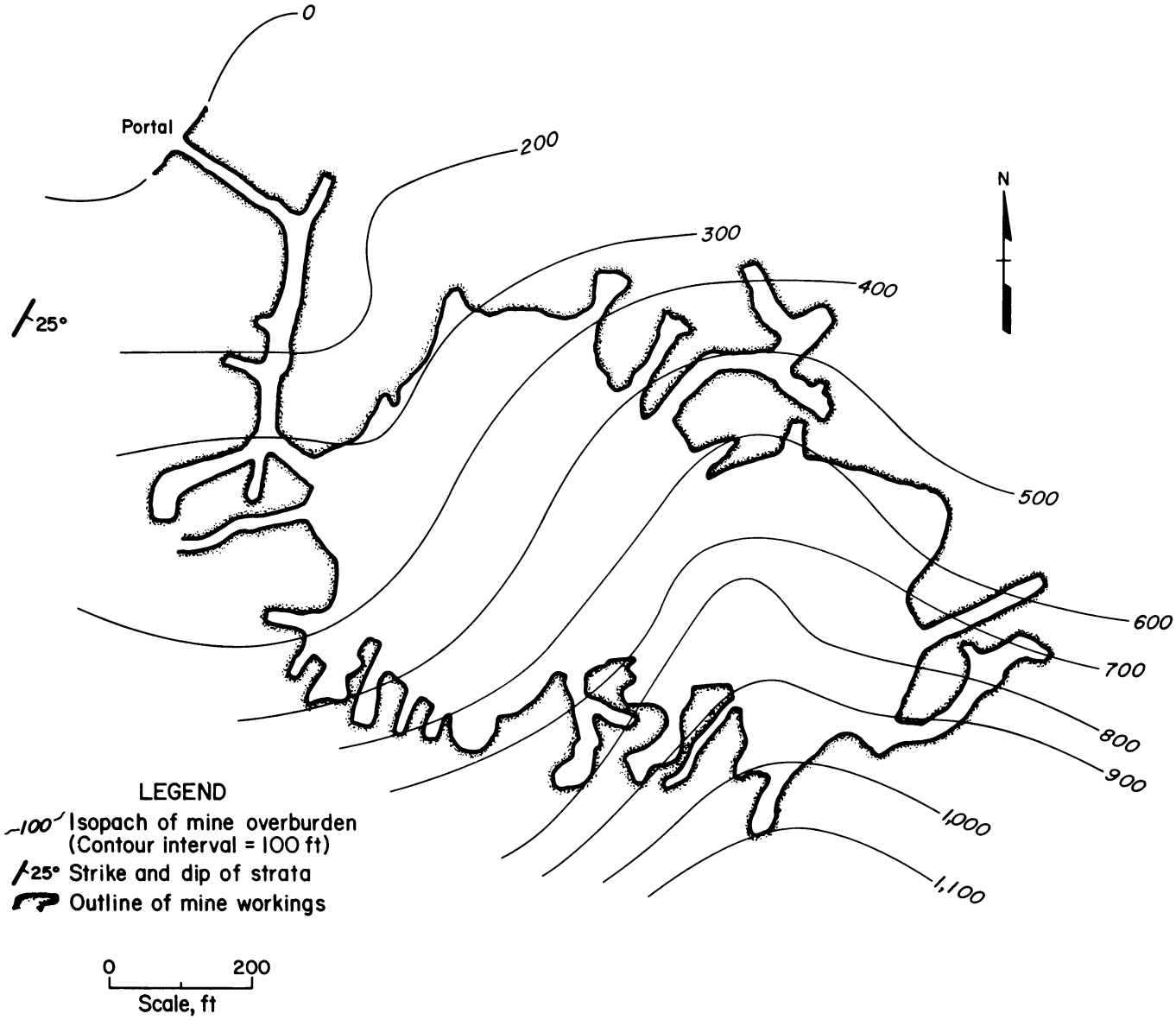


Figure 4.—Isopach map of mine overburden.

Earnest Mine produced on a regular basis from 1960 to 1978. Some talc also was produced intermittently from the old Fort Mine from 1965 to 1973.

Development of the Earnest Mine and intermittent production continued during 1979-81. The mine then was inactive until the spring of 1986, when regular production was resumed from the upper levels. By 1989, production was coming from several different levels of the mine. The mine now extends over an area of about 800 by 1,200 ft and has reached a depth of 1,100 ft below the surface (fig. 4).

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Southern Talc Co. and its staff for providing assistance in test procedures and for unlimited access to their mines.

SCOPE OF INVESTIGATION

This investigation consisted of the following activities:

1. Examining the geologic structures exposed in the mine and relating them to potential rock fall hazards.
2. Determining the physical properties of the hanging wall rock and talc ore.
3. Installing load cells in selected talc ore pillars and placing roof convergence stations.
4. Constructing a preliminary boundary element model of stress conditions in the mine.
5. Determining rock quality and support requirements.

The study was conducted over a period of approximately 18 months during which several large talc pillars were split, a small pillar was completely removed, and several development entries were advanced. These activities did not progress to the extent that would constitute a high level of extraction (for example, greater than 60 pct); nonetheless, the measurements and observations obtained from this study provided some indications of the response of the surrounding rock to the removal of talc ore. A suggested uniform pillar plan was devised as a substitute for the somewhat random method of mining that has been practiced in the district for almost a century, while recognizing that such a plan is not always viable because of the necessity to mine selectively at times. It is hoped that some of the findings from this limited study might be applicable to either other talc mines in the district or mining operations other than talc in a similar metamorphic rock setting.

GEOLOGIC SETTING

The Earnest Mine is located near Chatsworth, Murray County, GA, in the northwest portion of the State (fig. 5). Talc mines in this district lie along a north-south trending zone of reverse faults (fig. 6) along which Precambrian granite gneiss and Lower Cambrian sandstone, conglomerate, and slates have been thrust westward over younger shales, limestone, and dolomite. The resistant rocks of the thrust sheets have resulted in the Fort and Cohutta Mountain chain, a southward extension of the Blue Ridge Mountains of Virginia and Tennessee. This mountain chain separates the folded and faulted stratified rocks to the west from the largely crystalline rocks to the east.

All known commercial occurrences of talc in Murray County, GA, are located on the northern, western, or southern slopes of the Fort and Cohutta Mountain chain. The gneiss that constitutes these mountains dips about 25° eastward (fig. 7). The talc deposits almost always occur in Cohutta schist, a quartz-biotite-chlorite schist that has been altered in part to talc and serpentine. The Cohutta schist occurs chiefly as tabular or lenticular bodies within the thrust sheet of the Fort Mountain gneiss, and the schist probably was emplaced within the gneiss along thrust planes. The exact structural relation of one talc occurrence to another is uncertain: Outcrops of the talc are very sparse since much of the Fort Mountain gneiss is covered by talus. The distribution of the talc ore bodies, however, suggests that they occur intermittently and at different levels along the strike of the wedges of Cohutta schist included within the Fort Mountain gneiss.

The origin of the talc still has not been entirely resolved. Hopkins (*9*) in 1914 supposed the talc to be derived from igneous rocks, while Furcron and Teague (*5*) thought the talc was formed by metamorphism of dolomite lenses in the Cohutta schist.

The internal structure of most talc ore bodies is complicated by pronounced foliation, shears, slickensides, and distorted banding. In addition to zones of chloritic schist associated with the talc, lenses or masses of serpentine and

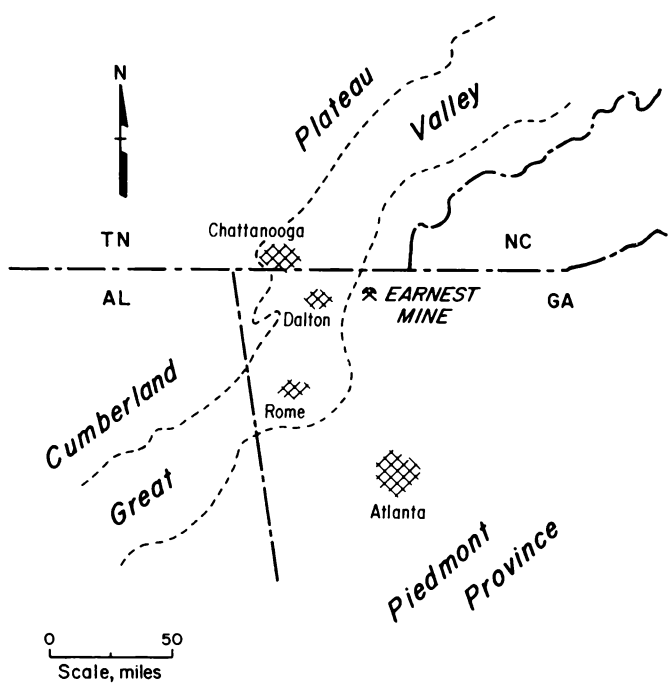


Figure 5.—Study area.

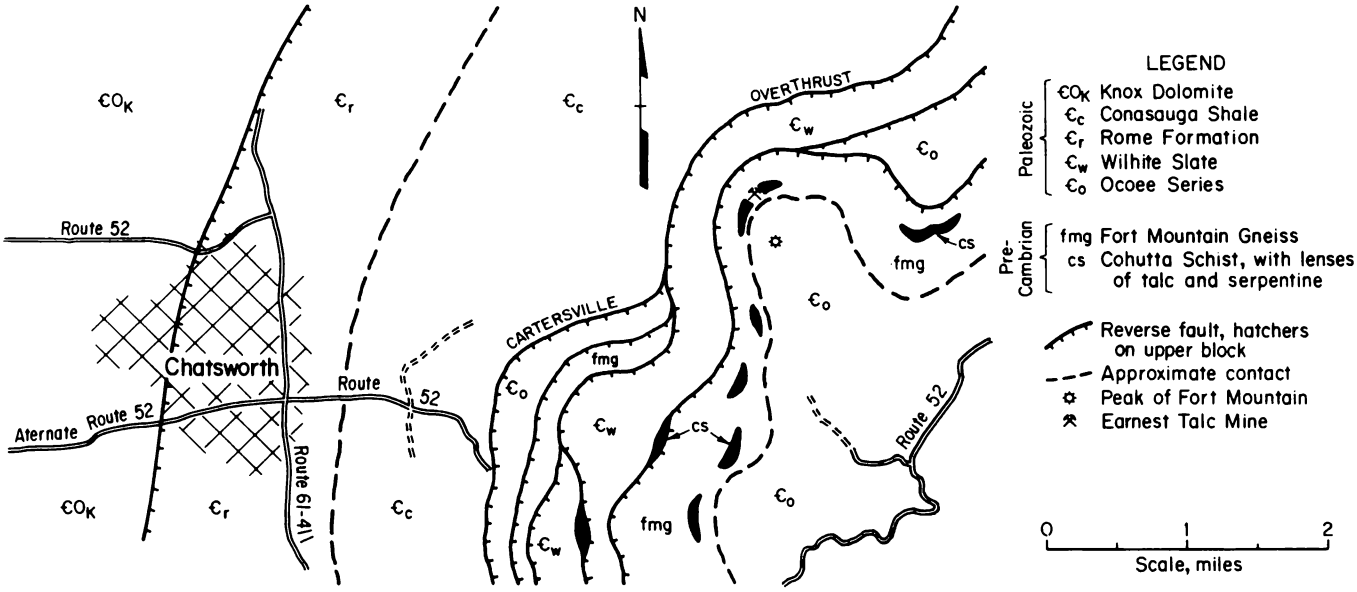


Figure 6.—Fault structures in talc district of northwest Georgia.

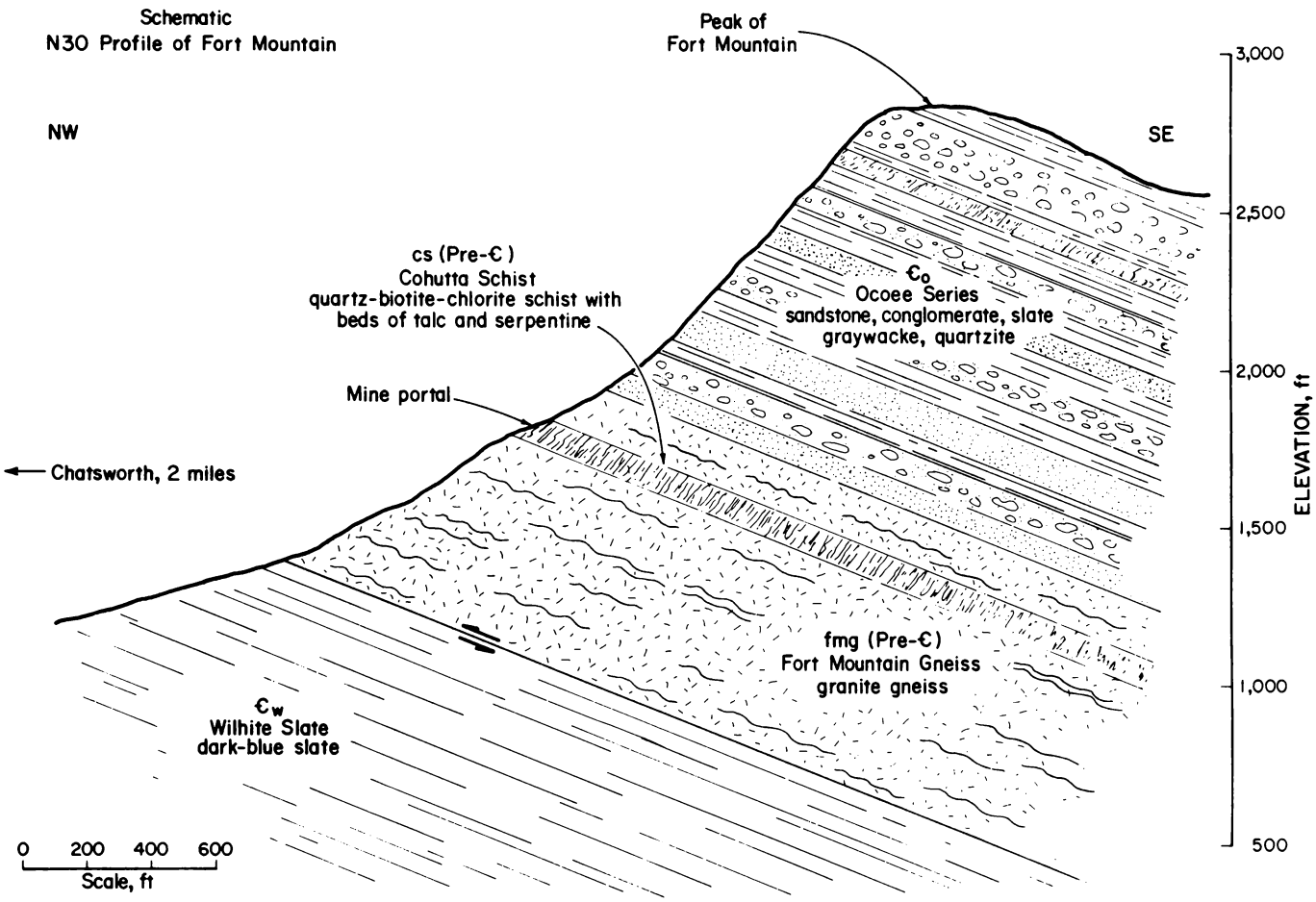


Figure 7.—Profile of Fort Mountain thrust block.

secondary dolomite commonly 6 to 25 ft long are present in most of the mines, sometimes together in the same mass. These inclusions are surrounded by highly slickensided schistose talc.

In some of the mines in this district, lenses of Fort Mountain gneiss occur within the talc ore bodies, probably intruded into the ore along thrust faults. However, because slickensides and foliation are so pronounced and key beds are absent, no definite displacement can be recognized. Similarly, large bodies of slickensided serpentine—some more than 100 ft long—occur within talc ore bodies; these bodies of slickensided serpentine are attributed to some sort of fault displacement, drag, or rotation during deformation of the surrounding rocks.

At the Earnest Mine, the strike and dip of the talc foliation is highly variable and is largely independent from the attitude of the hanging wall of Fort Mountain gneiss. The dip of the foliation averages about 33°, while the dip of the hanging wall ranges from 15° to 33° and averages about 25°.

CHARACTER OF FORT MOUNTAIN GNEISS HANGING WALL

The Fort Mountain gneiss is variable in character in the hanging wall of the mine but generally consists of an albite-quartz-biotite granite gneiss. Locally, it is highly schistose along biotite-chlorite-rich bands (fig. 8), or it exhibits a pronounced augen texture in the granite gneiss.

The augen gneiss phase of the hanging wall is well developed and exposed at several places in the mine roof (figs. 9-10), while rolls, shears, and irregular foliation in the schistose zone of the hanging wall are illustrated in figures 11 and 12.

Much of the hanging wall consists of augen gneiss, representing either a relic structure after an igneous porphyritic granite or feldspar porphyroblasts that have grown during metamorphism.

Quartz, calcite, and dolomite veinlets are scattered throughout much of the gneiss. In thin section the quartz grains exhibit granulation and wavy extinction indicating strong deformation. The thickness of the gneiss above the talc ore body is estimated to be about 150 ft. Gneiss also constitutes the footwall of the talc ore body.

CHARACTER OF TALC ORE

The talc ore consists chiefly of the mineral talc, a hydrous magnesium silicate, along with varying amounts of chlorite, dolomite, and serpentine. These minerals are often indistinguishable in the mine when fine grained and must be identified by laboratory methods. The ore ranges in color from an opaque dark gray to a translucent light green. The texture of the ore seldom is homogeneous but generally shows a thin banding of alternating light and dark colors or flecks of dark material arranged along the bands.

The intense deformation and metamorphism of the ore has resulted in strongly developed foliation. This foliation generally is parallel to the thin textural banding. The structural attitudes of the foliation and banding are highly irregular as a result of the deformation of the ore body. Small-scale drag folds, crenulations, slickensides, boudins, and flexural folds are common throughout the ore body (fig. 13). Jointing is only very locally developed.

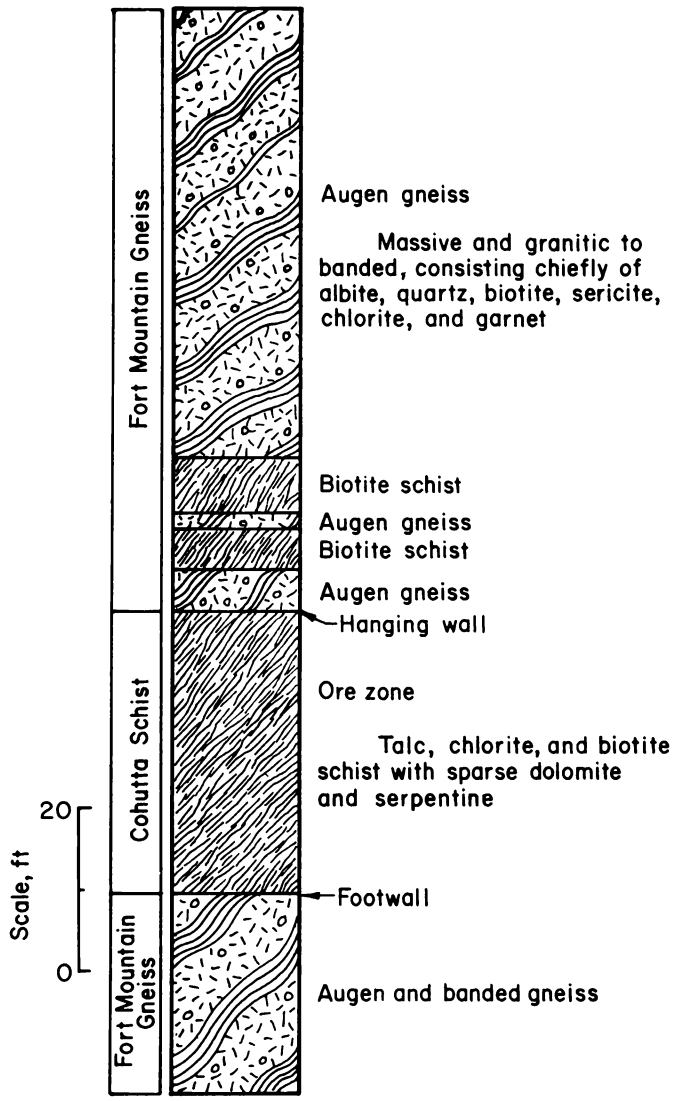


Figure 8.—Generalized stratigraphic column of talc district.

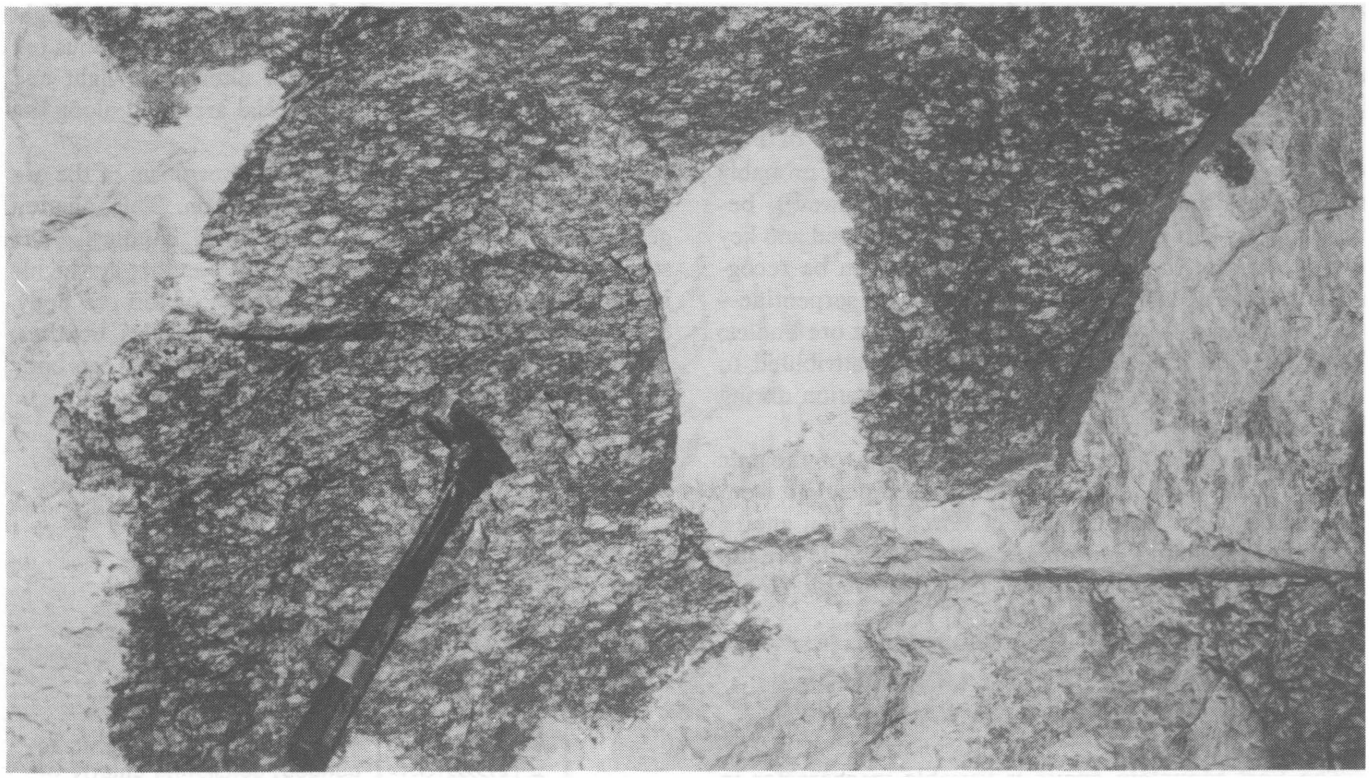


Figure 9.—Augen gneiss in Earnest Mine hanging wall.

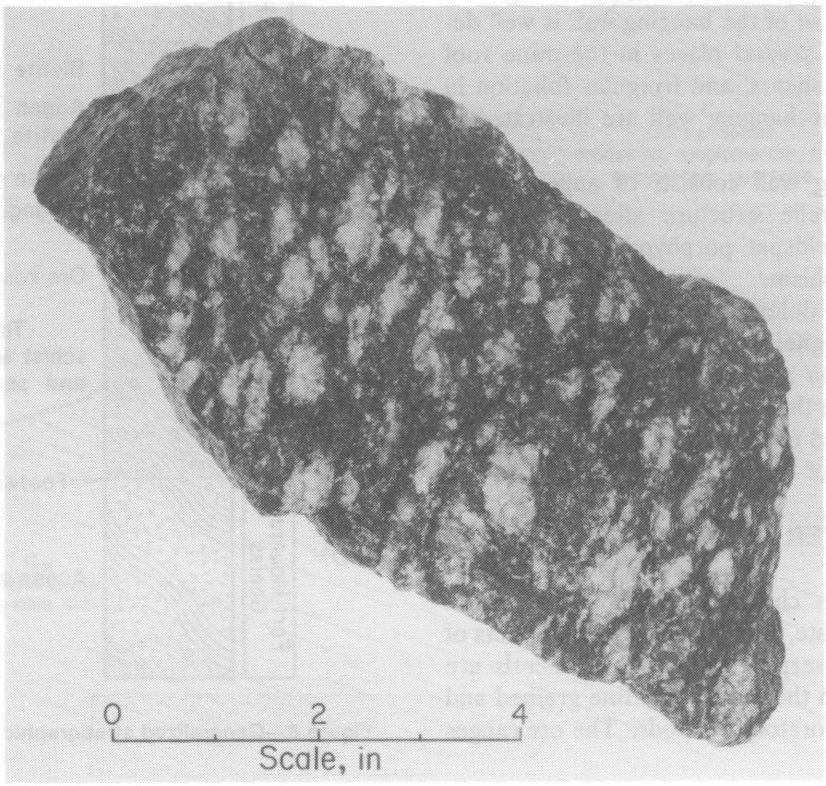


Figure 10.—Texture of hanging wall augen gneiss.

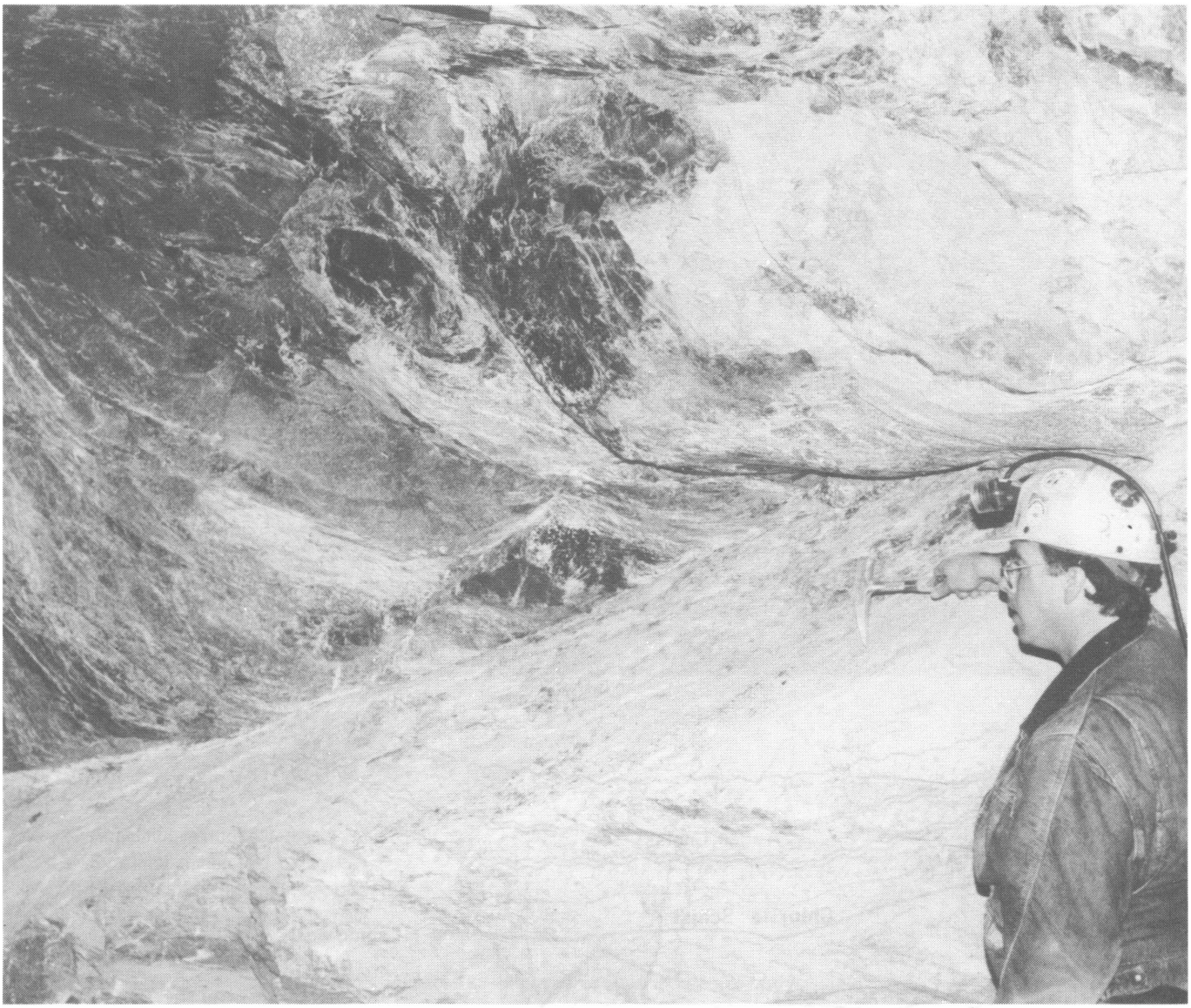
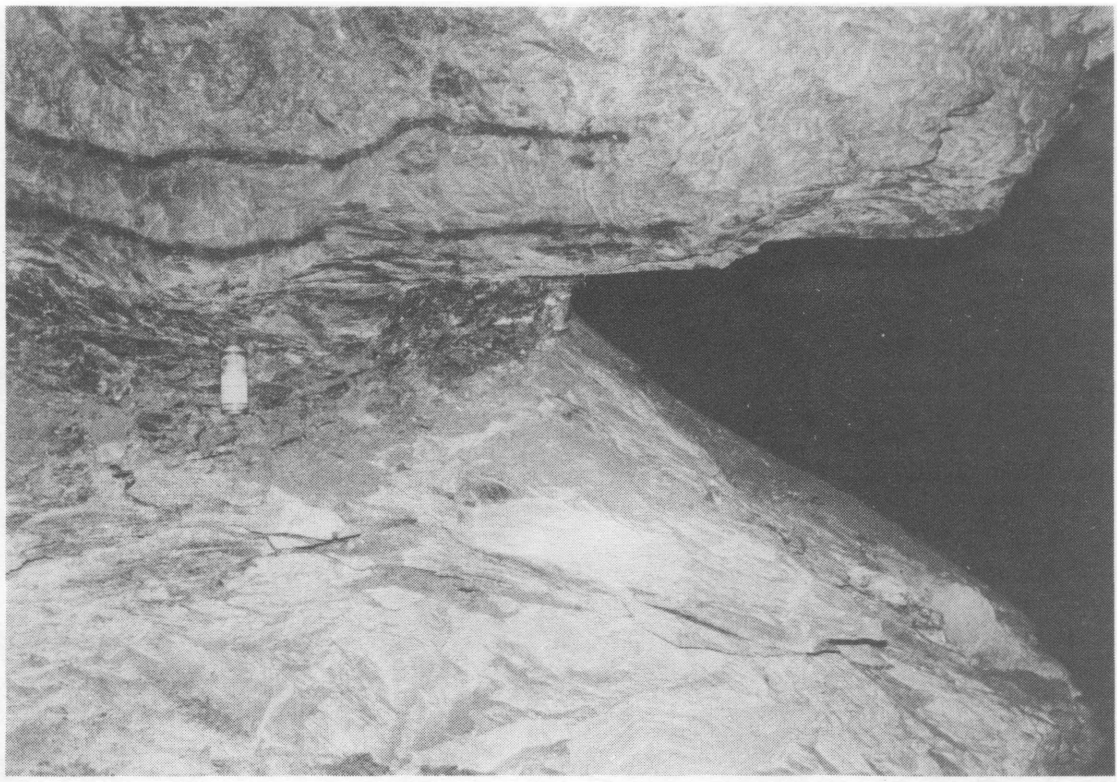


Figure 11.—Roof roll in hanging wall schist of Earnest Mine.



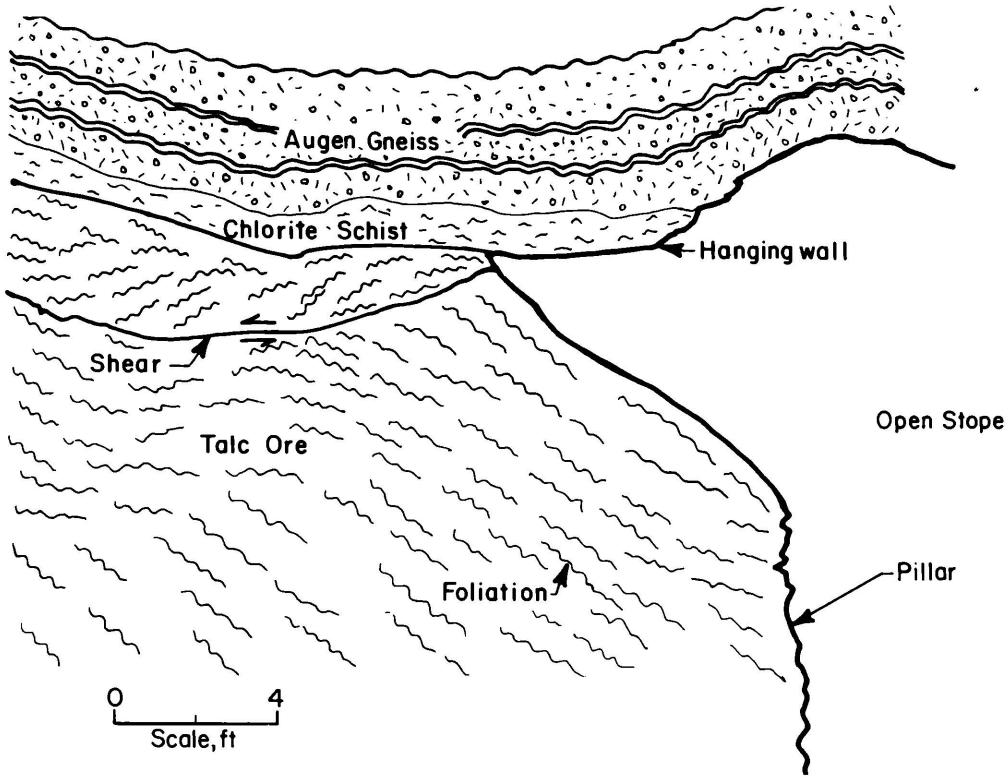


Figure 12.—Photograph (above) and sketch (below) illustrating structure in hanging wall.

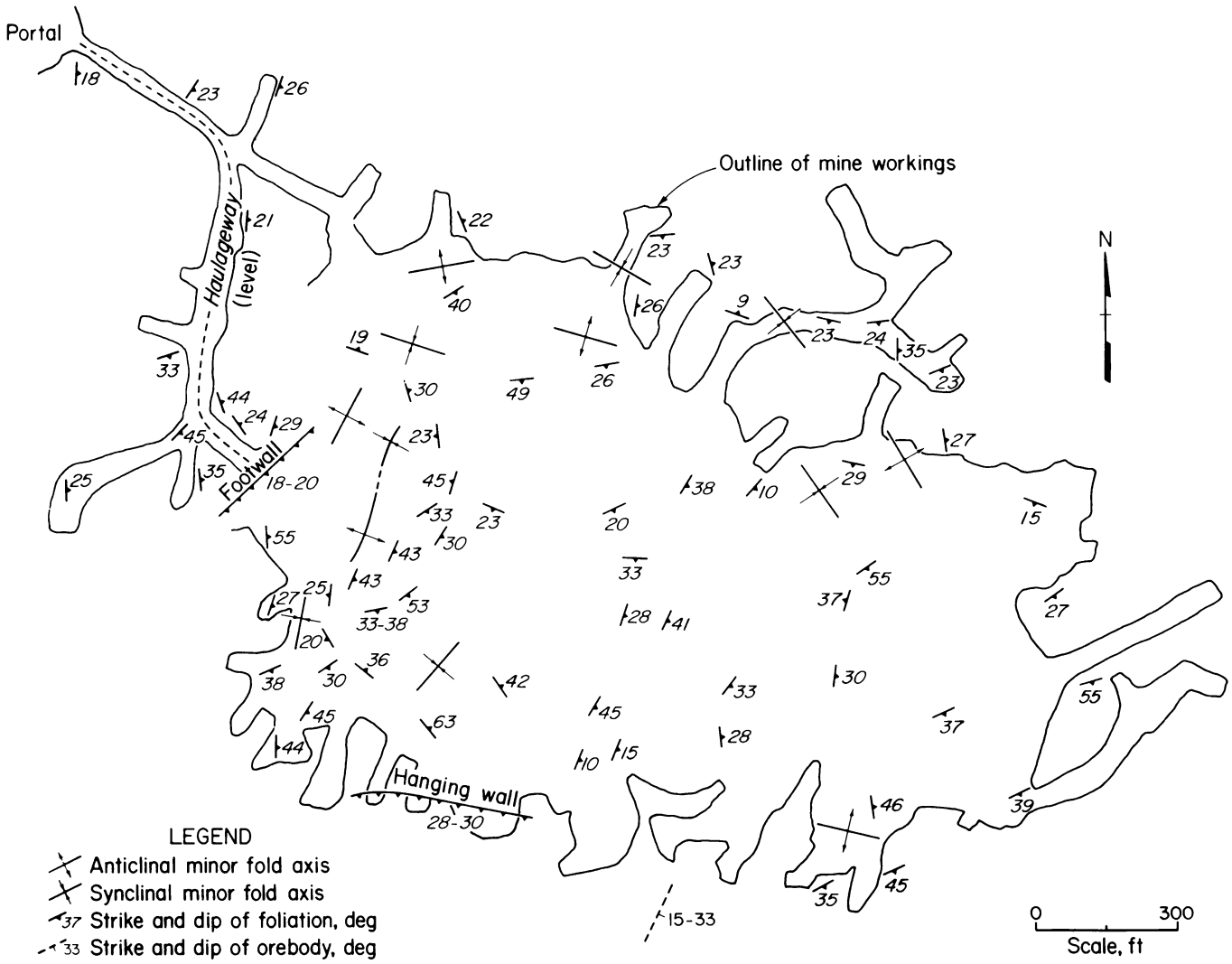


Figure 13.—Minor structures in talc ore body.

The highly developed foliation overshadows all other geologic features in determining rock stability in the mine. The foliation provides numerous planes of weakness along which rock movement tends to occur in the absence of any constraints. However, erratic and abrupt changes in the attitude of the foliation almost preclude a uniform pattern of artificial rock support and, instead, suggest that selective spot bolting might prove more effective in controlling rock movement.

ROCK STRENGTH TESTING

A knowledge of the basic physical properties of the rock and ore in a mining environment is always helpful in assessing the stability of a mine opening and is essential in developing a detailed boundary or finite element model of a mine. Physical properties such as compressive strength are an indicator of the overall strength of a rock and are factors in determining optimum pillar size and roof span.

The importance of physical properties, however, can be greatly overshadowed by structural geologic discontinuities such as shears, slickensides, faults, and foliation. When

these features occur in a disorganized profusion, as is common in Georgia talc mines, the features are very time consuming and difficult to map or record and evaluate. Thus, determining physical properties, such as compressive strength, which can easily be measured on samples of core, seems to offer quick results for analysis. However, physical properties alone must be used with caution, as they commonly are not truly representative of rock mass strength or character.

CORE SIZE EFFECT

Table 1 summarizes the results of a limited number of tests that were performed on drill core samples from the Earnest Mine of two different diameters. As expected, values were far ranging, because neither the gneiss hanging wall nor the talc ore are uniform in character but can vary both in composition and structure. This variation probably explains why the average compressive strength for schistose roof rock (16,070 psi) is greater than for the seemingly stronger gneiss (13,530 psi). In addition, core size can lead to different test results. For example, table 1 shows a pronounced size effect in the talc core when the test results are grouped by core diameter. The size effect ratio of over 2:1 for small versus large core diameter is greater than was anticipated but could be attributed to the unique character of the talc ore from this location.

Table 1.—Compressive strength of talc ore and roof rock, pound per square inch

Material	Average	Range	SD
Talc ore:			
1.25-in-diam core	9,660	2,540-15,510	4,500
1.88-in-diam core	4,380	1,250- 6,760	2,280
Average	6,820	1,250-15,510	4,310
Roof rock:			
Augen gneiss[1]	13,530	4,890-21,360	5,810
Biotite schist[1]	16,070	10,710-23,600	5,450

SD Standard deviation.
[1]1.88-in-diam core.

FOLIATION ORIENTATION EFFECT

The predominant foliation in the talc ore probably plays a large role in the strength of pillars at the Earnest Mine. Observations at the mine suggest that increasing the foliation dip relative to the plane of the ore horizon tended to promote deterioration and loss of strength in the talc pillars. Bureau researchers studied a similar strength problem in rocks containing a single predominant weakness plane (*10*), and found that the orientation of this weakness plane relative to the loading direction had a strong effect on the rock strength. Their testing program determined the strength of axially loaded rock cores containing a single dominant weakness plane of various orientations relative to the loading axis. When the weakness plane was oriented 0° to 30° to the loading axis (essentially parallel) or 60° to 90° to the axis (essentially perpendicular) the strength was considerably greater than the strength when the weakness was 30° to 60° to the loading axis. The magnitude of this strength differential depended on the shear strength properties of the weakness plane.

To examine the effect of foliation orientation on the strength of talc pillars, a simple laboratory testing program was conducted on 23 talc cores with three foliation orientations relative to the specimen axis (fig. 14). In the first group, foliation was parallel (0° to 15°) to the core specimen axis and loading axis; in the second group, foliation was 45° (30° to 55°) to the specimen axis and loading axis; and in the third group, foliation was perpendicular (75° to 90°) to the specimen axis and loading axis.

The strength tests were conducted using a 1-million-lb "stiff" Materials Testing System loading system operating in displacement control. This test mode generally ensured a stable failure and enabled recording of complete stress-strain curves. The three groups exhibited unique failure patterns (fig. 15). Those in the first group (parallel to foliation) failed by classical longitudinal splitting along

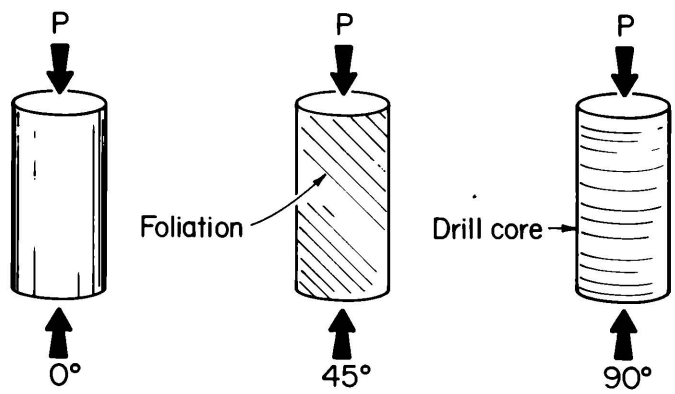


Figure 14.—Relation of applied load to foliation in drill core. Core diameter, 1.25 in; P indicates direction of applied load.

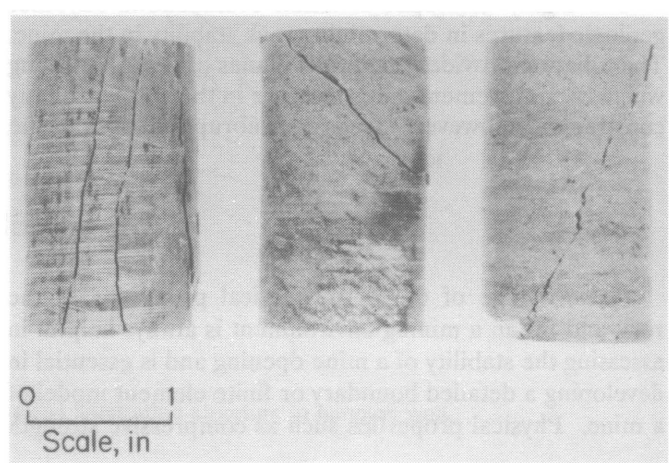


Figure 15.—Failure patterns (fractures) and orientation of foliation in cores of talc ore.

foliation. Those in the second group (45° to foliation) failed in shear along the preexisting weakness planes (foliation). Those in the third group (perpendicular to foliation) failed by classical shear fracture that went through the intact material and was oriented at about 30° to the loading axis.

Figure 16 shows the compressive strength data for the three orientation groups. The middle line indicates the mean for that group, and the upper and lower lines define a 90-pct confidence level for that mean.[4]

Summarizing the above foliation effect on talc strength, the talc strength when the specimen is loaded perpendicular to foliation averages 12,000 psi for a 1.25-in-diam core specimen. Strength decreases to an average of 8,000 psi when the specimen is loaded at 45° to foliation, and continues to decrease to an average of 6,000 psi when the specimen is loaded parallel to foliation. These results indicate that a foliation orientation parallel to the loading direction can result in a 50-pct strength reduction, approximately. A strong caution is warranted in that this interpretation is based on small-scale laboratory specimens. The full-scale strength of talc pillars is still largely unknown; however, based on these laboratory observations it is reasonable to expect that the strength of a full-scale talc pillar may also decrease when foliation is inclined or parallel to the loading direction.

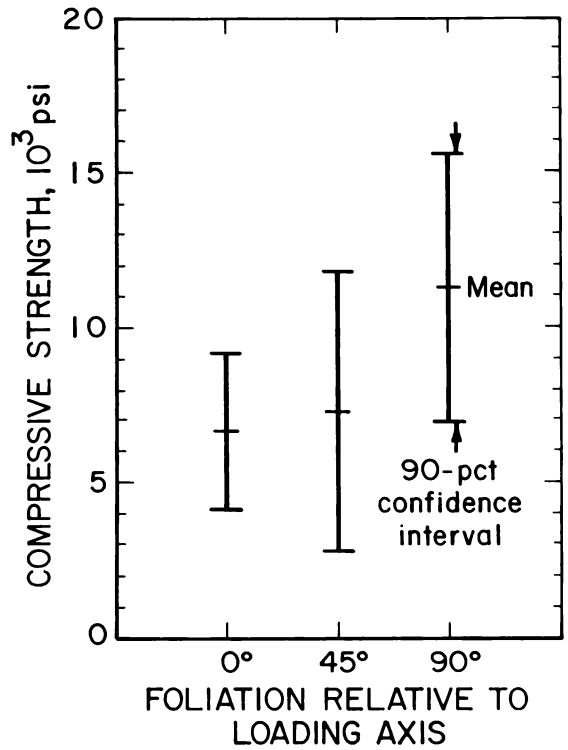


Figure 16.—Compressive strength of talc ore relative to orientation of foliation.

INSTRUMENTATION

PILLARS

A method of assessing pillar instability, changes in pillar loading, or excess loading of pillars is to measure relative pressures within a pillar. This can be accomplished by inserting a pressure-sensitive device in a small hole bored into the pillar.

Pillar pressures at the Earnest Mine were monitored at selected sites during mining by using a simple and inexpensive instrument known as the borehole platened flatjack (BPF). The application of this instrument in mining research is described in detail by Bauer, Chekan, and Hill (*11*). The instrument was developed for measuring mining-induced pressure changes in coal mine pillars. It consists of a steel flatjack or bladder positioned between two aluminum platens. The instrument generally is installed in a 2-in-diam borehole in a pillar, and the flatjack is inflated with hydraulic oil to a predetermined setting pressure based on the depth of overburden. BPF's can be oriented to measure pressure changes in any direction. At the Earnest Mine the BPF's were oriented to measure vertical increases in pillar pressure only.

Setting pressure for the BPF is determined by a commonly used method to calculate the pressure in the pillar due to the weight of overburden. The BPF is then set in the borehole to match this pressure, which is usually rounded to the nearest 100 psi. BPF setting pressure usually drops 200 to 300 psi in the first few days after installation as the instrument reaches equilibrium with the surrounding rock.

ROOF AND FLOOR CONVERGENCE

One method of assessing mine roof instability is to measure any changes that occur in the distance between a mine roof and floor, taking care to avoid areas of floor heave. Where distances between the roof and floor are much greater than about 6 ft, a tape extensometer (*12*) provides a better means of detecting entry or room convergence by measuring the change in distance between two permanent stations, roof to floor.

A tape extensometer consists of a steel engineer's tape, a dial-tensioning mechanism, and two snaphooks (fig. 17).

[4]This confidence interval signifies that if a group of tests were repeated, then 90 pct of the time a mean value for the new group of tests would fall somewhere within that stated confidence level.

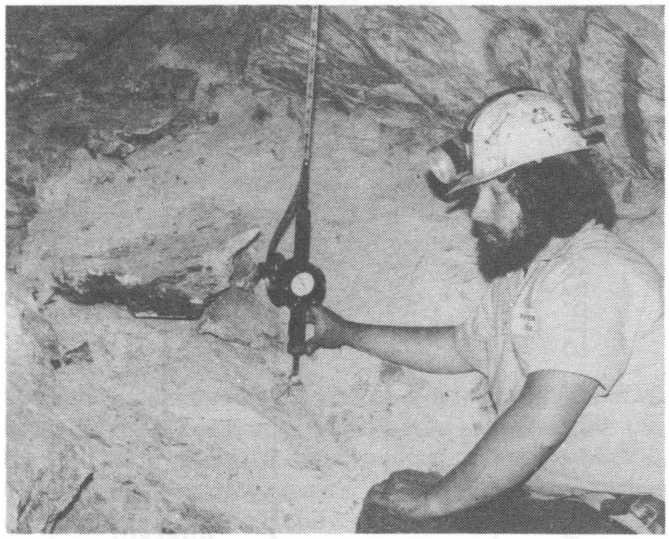


Figure 17.—Measurement of roof convergence with tape extensometer.

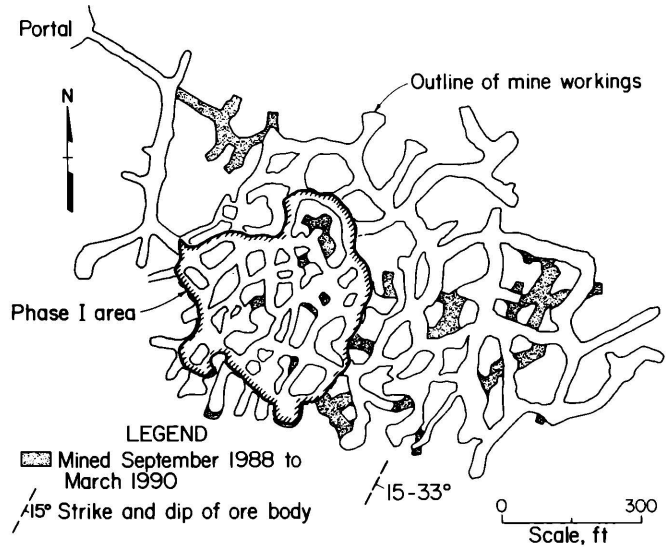


Figure 18.—Outline of phase I study area in Earnest Mine.

Anchoring stations usually are short 3/8-in-diam expansion bolts with eyebolts for connection to the instrument.

Normally one reading per week is adequate, depending on the rate of mining, but large changes require more frequent readings, while small changes require less frequent readings. The amount of measured movement indicating an unstable roof depends on the mine and the geologic setting. Only through experimentation can this value be determined. The limited data in this report suggest that convergence of 0.2 in is of little significance but that a higher rate could be meaningful.

RESULTS OF INVESTIGATION

The assessment of pillar stability by using BPF's to measure pressure changes within pillars and roof convergence to measure roof stability were conducted in two phases. Phase I was conducted during April 1989-July 1990 in the western portion of the mine (fig. 18). During this interval, six BPF's, I-1 through I-6, were monitored intermittently to detect changes in pillar loading, and three roof convergence stations, I-A through I-C, were measured concurrently with the BPF's. However, BPF I-6 lost all pressure shortly after installation and is not reported.

The BPF's were installed in pillars adjacent to a small pillar that was scheduled for removal (fig. 19). This location is under about 550 ft of overburden. Figure 20 shows that virtually no changes in pillar loading were detected after removal of the small pillar and no significant changes occurred throughout the remainder of the period, although additional mining was conducted in the vicinity (fig. 21). A small unexplained pressure loss is indicated for all BPF's from October to November 1989 (fig. 20).

The three roof convergence stations in the same area generally showed only minor fluctuations of ±0.1 in during April-October 1989 (fig. 22). During the remainder of the study period somewhat larger changes occurred.

Phase II of the pillar and roof instrumentation was conducted from February 1989 to July 1990. It consisted of the installation of six convergence stations, II-A through II-F, and six BPF's, II-1 through II-6 (fig. 23). Several installations were damaged within a short time after placement and are not shown on figures 24-25. Data from these instruments indicate that no major changes were detected throughout the monitoring period (figs. 24-25). The initial roof movement of II-A (fig. 25) was attributed to the effects of mining equipment on the anchor in the floor. The initial loss of pressure in BPF II-6 suggests fluid leakage. The loss of pressure in BPF's II-1, II-2, II-4, and II-5 suggests a period of adjustment prior to stabilization (fig. 24). The mining that occurred during both phase I and phase II is shown on figure 26, along with the location of some severe pillar sloughing that developed throughout the monitoring.

The absence of any major changes in the convergence stations or BPF's indicates that pillar overloading is not occurring and the span of exposed roof is well below a critical dimension at the current extraction ratio. Several small- to medium-sized pillars have separated slightly from the roof along the hanging wall contact, and pillars of various sizes have developed cracks across foliation and are sloughing, indicating adjustment to changing loads and confining stresses.

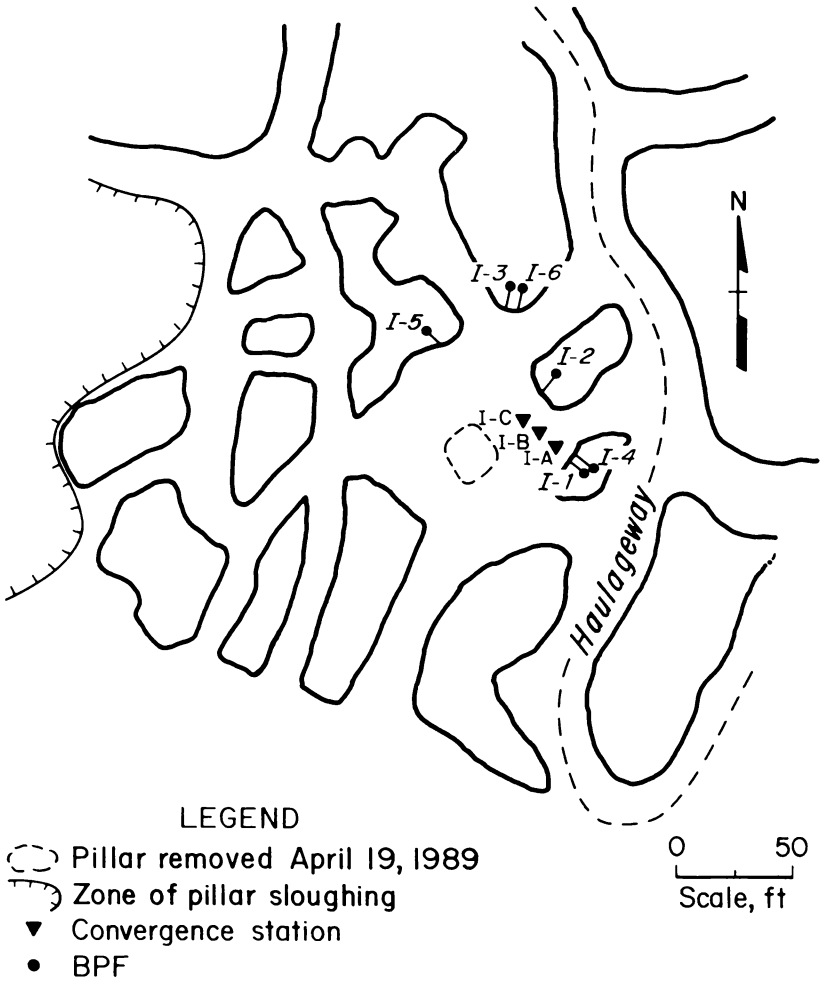


Figure 19.—Location of phase I instrumentation. (BPF = borehole platened flatjack.)

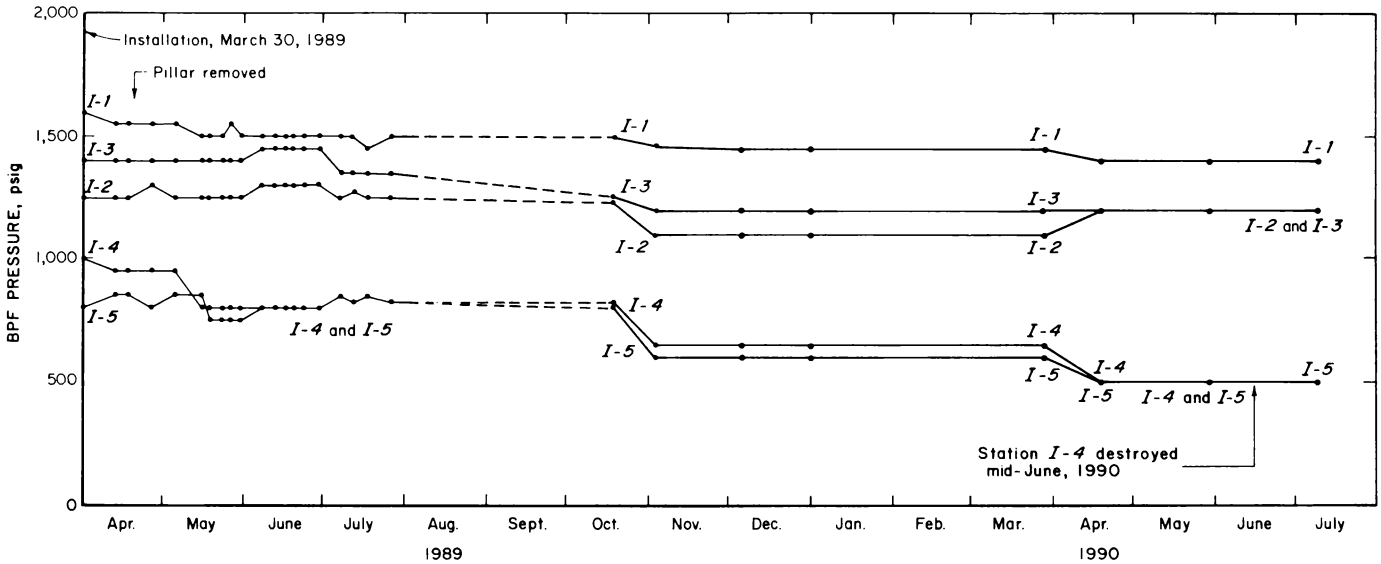


Figure 20.—Phase I pillar loading. No measurements taken during period of August-October 1989. (BPF = borehole platened flatjack.)

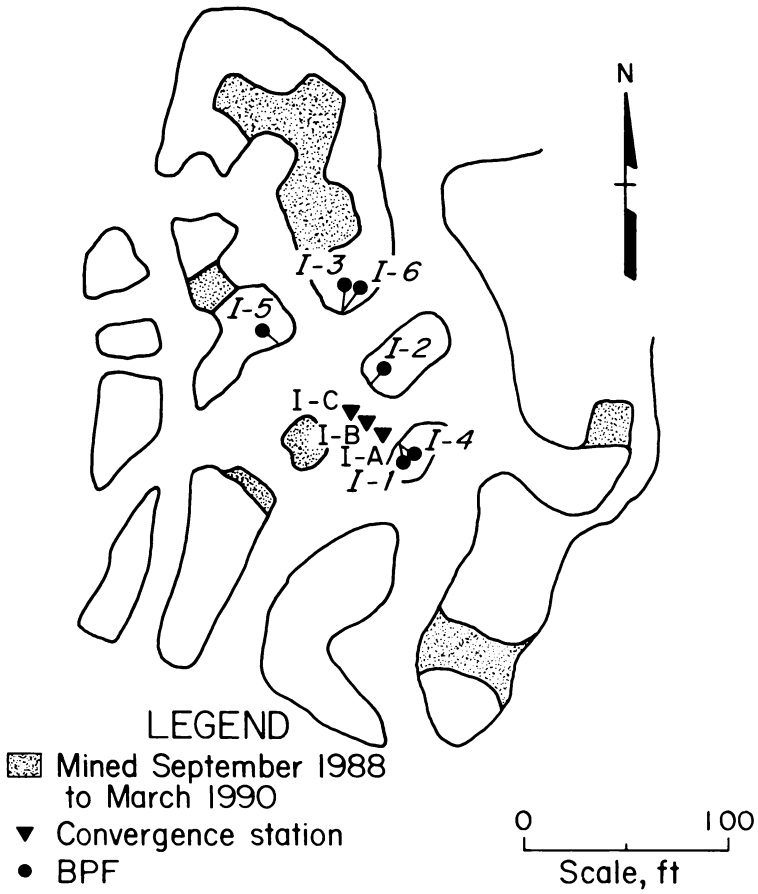


Figure 21.—Ore extraction in phase I area.

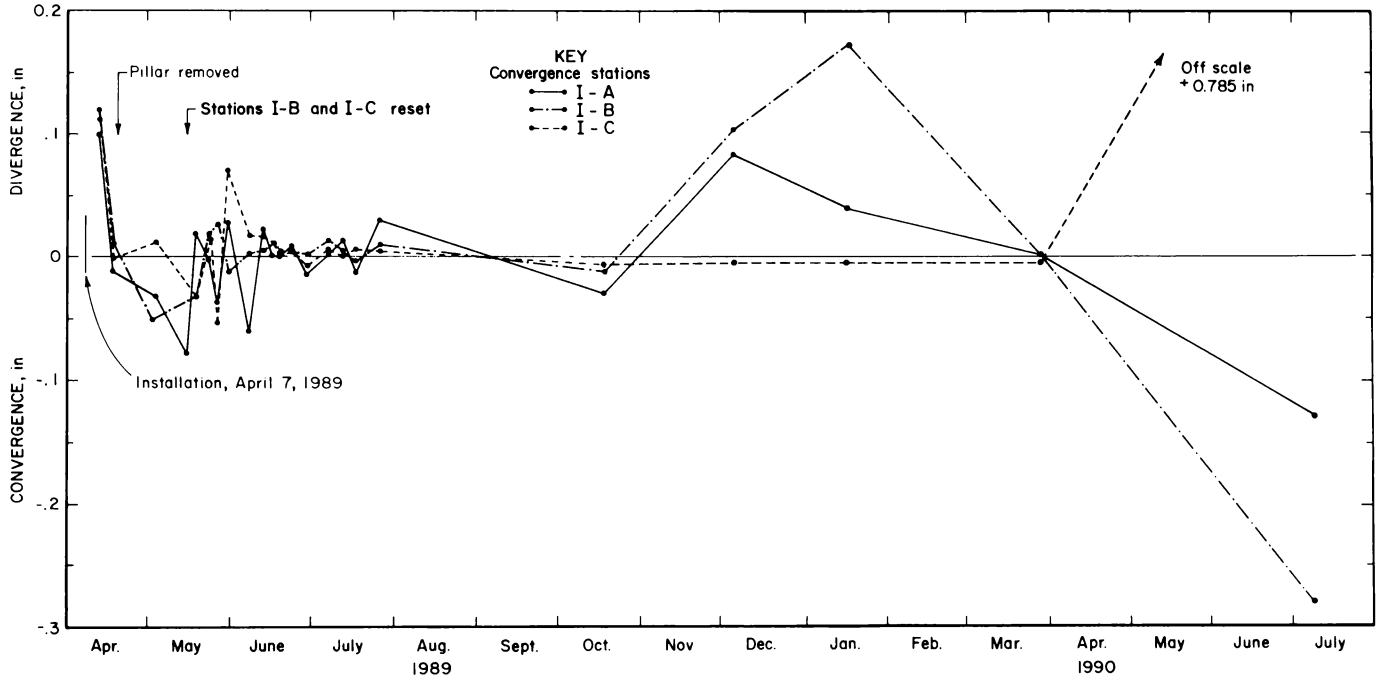


Figure 22.—Phase I roof convergence.

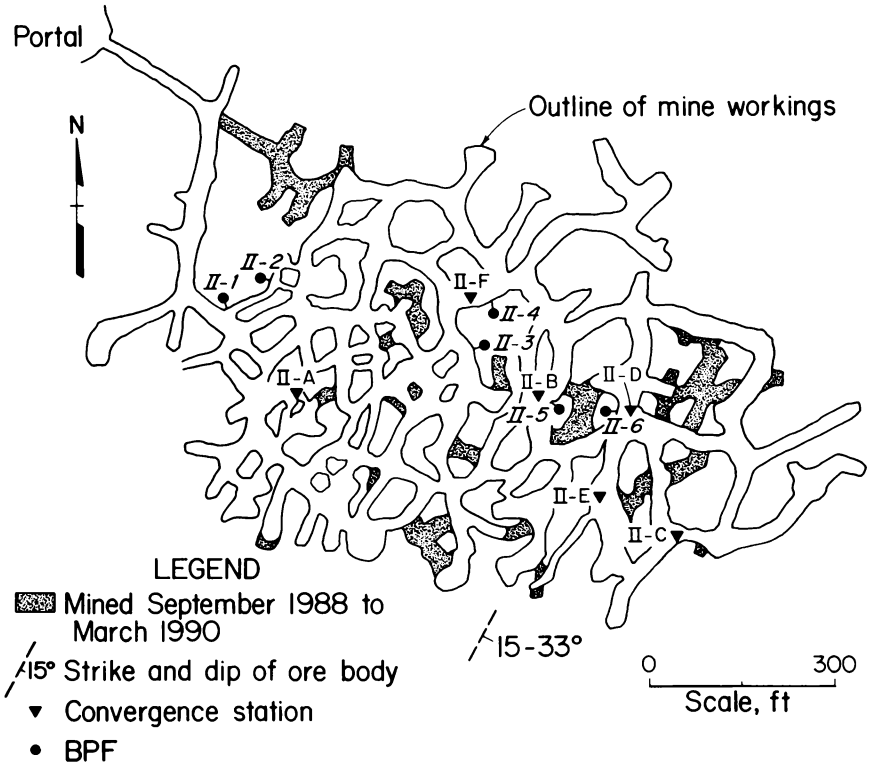


Figure 23.—Location of phase II instrumentation.

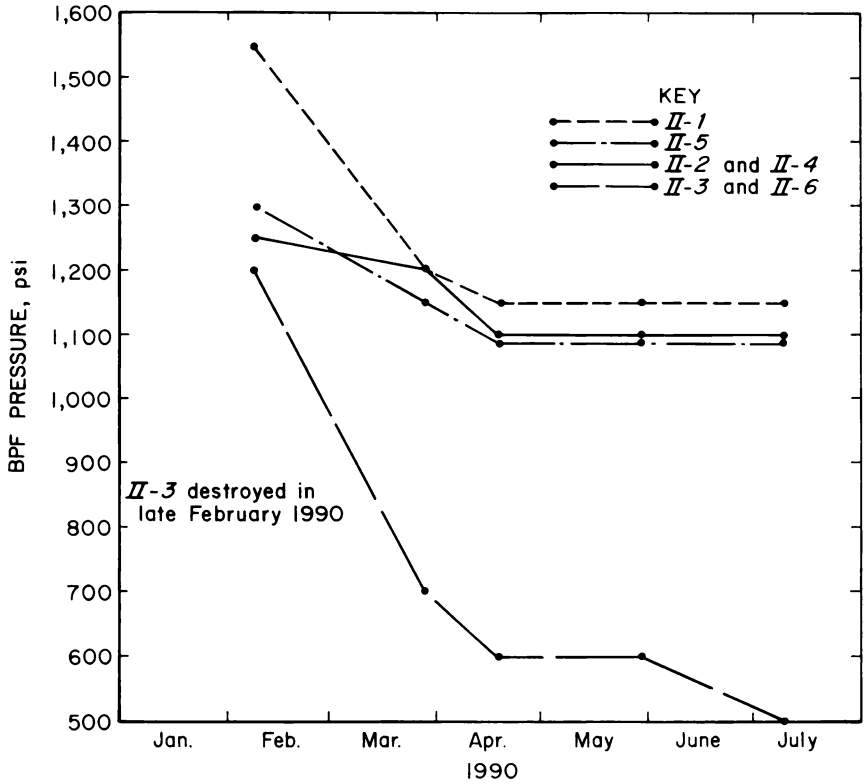


Figure 24.—Phase II pillar loading.

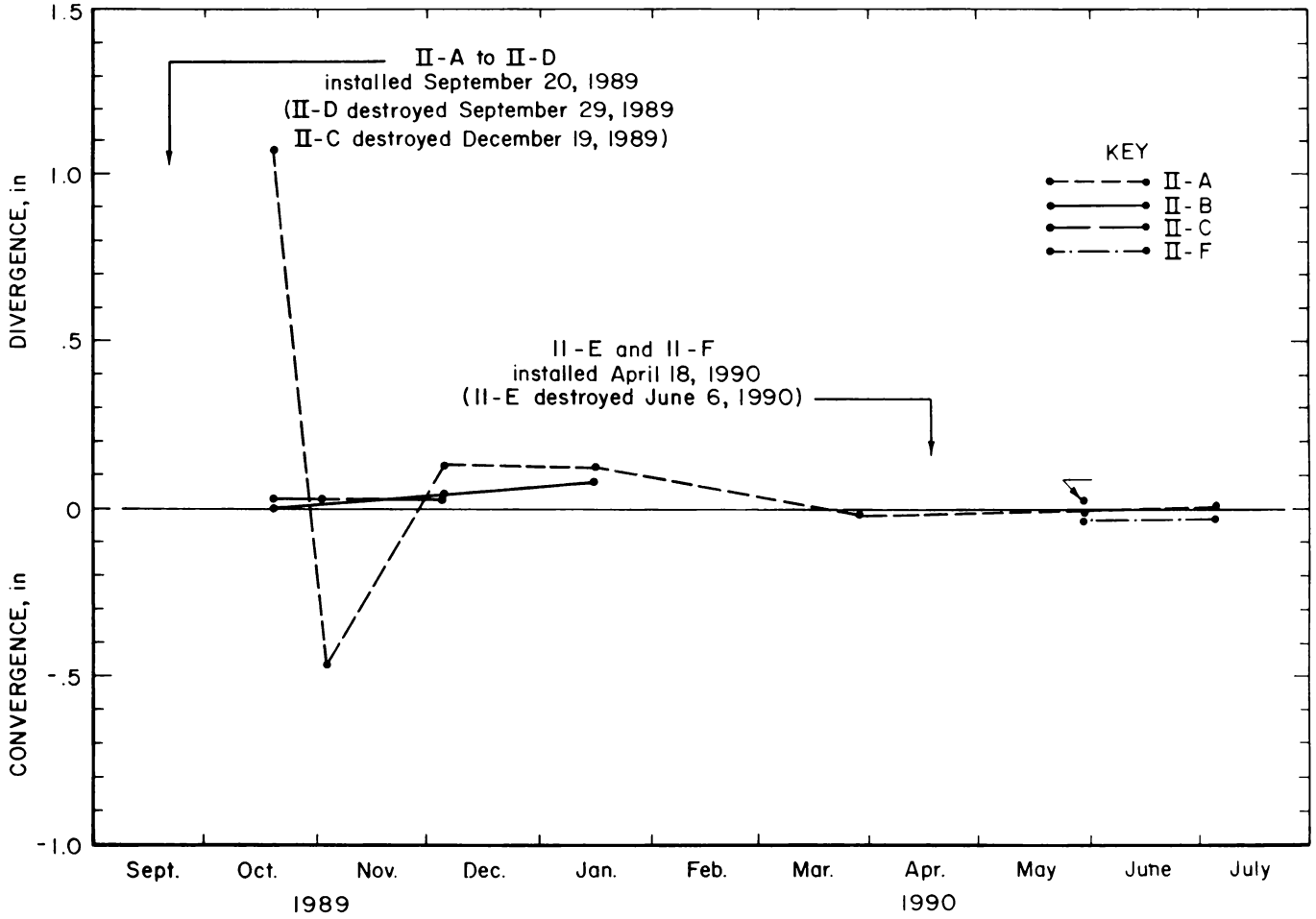


Figure 25.—Phase II roof convergence.

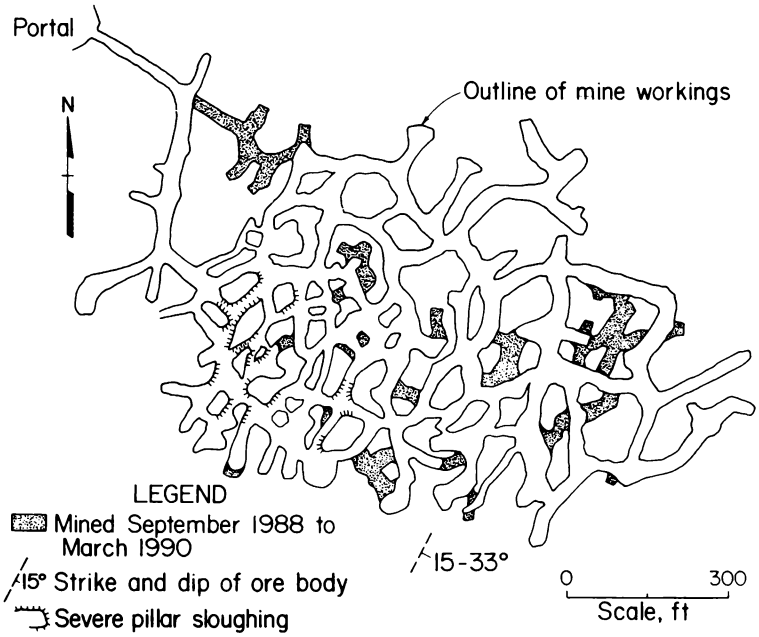


Figure 26.—Areas of severe pillar sloughing in Earnest Mine.

BOUNDARY ELEMENT MODEL

The Earnest Mine represents a complicated problem in pillar design. The talc ore body dips at approximately 22° and the hillside above the mine rises with a slope of about 35°. The practice of selective mining and blending and unsymmetrical pillar layout has resulted in a fairly random pattern of pillars of various sizes and shapes separated by entries of various widths. Within the ore body the attitude of the foliation is highly variable and unpredictable. All of these geologic and geometric variables cause pillar stability analysis and, in particular, pillar stress determination to be exceedingly complex.

However, to obtain some reasonable idea of the complex pillar stresses in the mine, a mathematical model of the mine plan was developed using the computer program MULSIM/BM (*13*). This program, based on the displacement-discontinuity (DD) version of the boundary-element method, can accurately assimilate the complex stresses generated by the dipping seam, changing overburden, and random pillar pattern. The input from this model should provide the mine design engineer with a better knowledge of the present and expected pillar stresses for analyzing the pillar stability of the mine design.

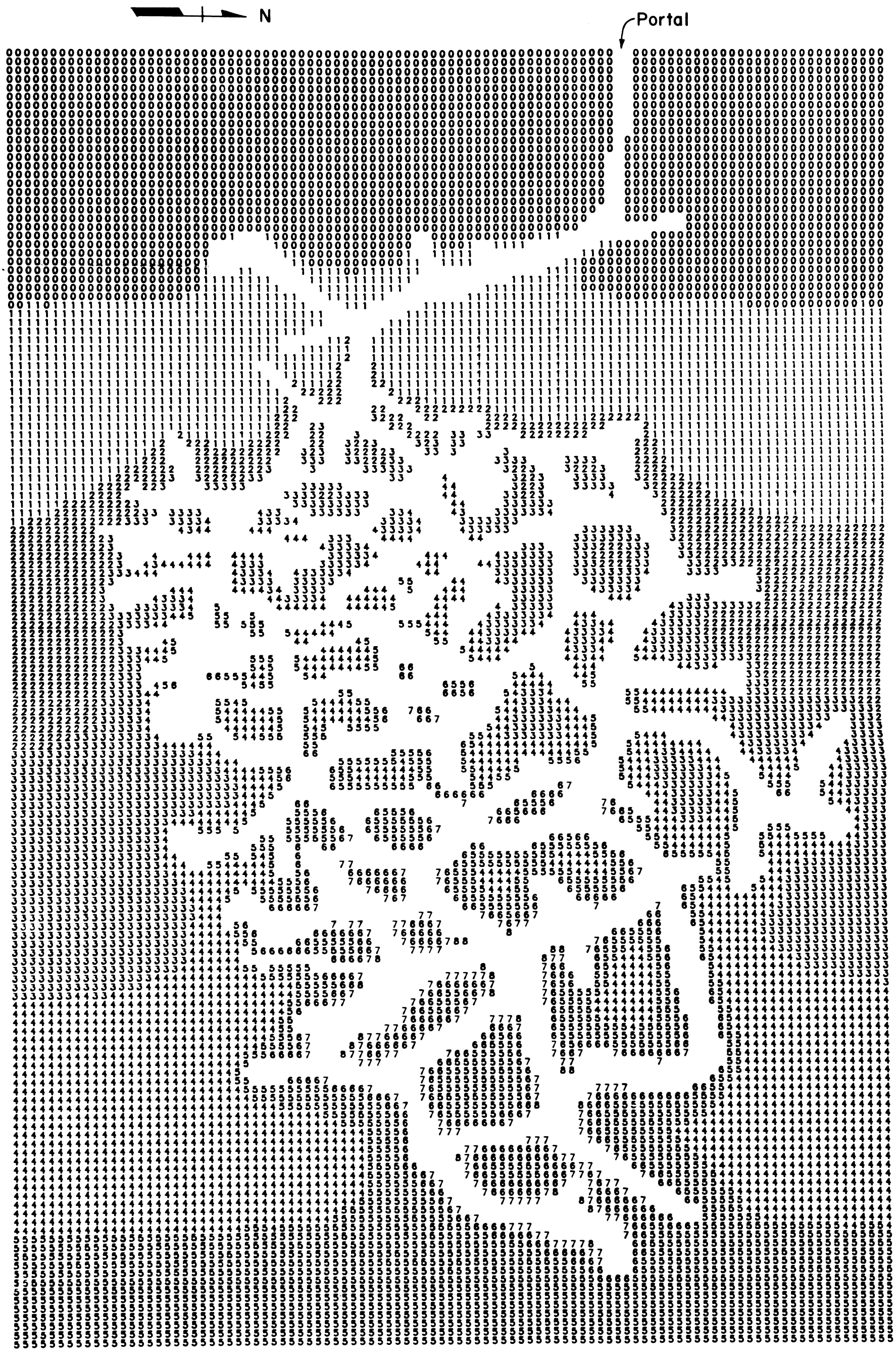
The MULSIM/BM model of the mine used in this analysis consists of a 40- by 50-block coarse grid containing a 100- by 150-element fine grid, which covers the center of the coarse grid from block 10 to block 30 in the X direction and from block 10 to block 40 in the Y direction. This arrangement of a fine grid surrounded by a coarse grid allows the actual Earnest Mine plan to be detailed using the fine grid elements and the far-field stress effects to be included using the coarse grid blocks with a minimum of computational effort. The pillar plan was discretized in the fine grid using 10-ft elements with an elastic modulus of 2 million psi and a Poisson's ratio of 0.25. The schist and gneiss surrounding the talc ore were modeled using an elastic modulus of 6 million psi and a Poisson's ratio of 0.25. The ore body was given a 22° dip and a 20-ft thickness in the model. Also, the overburden stress was adjusted to account for a 35° slope of the hillside over the mine.

The MULSIM/BM model of the mine was used to make stress calculations at two steps in the mine development. These two steps correspond with the beginning and end of the study period. The calculated stress results from the two steps are shown in figures 27 and 28, and the changes in stress between the two steps caused by mining of the indicated areas are shown in figure 29. These results clearly indicate the increasing stress with distance down dip. The highest stress indicated in the model is 2,500 psi, which is fairly close to the 2,600- to 3,200-psi laboratory strength of the talc ore. However, this peak stress is only evident at isolated locations on pillar projections into the rooms or along pillar ribs. These isolated high-stress concentrations do not immediately suggest any acute or imminent pillar failure problems but may suggest that some isolated pillar sloughing will occur. A combination of the high stress with steeply dipping ore foliation may cause much greater pillar sloughing. A number of laboratory tests showing the relationship between the ore strength and the orientation of the foliation, as described earlier in this report, appear to confirm this hypothesis.

A second result indicated in the model is the increase in pillar stress associated with small pillars or narrow sections of larger pillars. In other words, the model shows that large, equidimensional pillars control stress better than small pillars or narrow sections of larger pillars. This agrees with present theories emphasizing the importance of a confined pillar core for carrying overburden loads.

Several words of caution should be stated concerning the interpretation of the model results. First, this type of DD model cannot predict failure in the seam materials; therefore, high-stress areas in the model may or may not fail in real situations in the mine. Also, any areas in the mine that have failed would certainly have different stress levels than indicated in the model, since the model assumes complete integrity of the ore body. A second word of caution concerns prediction of roof failures. The DD model of the mine does not consider stresses in the roof or floor; therefore, it gives no information concerning possible roof instabilities. If roof stability is a problem, some other method, such as beam analysis or rock mass classification, should be used. An assessment of roof rock quality (rock mass classification) has been attempted in the following section of this report.

So, how should the model results be used? The best practical use of the stress values generated by the MULSIM/BM program is in combination with other analytical and empirical information about the mine. For example, if a long, narrow wing of a pillar fails under a given stress load for no other apparent reason than the stress, then that level of stress should be avoided for that width of pillar, or the width of the pillar should be increased in stress fields of that magnitude. Also, areas of pillar failure in the mine may be caused by combinations of conditions such as stress and entry width or stress and foliation dip. Once these relationships are known, the results of the DD model can be used as a tool to help predict and avoid the critical combinations of factors that cause failure. Finally, the MULSIM/BM model works very well for modeling projected mine plans to compare relative stress states for optimizing mine design.



LEGEND

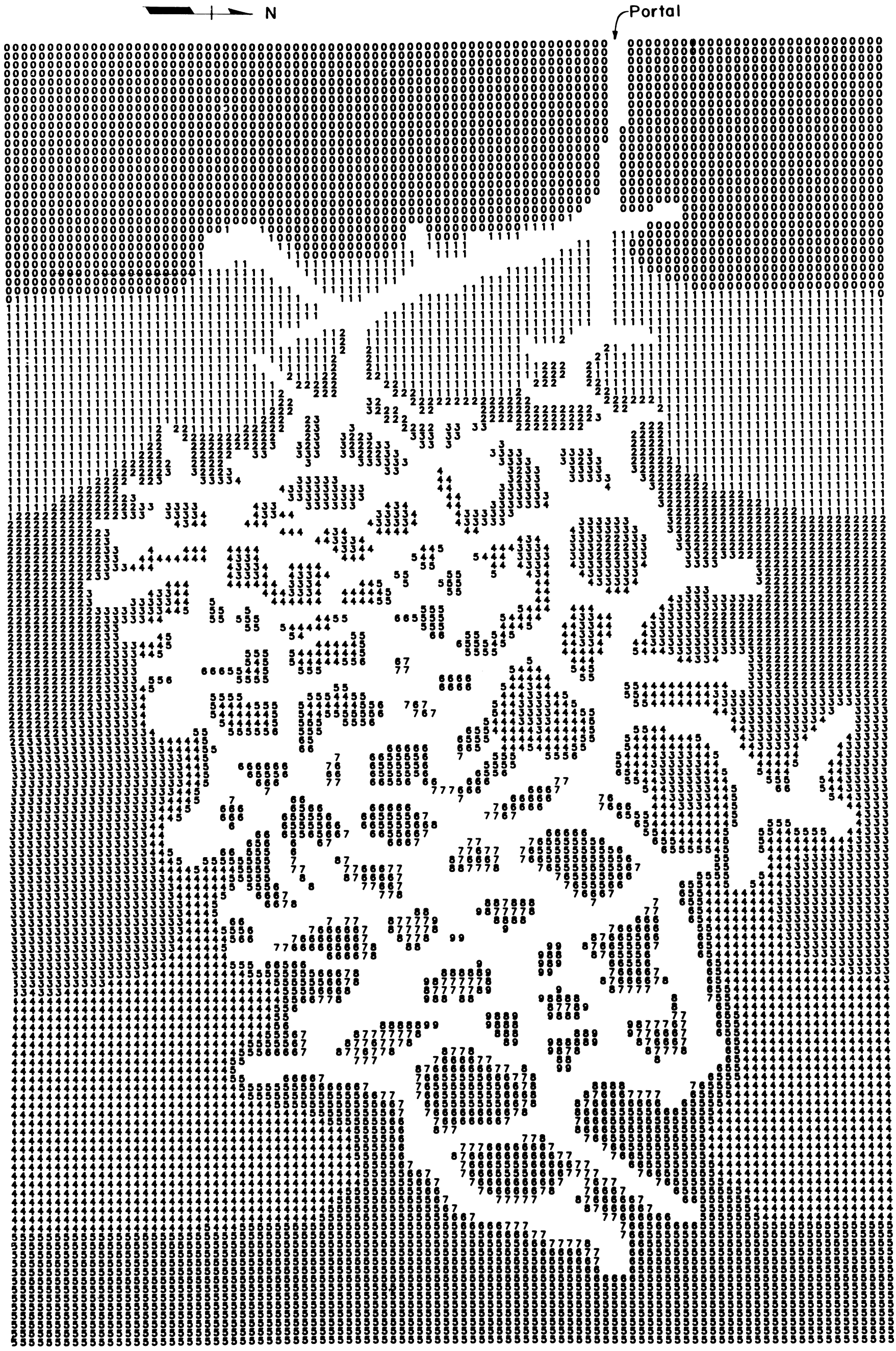
Total vertical stress, psi

9999 9999	2250-2500	6666 6666	1500-1750	3333 3333	750-1000
8888 8888	2000-2250	5555 5555	1250-1500	2222 2222	500-750
7777 7777	1750-2000	4444 4444	1000-1250	1111 1111	250-500
				0000 0000	0-250

0 200

Scale, ft

Figure 27.—Vertical stress at beginning of study period.



LEGEND

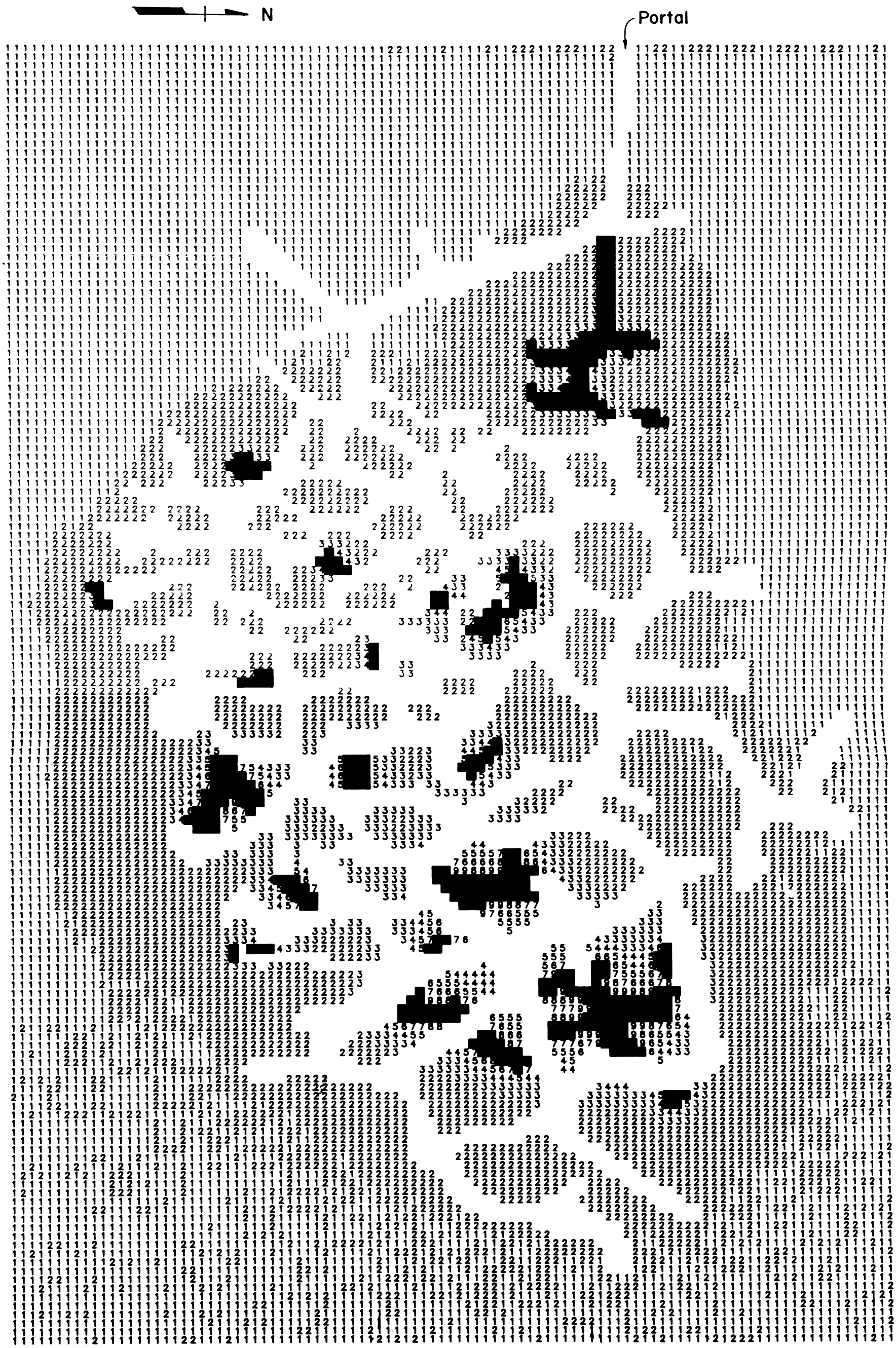
Total vertical stress, psi

9999 9999	2250-2500	6666 6666	1500-1750	3333 3333	750-1000
8888 8888	2000-2250	5555 5555	1250-1500	2222 2222	500-750
7777 7777	1750-2000	4444 4444	1000-1250	1111 1111	250-500
				0000 0000	0-250

0 200

Scale, ft

Figure 28.—Vertical stress at end of study period.



LEGEND

Stress change, psi

9999 9999	800-700	6666 6666	500-400	3333 3333	200-100
8888 8888	700-600	5555 5555	400-300	2222 2222	100 - 5
7777 7777	600-500	4444 4444	300-200	1111 1111	5 - 0

Mined area

0 200

Scale, ft

Figure 29.—Change in vertical stress during study period.

ROCK QUALITY AND SUPPORT REQUIREMENTS

Many technologists have attempted to devise a general purpose numerical rock mass classification system for assessing rock strength. Some, such as Wickham, Tiedenmann, and Skinner (*14*) and Bieniawski (*15*), have described rock classification systems specifically for estimating artificial support requirements that are based on a large number of parameters. The authors have attempted to estimate support requirements and limits of roof span at the Earnest Mine by using a rock classification system devised by Barton, Lien, and Lunde (*16-17*). This system seemed to be most appropriate for the purposes, and it included provisions for joint roughness, strength of joint fillings, and the rock load.

The rock mass quality value, Q, as devised by Barton, Lien, and Lunde, is based on experiences documented in 200 tunneling case studies. This empirical method for determining rock mass quality encompasses a large number of geologic parameters; it is expressed in the equation

$$Q = (RQD/Jn)\ (Jr/Ja)\ (Jw/SRF),$$

where RQD = rock quality designation,

Jn = joint structure number,

Jr = joint roughness number,

Ja = joint alteration number,

Jw = joint water reduction factor,

and SRF = stress reduction factor.

Barton, Lien, and Lunde then developed support categories as a function of their Q value to an equivalent dimension, De. De is the opening span divided by an equivalent support ratio (ESR), which is related to the purpose of the opening. Two values of Q, one representative and one conservative, were used to estimate support requirements for increasing roof spans in the gneiss hanging wall of the Earnest Mine. An ESR of 1.6 for permanent mine openings was selected to determine De for the increasing spans.

The geologic parameters selected for Q as representative of the gneiss hanging wall were as follows: RQD = 100 (excellent), Jn = 1 (massive, no or few joints), Jr = 1 (smooth, planar), Ja = 1 (unaltered joint walls), Jw = 1 (dry excavation), and SRF = 1 (medium stress). The resulting Q value of 100 falls on the border of very good and extremely good rock mass.

With a Q of 100 and spans of 25 and 50 ft, no support is indicated. The same parameters with 100-, 150-, and 200-ft spans result in suggested spot bolting with untensioned, grouted bolts. This support method closely matches the one currently practiced in the Earnest Mine, although the mine's largest spans at the time of this study were approximately 150 ft.

The geologic parameters chosen for a conservative estimate of Q for the gneiss hanging wall were as follows: RQD = 100, Jn = 3 (one joint set plus random joints), Jr = 1, Ja = 1, Jw = 1, and SRF = 1. This results in a Q value of 33, indicating a good rock mass.

With a Q of 33 and a span of 25 ft, no support is indicated. Spot bolting with untensioned, grouted bolts is suggested for the same parameters with a 50-ft span. Systematic bolting with tensioned, grouted bolts on 4- and 6-ft centers is suggested for 100- and 150-ft spans. Systematic bolting of chain link mesh on 4- to 6-ft centers is indicated for a 200-ft span. The conservative nature of a Q value of 33 is evident in that none of these indicated supports are currently in use, or deemed necessary, at the Earnest Mine.

For comparison with the gneiss, a Q value was determined for the talc ore body with the following parameters: RQD = 25 (very poor), Jn = 6 (two joint sets plus random joints), Jr = 4 (low friction talc), Jw = 1 (dry excavation), and SRF = 2 (stresses unfavorable to stability). These parameters result in a Q value of 0.26, or a very weak rock mass.

Had a rock mass of Q = 0.26 occurred in the *roof* of the Earnest Mine, supportable spans would have been dramatically reduced. For example, for a span of 25 ft, the suggested support is systematic bolting on 3-ft centers with tensioned grouted bolts and 1 to 2 in of shotcrete. Increasing the span to 50 ft falls outside the supported spans for case studies in that Q value range.

Substituting pillar height for span and a temporary mine opening for a permanent one results in support suggestions for pillar stability. Average pillar height in the Earnest Mine is 25 ft. The support indication resulting from these changes is systematic bolting of the pillars on 3-ft centers with tensioned grouted bolts. Experience in the Earnest Mine, where no supplementary pillar supports currently are employed, indicates that this would be an overly conservative approach to pillar stability. However, occasional failure at pillar margins along slickensided planes has occurred. This may suggest that spot bolting obvious planes of weakness that dip toward the opening in traveled areas may be prudent.

SUMMARY AND CONCLUSIONS

An investigation was conducted of talc mining operations in the Murray Country district of northwestern Georgia to determine the potential magnitude of ground control hazards and geotechnical methods by which these hazards might be detected and reduced. The investigation was conducted principally at the Earnest Mine near Chatsworth.

This study was somewhat handicapped by the frequent loss of monitoring instrumentation due to pillar sloughing and underground equipment movements. The relatively slow rate of mining did not allow for the long-term monitoring necessary to fully assess roof-and-pillar stability at high levels of ore extraction. Nonetheless, the data collected over a short time span provide insight on the causes and remedies for potential ground control problems and should be helpful in developing improved pillar design and artificial support methods.

The principal ground control problem and potential hazard appears to be pillar instability, that is, the tendency of talc ore pillars to slough along the planes of foliation, which generally dip in the same direction as the ore body but more steeply. Some local sloughing occurred across foliation and parallel to the rib line (fig. 30). The cause of sloughing is somewhat obscure, but sloughing can be attributed chiefly to gravity facilitated by the steeply dipping planes of foliation, which may be lubricated by condensation on rock surfaces in the upper portion of the mine, where moisture is detectable and sloughing is most severe. Pillar overloading was not indicated by the monitoring. In some instances the periphery of a pillar actually separated slightly from the hanging wall (fig. 31), possibly because of slight sagging of the outer portions or "skin" of the pillar. Boundary element modeling suggests that stresses are concentrated near the acute angles of pillars and that a better load distribution might be achieved by a more equidimensional shape. The model also clearly indicates the increasing stress with distance down dip from outcrop. However, the highest stress in the model at a depth of nearly 1,100 ft is only 2,000 psi. This level of stress appears safely below the 3,150- to 6,760-psi laboratory strength of the 1.88-in-diam cores of talc ore. However, this relationship may be misleading because of the uncertain influence of the pronounced foliation and slope on a rock mass, such as a pillar or irregular shape, and the size effect in comparing vastly different scales.

The roof of the Earnest Mine, consisting of a granite gneiss, showed no evidence of convergence during partial mining as nearly as could be detected by the installed tape convergence stations. This absence of convergence suggests that the gneiss forms a very strong roof beam despite an occasional zone of biotite schist within the gneiss. Occasional falls of roof rock generally consisted of a thick "plaster" of talc ore remaining at the roof, particularly in the vicinity of a roof roll, or immediately adjacent to a pillar where an upper portion of the talc ore pillar extended a few feet outward from the pillar, forming an overhang (fig. 32). The hanging wall is not always easy to distinguish from talc ore in a mining environment, thus compounding the problem.

Estimates of rock mass quality (Q) were obtained by assigning empirical values to a number of geologic parameters of the hanging wall gneiss and the talc ore. The Q

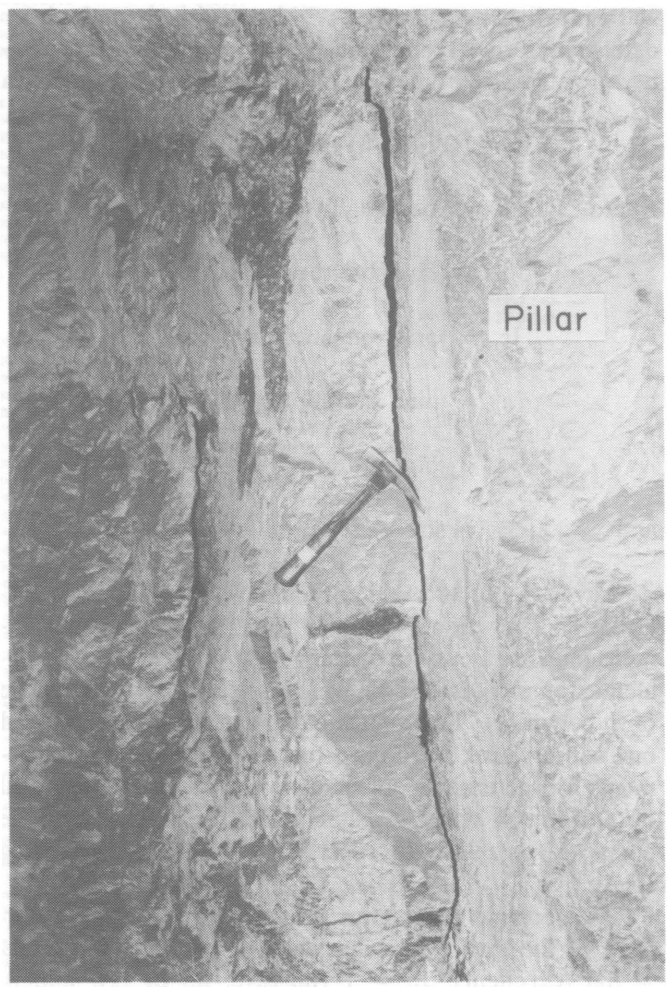


Figure 30.—Pillar sloughing fracture (hammer point) cutting across talc ore foliation.

Figure 31.—Separation of pillar top from hanging wall (hammer at plane of separation).

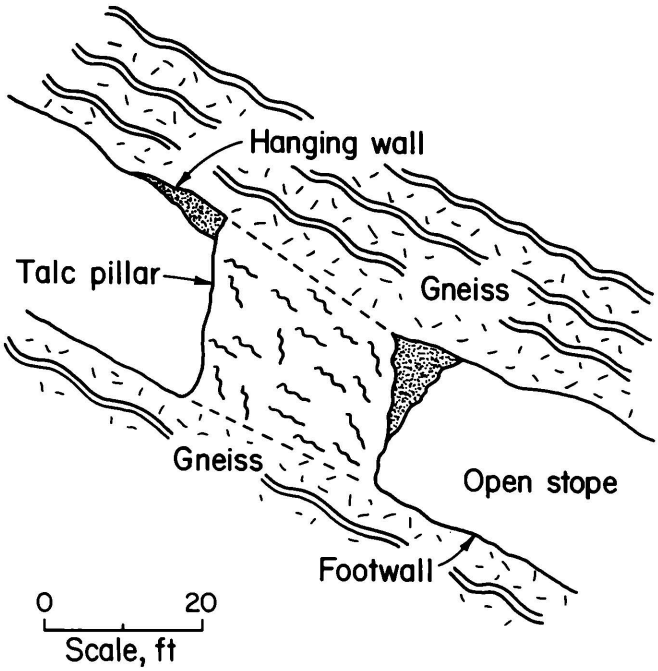


Figure 32.—Overhang of talc ore adjacent to pillar top.

values for the hanging wall gneiss indicate that no artificial roof support is necessary for mine roof spans of up to 50 ft and that only spot bolting is indicated for spans of up to 200 ft. By calculating a more conservative Q value for the gneiss as a safety factor, spot bolting is indicated for spans of 50 ft while systematic bolting of chain link mesh is indicated for a 200-ft span. Except for occasional spot bolting, the above measures, to date, have not been judged necessary at the Earnest Mine.

Using Q values calculated for a talc ore roof, systematic bolting and shotcrete were indicated for a roof span of only 25 ft. Spot bolting obvious planes of weakness that dip toward traveled areas is always a prudent decision.

Talc mining operations in northwestern Georgia are unique and generally have been unsystematic and random because selective mining has been practiced. New underground mines, especially, should be planned, as nearly as possible, to take advantage of improved methods of geotechnical investigations, pillar design, and hazard detection. With the improvement of continuous mining machines and jet-assisted cutting bits it may be feasible to eliminate most use of explosives in talc mining, thereby reducing vibrations in the mine that probably contribute to movement along foliation and pillar sloughing.

REFERENCES

1. Virta, R. L. The Talc Industry—An Overview. BuMines IC 9220, 1989, 11 pp.

2. U.S. Bureau of Mines. Mineral Commodity Summaries 1990. 199 pp.

3. Robertson, J. L. Is Underground Mining in Your Future Expansion Plans? Rock Prod., v. 86, No. 6, 1983, pp. 29-34.

4. Miller, R. N. Talc Mining in Vermont—The Application of Continuous Mining Machines. Soc. Min. Eng. AIME, preprint 84-358, 1984, 4 pp.

5. Furcron, A. S., and K. H. Teague. Talc Deposits of Murray County, Georgia. Geol. Surv. GA Bull. No. 53, 1947, 75 pp.

6. Roe, L. A. Talc and Pyrophyllite. Ch. in Industrial Minerals and Rocks. Soc. Min. Eng. AIME, 4th ed., 1975, pp. 1127-1147.

7. Teague, K. H. Georgia Talc Industry Helped by Geologic Study. Eng. and Min. J., v. 147, No. 11, 1946, pp. 63-65.

8. Needham, R. E., and V. J. Hurst. Talc Deposits in the Coosa Valley Area, Georgia. Geol. Dept., Univ. GA, Athens, GA, March 1970, 58 pp.

9. Hopkins, O. B. A Report on the Asbestos, Talc, and Soapstone Deposits of Georgia. Geol. Surv. GA Bull. No. 29, 1914, 319 pp.

10. Horino, F. G., and M. L. Ellickson. A Method for Estimating Strength of Rock Containing Planes of Weakness. BuMines RI 7449, 1970, 29 pp.

11. Bauer, E. R., G. J. Chekan, and J. L. Hill, III. A Borehole Instrument for Measuring Mining-Induced Pressure Changes in Underground Coal Mines. Paper in Proceedings of the 26th U.S. Symposium on Rock Mechanics (SD Sch. Mines & Tech., Rapid City, SD, June 26-28, 1985). Balkema, 1985, pp. 1075-1084.

12. Bauer, E. R. Ground Control Instrumentation—A Manual for the Mining Industry. BuMines IC 9053, 1985, 68 pp.

13. Beckett, L. A., and R. S. Madrid. MULSIM/BM—A Structural Analysis Computer Program for Mine Design. BuMines IC 9168, 1988, 302 pp.

14. Wickham, G. E., H. R. Tiedenmann, and E. H. Skinner. Support Determinations Based on Geological Predictions. Paper in Proceedings of the North American Rapid Excavation and Tunneling Conference. Soc. Min. Eng. AIME, v. 1, 1972, pp. 43-64.

15. Bieniawski, Z. T. Engineering Classification of Jointed Rock Masses. Civ. Eng. S. Africa, v. 1, No. 12, 1973, pp. 335-343.

16. Barton, N., R. Lien, and J. Lunde. Analysis of Rock Mass Quality and Support Practice in Tunneling, and a Guide for Estimating Support Requirements. Intern. Rep., Norw. Geotech. Inst., Oslo, Norway, June 19, 1974, 74 pp.

17. ____. Engineering Classification of Rock Masses for the Design of Tunnel Support. Rock Mech., v. 6, No. 4, 1974, pp. 189-236.

APPENDIX—GLOSSARY OF TALC INDUSTRY TERMS

Adit.—A nearly horizontal passage from the surface in a mine.

Agalite.—An industry term for talc or talcose products.

Blackwall.—The outer border of a talc ore body commonly consisting of a chlorite schist or biotite schist.

Blue-John.—A dense, green schistose talc-chlorite rock similar to crayon talc but harder because it contains chlorite, carbonate, quartz, pyrite, and magnetite.

Chlorite.—A group of platy micaceous greenish minerals commonly occurring with talc ore and composed of hydrous iron, magnesium, and aluminum silicate.

Crayon or Saw Talc.—Straight-grained or schistose talc with very low amounts of chlorite, magnetite, and pyrite.

Dark Grinding.—A rock composed essentially of talc and minor accessory minerals that, when ground, produces a gray powder.

Filler or Extender.—A substance, such as talc, added to a product so as to increase bulk, weight, viscosity, opacity, or strength.

Foliated Talc.—A relatively pure mass of talc displaying prominent micaceous cleavages.

Footwall.—The underlying side of an ore body or mine working.

Grit.—A rock composed essentially of talc and carbonate.

Hanging Wall.—The overlying side of an ore body or mine working.

Soapstone or Steatite.—An impure talc-rich rock of massive texture, usually associated with altered ultrabasic igneous rock.

Talc.—An extremely soft, whitish, greenish, or grayish mineral consisting of hydrous magnesium silicate.

Taylor's Chalk.—A soft, pure, white talc used in cloth marking.

White Grinding.—A rock consisting of talc and dolomite that, when ground, produces a white powder.

INT.BU.OF MINES,PGH.,PA 29513

U.S. Department of the Interior
Bureau of Mines
810 7th Street, N.W., MS #9800
Washington, D.C. 20241-0001