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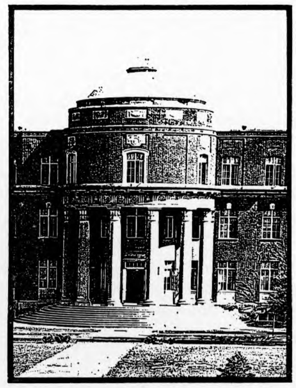

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Stabilizing Underground Excavations

ROBERT STEFANKO, *Professor and Head of the Department of Mining*

Introduction

Because nature abhors a vacuum, when man creates an underground excavation the forces of nature are directed against it in an attempt to destroy it. Thus, during mining operations there is a relentless struggle between the miner who tries to keep his excavation open and intact and the forces of nature which attempt to close it. The miner employs both natural and artificial supports for this purpose. Before he can select the most suitable support, however, he must have a sound knowledge of the mine structure and how it responds to forces. The science of rock mechanics, which is the study of the behavior of rock under load, is very helpful in optimizing supports. Before the various systems of support are discussed, a brief summary will be given of the virginal forces in the earth, how these are redistributed by the introduction of the opening, and how the properties of the rock influence the choice of supports.

Underground Stresses

Massive Rock

It is generally accepted that the vertical stresses (σ_v) in undisturbed ground are a function of the superincumbent weight and vary at the rate of 1.0-1.2 psi per foot of depth. Depending upon Poisson's ratio, the horizontal stresses (σ_h) induced by the vertical load can vary from zero to a value equal to σ_v. At great depth it is believed that rock behaves hydrostatically and therefore $\sigma_v = \sigma_h$. During the past decade rapid progress has been made in underground stress instrumentation, and field investigations have revealed that the simple relationship between superincumbent load and lateral restraint does not provide a complete answer. Because of large tectonic components, residual stresses, and orogenic conditions, the horizontal stress often exceeds the vertical component by a factor of two or more (Hast 1958).

When an excavation is made into the earth the original forces are disturbed and a stress concentration is established in the rock surrounding the mine excavation. If the rock behaves elastically this stress concentration is highly localized, and at a distance of 2 diameters from the periphery of the opening the stresses would be equal to the original values, and the opening would have no influence (Obert 1960). Actually, there are three stresses in the vicinity of an opening that one must consider: radial stress (σ_r), tangential stress (σ_θ), and shear stress ($\tau_{r\theta}$) (Figure 1). For an elastic medium, the tangential stress is greatest at the periphery of the opening while the radial stress is zero. The tangential stress diminishes rapidly to the undisturbed value while the radial stress becomes finite a short distance into the rock, but remains relatively small compared to the tangential component. Since the radial stress is so small, it will not be considered in this article. If σ_θ and σ_r are the principal

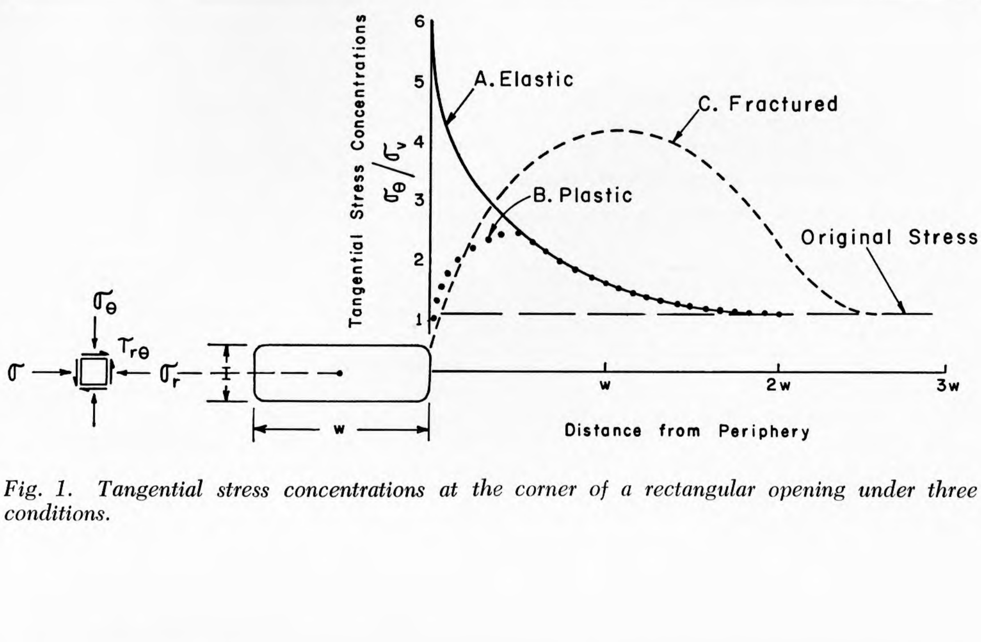


Fig. 1. Tangential stress concentrations at the corner of a rectangular opening under three conditions.

stresses (and there is considerable justification for assuming this) then the maximum shear stress at any point in the structure is $\frac{\sigma_\theta - \sigma_r}{2}$. Since this value will be greatest at the periphery, the opening is subject to high shear stresses which can, and do, lead to shear failures. Studies of the openings of various geometric shapes subject to varying stresses in massive, elastic, homogeneous, and isotropic media have led to the following conclusions:

1. With a uniaxial load condition, $\sigma_h = 0$, for all shapes a tensile stress exists at midspan and is equal in magnitude to the vertical stress σ_v. With increased confinement, the tensile stress is reduced until at approximately $\sigma_h = 1/3\ \sigma_v$ this value becomes zero for all geometric shapes. For horizontal stresses in excess of this value, the midspan value becomes compressional.

2. Since the width-height ratio (W/H) greatly influences the stress condition, for optimum effect the major compressional stress should always be oriented parallel to the long axis of the opening.

3. The geometry affects the opening, and corners act adversely as stress concentrators.

Therefore, the first step in effectively supporting underground openings in massive rock is to obtain the optimum geometry, spacing, and orientation of these openings with respect to the principal stresses underground. If this is done properly, the mine structure itself will provide maximum support and the amount of artificial support needed will be minimized. Unfortunately, inability to determine original principal stresses and their directions has been a serious handicap. Recent advances in underground stress instrumentation techniques, however, promise to improve our knowledge in this area. (Emery 1963 and Leeman 1964).

Bedded Rock

Up to now we have considered the rock to be massive and have ignored the effect of joints and bedding planes. Obviously, this cannot be neglected for many rocks and, more realistically, the rock must be analytically treated as a clamped beam (Figure 2). Under such conditions, the maximum tensile stress will occur at the top of the beam near the rib and can be expressed mathematically:

$$\sigma_1 = pg\frac{L^2}{2t} \qquad (1)$$

The maximum shear stress also occurs near the rib and can be expressed as:

$$\tau_{max} = \frac{3pgL}{4} \qquad (2)$$

Where:

σ_1 = maximum tensile stress, psi
τ_{max} = maximum shear stress, psi
L = span of roof layer, in.
t = thickness of roof layer, in.
pg = weight-density of rock, lb/in.^{3}

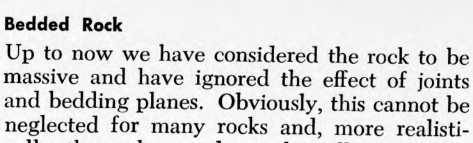


Fig. 2. Stresses around a mine opening in bedded strata.

Maximum sag occurs at midspan where the outer fiber stress is one-half of the maximum value. It is apparent that decreasing the span and increasing the thickness of the beam have beneficial effects and may reduce stresses below fracture values.

Reduction of span is limited because of operational features related to mining equipment. While the physical thickness of the strata was fixed during geologic formation, the effective thickness may be increased. Any type of support which bonds many thin strata into a thick monolithic beam can prove quite effective. As will be seen later, this principle is primarily responsible for the success of roof bolts in coal mines.

One might ask whether it is realistic to assume that rock behaves in an elastic manner, and question how closely the stress distributions in an actual mine opening will approximate the conditions shown in Figures 1 and 2. It is well-known that rock is subject to creep phenomena, even under relatively low stresses, and the curve shown in Figure 1 for an elastic medium A will be modified as shown in B. Finally, the stresses induced in the rock because of an opening might exceed the fracture strength of the rock, and curve C would then represent the tangential stress concentrations around an opening. Even when mining occurs under apparently similar conditions, differences in the physical properties of the rock can result in stress conditions that are completely dissimilar.

Supports

Pillars

Under all underground mining conditions a certain amount of solid ore is left in place to help support the excavation: these supports are known as pillars. It has already been shown that for clamped beams a short span is beneficial. In massive rock, for a given seam thickness, reducing the span will give a favorable W/H ratio and stresses will be minimized. Considering either condition for a given extraction ratio, the use of many relatively small pillars will affect a span reduction and subsequent stress reduction. Naturally, this cannot be carried out indefinitely since the compressive strength of the pillar is involved.

When openings are close together the stress concentrations around each are superposed in intervening pillars. Studies have shown that the average stress concentrations rise much more rapidly than the maximum value (Obert 1960). Therefore, at least for a first approximation, the superincumbent load will induce uniform stresses in the pillars. As long as this average stress is below critical values the excavations will remain stable.

While natural pillars can provide support in an excavation, many factors must be considered if the optimum effect is to be obtained. It is well known that specimen size, degree of confinement, environmental conditions, etc., affect compressive strength values, and a sizeable safety factor must be employed. Usually only in underground excavations used for non-mining purposes is it possible to take advantage of optimum pillar spacing, geometry of opening, and orientation. Nevertheless, there are some mines utilizing natural pillars alone—the limestone mines at shallow depth providing some of the best samples.

Artificial supports

Underground excavations in rock competent enough or with induced stresses so small as to obviate the use of artificial supports are the exception rather than the rule in mining. Usually, depending upon conditions several types of supports are used in a single mine. For instance, mining often takes place in strong ores that lie in an almost vertical position between weak walls. Under such conditions the system of mining called shrinkage stoping is employed. Mining is carried out upward into the ore and the back (roof) is blasted in horizontal layers. Since the volume of blasted material is greater than solid material, some ore will be drawn off from chutes placed in the bottom of the stope. The remaining ore is left in the stope to support or stabilize both walls, as well as to provide a working platform for the miners who must enter the stope after each drawoff to drill and blast an additional horizontal layer of rock from the back. Only after the stope reaches its final vertical dimension will all the ore be removed. Since the back remains unsupported, the ore must be relatively strong.

Shrinkage stoping cannot be employed successfully when natural conditions are a degree poorer. Then a somewhat similar system of mining is employed which is referred to as cut-and-fill mining, in which mining proceeds upward as before, but after each slice of ore has been removed waste fill is introduced into the stope to stabilize the walls. Although rock from the mine, sand, gravel, smelter slag, and other similar materials have been employed for this purpose, hydraulic fill has been found to be much more effective and has been thoroughly studied (Jerabek 1963). Though stope preparation, pipe wear, optimum particle size, solid suspension, and removal of water from the stopes when the fill is in place present problems, hydraulic fill can set up in the stope with almost the consistency of concrete to provide effective support for the walls. Again, the ore must be comparatively strong since the back is rarely supported in this system.

Invariably one will find timber employed underground in the form of props, stulls, sets, or cribs. If the top is not too fragile, a single stick of timber (prop, stull, or post) placed in a vertical position with a cap piece on top will suffice. If this is not adequate, posts can be placed on either side of an opening with a bar across them (set). Sets are often lagged with boards placed above the bars, parallel to the axis of the opening, in running or very fragile ground. While this method is employed to support relatively flat thin seams, a different type of set is required to support nearly vertical ore deposits that are weak and are located between weak walls.

Square sets begin at a sill on the lowest level and are developed set by set, vertically and laterally, each set being blocked into position and dovetailed with its neighbor. Each set consists of 12 posts arranged as a hollow cube and tied to adjacent sets on all six sides. For interior sets a joint will consist of six members and must be formed to meet (framed) in a certain way. It is difficult to fashion the sets underground, and square sets are usually carefully cut to dimensions and properly framed on the surface. Underground, it is only necessary for the miner to assemble the support, except near the stope borders where some fitting might be required.

Because of the exact dimensioning and framing required, square sets are expensive, and since they are placed continuously in the stope, it is not difficult to see why square-set mining is the most costly method. For the Homestake Gold Mine in Lead, South Dakota, a timber crew of 200 is employed at a sawmill in Spearfish, S. D. to cut and frame material to meet the needs of the mine.

Square sets are usually filled with rock waste to keep the sets in line and provide a more permanent support. A few sets are kept open for manways and ore passes by lagging all four sides.

Timber arranged similarly to square sets is used in shafts. Since shaft sets must be installed from the surface downward, sets are blocked in place with larger bearing plates placed every 50 to 100 feet in hitches in the wall rock as a safety measure in case the friction blocking is dislodged.

Where excessive pressures are a factor a crib is utilized. Here, props are laid horizontally, in alternating planes of at least two timbers each, each set on a plane being perpendicular to the plane above and below, similar to cordwood stacked for drying.

Cheapness, ability to be cut to size, lightness and audible warning under load are all advantages of timbers. The compressibility (low E) of the prop is a mixed blessing. For rocks that behave elastically, it is impossible to apply suitable prestress to stabilize the opening. In fact, the prop does not become operative until the opening has failed. Under conditions of creep, the prop will continue to yield and will provide increasing support without being destroyed. Nevertheless, where creep is large the prop will be destroyed since its ability to yield is limited.

The ability to yield when excessive forces react against the prop is an important consideration. The layman has a misconception about the function of a support; obviously it is not used to resist the tremendous forces resulting from the superincumbent load. Rather, it is used to redistribute the stresses in the rock below critical values and to reinforce the mine rock structure itself so that it forms a more competent self-supporting structural element.

One disadvantage of timber is that it is subject to rapid decay, especially in the highly humid conditions normally encountered underground. Because of this timber is generally used as only a temporary support, although its life can be greatly extended by treating it with creosote, zinc chloride, or other chemicals.

Steel beams are often used to replace timber sets because of their greater strength. However, their rigidity may be the cause of their rapid destruction in strongly converging ground. Also, because steel deteriorates quickly when attacked by acid water, it cannot be used in a corrosive environment.

Where practical, the use of steel supports can result in low final cost because of their long life. In addition, labor costs are reduced for erection time is shorter and sets do not have to be renewed so frequently as those of timber. Many mines employ old rails in 3-piece sets for caps; however, the author questions the advisability of this practice since such rails usually have become crystallized and embrittled because of haulage fatigue action which makes them unsuitable for supports. Steel is also frequently used to replace timber for shaft linings because of its fireproof characteristics, greater strength, and increased degree of permanence.

Single stick steel friction props although extensively employed abroad, especially in longwall openings, are seldom considered for use in the United States. While they can better resist the large forces to which props are subjected by heavy roof pressures along longwall faces, the greater weight of steel props adds to overall labor costs. In fact, steel support erection is so expensive that only in areas where labor costs are low are they economically feasible.

Steel tubbing has been found to be useful in difficult ground conditions during shaft sinking. In this application cast steel sections are bolted together into a circular section and backfilled with concrete. Utilization of this method made possible the sinking of a shaft through the difficult Blairmore seam at the Esterhazy Mine of the International Minerals & Chemical Corporation in Saskatchewan.

Use of hydraulic props frequently answers the problem of achieving the high bearing capacities obtained with rigid props while still permitting release of loads when the prop itself is threatened with destruction by excessive convergence. Here single hydraulic posts are used effectively in pillar-pulling sections. They can be set at high load values and the hydraulic mechanism tripped remotely, thus permitting the prop to be removed without needlessly exposing personnel to bad top. This system of support is finding increased use in the room-and-pillar workings of western Pennsylvania coal mines utilizing continuous miners in the pocket-and-wing technique of pillaring (Snell 1960).

The application of the self-advancing hydraulic prop promises to make longwall mining competitive with the highly productive continuous mining pillaring systems in use in American coal mines. In one such system three-prop and two-prop units are alternately arranged along a longwall face, with a roof bar cantilevered across each unit (Figure 3). All units are connected by a hydraulic ram to an armored (flexible) conveyor on which a 30-inch rotating-drum type of continuous miner rides. When the miner passes a two-prop unit the hydraulic pressure on the unit is released, the roof bar is depressed, the unit is drawn up by the ram attached to the conveyor, and the props are hydraulically reset. When several two-prop units thus have been extended sequentially the conveyor is pushed (snaked) laterally by the same hydraulic rams to the new face position. Then, sequentially, the three-prop units are extended in a similar manner and placed in line with the two-prop units (and the new position of the conveyor). This cycle is continually repeated.

It is important that the hydraulic props closest to the face assume their fair share of the load so that the main stresses are borne by the face abutment. Shear stresses will build up at the waste edge producing rock failure and the release of strata pressures. It is important that this release of pressure occurs rhythmically as the face advances. If the rock hangs up, the props will be overloaded and will collapse, permitting the top to break along the face, thereby creating a very hazardous situation. In one central Pennsylvania coal mine, the persistence of this condition led to the abandonment of a longwall mining experiment (Stefanko 1963). The remote, automated feature of these props makes longwall potentially amenable to complete automation. Such units are being experimentally tested in Great Britain today, and in the not too distant future mining will occur without a single man being exposed along the longwall face.

To provide adequate support for an opening subject to excessive creep, the yieldable arch has been developed (Figure 4). Steel circular sets are employed, but several frictional joints are provided. As the rock around the opening begins to converge inward, pressure builds up on the sets and support is provided. When the pressure approaches a critical value and the set is threatened with destruction, the joints slip slightly allowing a stress redistribution to occur. It is postulated that because of yielding, the rock overlying the excavation forms a natural arch of its own and is thus self-supporting. Once the arch has yielded it becomes stronger and even more able to resist.

Roof bolting is a new and effective support system developed to a fairly high degree in the last two decades. The support consists of a threaded bolt with an expansion type mechanism at one end. A hole is drilled perpendicular to the roof and the bolt installed with

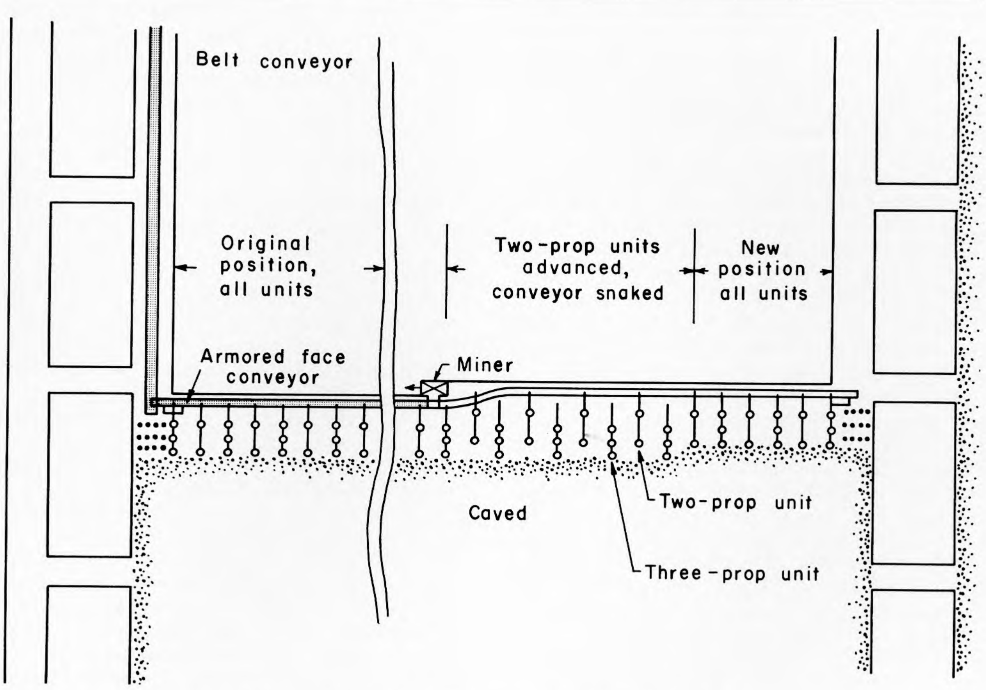


Fig. 3. The use of self-advancing hydraulic props in longwall mining.

the expansion mechanism at the back of the hole. The expansion mechanism can be of two types: a split wedge or an expansion shell. With the split wedge type the bolt is driven by a pneumatic hammer after the wedge is inserted to the back of the hole, splitting the bolt longitudinally and embedding each half in the sides of the hole. Placing a plate and nut on the collar side of the rod and tightening the nut tensions the bolt, effectively binding the intervening strata. With the expansion shell type of anchorage continued rotation of the bolt causes a plug to wedge out leaves which penetrate the sides of the hole, prestressing the bolt, and binding the strata into a thick, competent beam.

Tensioning a bolt improves anchorage in either of two ways: (1) as a clamped beam, whereby an increase in effective thickness results in a reduction of critical stresses, and (2) because of Poisson's effect a normal stress component on joint planes or other discontinuities increases the strength of rock (Mohr's criterion of failure). Thus, it is important that the bolt be prestressed to a certain level, which should then be maintained. Unfortunately, it is not yet possible to determine analytically what this level should be.

Because of the method of anchorage, very large stresses are concentrated at the anchorage site, resulting either in instant fracturing of the rock or in progressive deterioration caused by creep. In any event the tension on the bolt is reduced and its efficiency subsequently impaired. The author (1962) has shown that commercial shells installed in rock are subjected to high rates of load bleed-off. Other work at Penn State has revealed that merely rearranging the configuration of the serrations with respect to the force system minimizes bleed-off and improves performance (de la Cruz 1964). However, a radical change in the design of the anchorage can result in a much higher anchorage efficiency. In laboratory tests of a conical shell bleed-off was practically eliminated (de la Cruz and Stefanko 1965). Before this shell can be used underground, though, an effective method must be found for drilling a conical hole. A promising bit is now undergoing experimental testing in a local mine.

A possible solution to the problem of improving anchorage efficiency is to replace the mechanical anchor with a type of grouting agent. The use of epoxy resin was shown to increase the anchorage efficiency considerably (de la Cruz 1964). A new technique imported from Germany involves the use of a glass insert containing an epoxy resin and sand mixture which is placed in the hole ahead of the bolt. Rotation of the bolt breaks the cylinder, allowing the resin to be thoroughly mixed and the rod grouted in place. Tests to date reveal that this might answer the problem of bolting in ground in which adequate bolt loads cannot be maintained.

Roof bonding with epoxy resin, polyesters, and cement grouting has been used to stabilize roofs with indifferent success (Maize 1958). Holes are drilled well ahead of the face and a grouting agent is pumped under pressure into cracks and discontinuities to bond the top into a competent stratum. However, the problem of forcing the grout into hairline cracks and fissures is formidable, and the cost is quite prohibitive. Grouting generally is useful where a mine opening is affected by moisture and tends to slough. Placing the grout on the periphery creates a moisture barrier and prevents deterioration of the opening; however, this is not a support

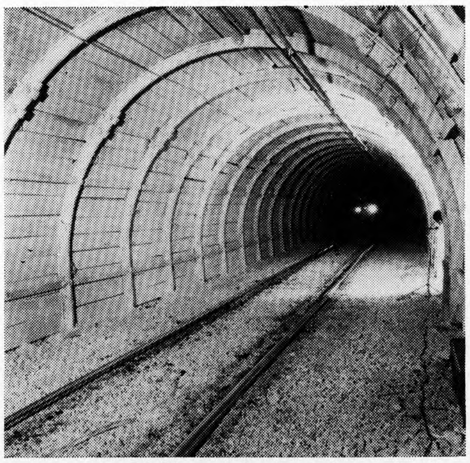


Fig. 4. Yieldable arches used as haulage support in a coal mine. (Courtesy Bethlehem Steel Corp.).

mechanism as generally defined. The use of cement to seal off water during shaft sinking operations has been very effective; it also helps to stabilize the opening.

Concrete has been used increasingly in recent years for lining openings to provide greater stability. Improved techniques which permit the lining to be carried to within 30 to 50 feet of the bottom in shaft sinking operations, together with the popularity of circular shafts for attaining greater depths, have resulted in greater concrete use (Gillingham 1964). Concrete piers are used quite successfully around shaft bottoms and sidings in conjunction with steel beams and wooden sills. Reed (1961) demonstrated that concrete could be effectively used as a pillar where necessary to provide protection. Using hydraulic jacks, this concrete pillar was prestressed so that it would assume its fair share of the load.

Research Efforts

The application of scientific principles to roof control continues to lag, and in the vast majority of mines today, trial-and-error techniques are still utilized in an attempt to develop adequate support systems. Even when apparent success has been achieved by modifying an existing system, there is usually no quantitative assessment of whether the improvement resulted from changes in engineering design or from altered natural conditions; thus, the old system might have been just as effective.

Although basic research in this area is still barely adequate, it has outdistanced applied research. Experimental and mathematical models are very helpful in visualizing stress systems and in understanding the effect of supports on mine structures, but they represent only a first approximation. Correlations must be sought with data from underground stress measurements if the results are to be practically significant. Actually, laboratory and field investigations supplement one another. Field data permit better similitude between model and prototype while the results of laboratory analyses permit better design of the field experiment.

Greater efforts must be expended in the development and application of underground instrumentation. Because of technological advancements in allied fields a whole new group of instruments has been made available to the mining engineer. Although various electrical, hydraulic, and mechanical gauges already exist they must be adapted to the special conditions that exist underground. These instruments are described in detail elsewhere (Hetenyi 1957).

To determine the effectiveness of pillars and other mine structural members various borehole devices have been employed. An excellent analysis of these has been given by Leeman (1964) and therefore, will not be discussed in detail here. Basically though, there are two types of borehole devices: (1) a solid inclusion type (stressmeter) and (2) a deformation or displacement measuring gauge. Theoretically, it can be shown that the solid inclusion type is not sensitive to moderate rock property changes (Young's modulus and Poisson's ratio), while the deformation gauge will produce proportionate errors in stress calculations when changes do occur.

Mechanical gauges employing gear trains and levers provide strain measurements from which stresses or loads on props, sets, linings, etc. can be determined. Since a single gauge can be used to make measurements at many points, it is economical; nevertheless, electrical resistance strain gauges and photoelastic gauges can be bonded to supports as well as to the surface of the openings themselves. Load cells, which have been found useful for measuring prop loads, may be of the hydraulic or electrical resistance type.

One such cell used with longwall props consists essentially of a steel cylinder to which is attached bonded electrical strain gauge arranged in a bridge configuration. When the cell is placed between the prop and top, roof pressure applied to the cell causes an unbalancing of the bridge which is calibrated in terms of prop load. This cell can be easily modified for use as a roof bolt load indicator by placing holes in the caps for inserting the bolt. The installed load can be carefully controlled, and with the aid of a recorder, the load history of the bolt can be accurately determined. The author (1962) has conducted many such tests and the results indicate that substantial bolt load bleed-off can occur which impairs the efficiency of the support.

To avoid the use of electrically operated indicating device in a gaseous atmosphere, a device based on the proving ring principle has been used (de la Cruz and Stefanko 1965). Two diametrically opposed holes are drilled in the periphery of a steel ring so that the device can be placed between the head of the bolt and the roof. When the bolt is torqued, bolt tension causes an elastic deformation which is measured by a dial gauge which is calibrated in terms of bolt load. Any subsequent bleed-off can be determined at a later date by remeasuring the deflection. Accuracy, sensitivity, simplicity, and economy are all characteristics of this gauge.

Convergence measurements have been found to be useful in the selection of suitable supports. Schwartz (1961) found that the initial convergence for the first fourteen days after a set of plugs was placed at the face of an entry is an excellent parameter for predicting future conditions. Although large variations were present among plugs placed along a given entry, a linear relationship usually existed between this parameter and another one, for example, the total convergence value recorded 229 days later. Once the relationship is established for a given mine, it is possible to predict future convergence values with an accuracy of plus or minus 5 per cent.

The ability to measure differential sag, which is an indication of bed separation, can be quite useful. From elementary beam formulas, one can calculate the stress distribution in an elastic beam for a given thickness. It is then possible to compare the theoretical stress distribution within the beam with the modulus of rupture to determine the validity of the theory. Likewise, in bolting systems the efficiency of the support can be assessed.

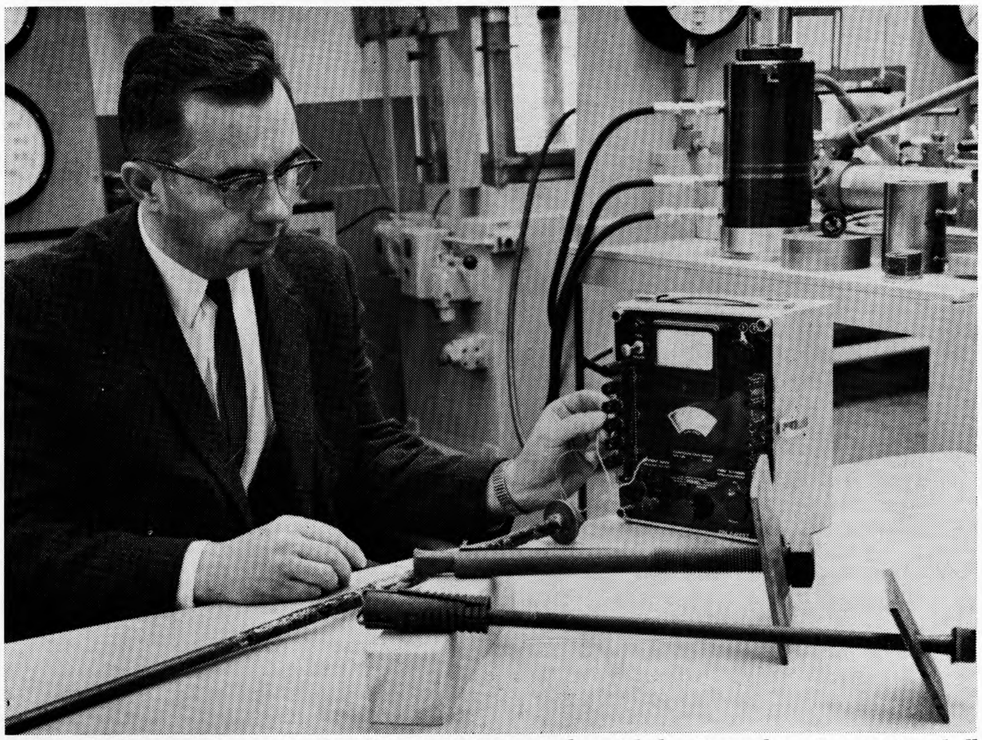
Research Problems

Contributing to the lag in underground stress instrumentation are the complexity of relating displacement and strains to stresses, the cost of developing instruments, permissibility requirements, installation costs, and the possibility of production delays. Furthermore, while it is relatively easy to make measurements, it is difficult to determine the significance of the measurements and to apply the results to actual situations. Interpretations of results and correlations with observed underground phenomena require experience in both rock mechanics and mining, otherwise, hasty and erroneous decisions may be made. The following is an example of a practical problem and how it can be approached.

In central Pennsylvania coal fields solid rib failures generally occur in development entries employing the half advance and half retreat system. Two plausible explanations for this might be given. Bed separation causes the development of maximum tensile stresses at the top of the beam and, since rock is weak in tension, failure begins at this point and propagates downward. It is also possible that no bed separation occurs and that conditions for massive rock apply. For a rectangular opening, the maximum tangential stresses occur at the corners. Here also maximum shear stresses equal to one-half the tangential value also occur. Thus there exist potential shear failure planes along the solid rib. Along the mined side these stresses are less than those along the rib because of stress relief resulting from pillar fracture or creep. In either situation, failure occurs at the same location and it is impossible to distinguish between shear and tensile failures by visual observation of the caved area.

One's first impulse is to reject bed separation as a cause of failure, the argument being that tensile stresses should be the same in all entries, for assuming similar spans and beam thicknesses, the probability of failure is equal in all entries; but the degree of clamping influences stress distribution and the clamping along the rib side may materially differ from that over the smaller pillars. Adler (1961) has shown that the relevant moduli of beam and foundation materials strongly effect the magnitude and location of the stresses.

While model analyses are helpful in establishing an insight into the problem, underground instrumentation is necessary. Roof bolts can be instrumented with load cells to measure the rate of bleed-off to determine whether it is excessive. Simultaneously, differential sag stations could be placed at various horizons in the strata to detect any bed separation. Such tests would reveal: (1) if and where bed separation occurs; (2) the bolt clamping force required to prevent initial separation; and (3) the efficiency of anchorage. Borehole measurements in the rib and pillars would reveal whether potential shear failure planes exist. One part of such an investigation has just been completed, and a report is available (de la Cruz and Stefanko 1965). Other aspects of the study are now being conducted.



Author checking strain gauge circuitry on instrumented roof bolt. Examples of expansion-shell (foreground) and split-wedge types of roof bolts are shown.

The next question that arises concerns what can be done to avert such failures, assuming the data reveal the cause. In Figure 2, three possible tangential stress concentrations are shown to exist at the side of an opening, depending upon the properties of the material. A horizontal line could be drawn on this curve representing the strength of the material, failure being indicated if this line intersects any other, and stability being achieved if the fracture value lies above the actual stress conditions. Actually, since the strength of rock (and coal) increases with confinement, this line is not horizontal, but probably increases within the interior portions of the rib. Roof conditions could be improved then by the mere transferral of the maximum stress into the rib without any reduction in its magnitude. In any event, the object is to limit the stresses in the rib below the critical value. These stresses might be reduced at the periphery of the opening and transferred into the rib by inducing plastic flow or fracture in the coal rib. In fact, because of the greater extraction on the mined side, the author contends that a more favorable distribution of stresses has occurred naturally, and this is why failure seldom occurs there.

A primary objective is to secure a more favorable stress distribution on the rib side. It has been suggested that the rib might be undercut and packed with the cuttings or other material. However, the degree of packing is critical and difficult to control. It would be necessary to progress from complete packing (solid coal) at the back of the cut to no packing in front. While this is not impossible to achieve, it is very difficult and can be relatively expensive. A simpler and cheaper way of achieving the desired result is by vertical shearing of the solid rib into a v-pattern. Another possibility is to use an augering machine to drill holes along the rib at different depths. Either condition would cause stress relief in the top rock along the solid rib, reducing maximum stresses and transferring them into the interior portion of the rib, thus providing a beneficial effect and reducing the incidence of failure.

When a study reveals that high bolt load bleed-off occurs which could lead to bed separation and subsequent roof failure, a redesigned shell or grouted bolts may increase anchorage efficiency. The author contends that the standardized pull test (AMC 1959) adopted by the mining industry does not properly assess the adequacy of a bolting system. Because the testing procedure is of short duration, it is a test of anchorage capacity and not anchorage efficiency. Since rock deformation is time dependent, a valid testing procedure must reflect the time parameter.

Conclusions

While strata control has not been very scientific in the past, the application of rock mechanics principles can lead to optimization of support systems. The development of new instruments for measuring the stress state underground provides for the first time in the history of mining, some rational basis for mine design. However, the inability to successfully cope with all situations that arise can be attributed to a lack of sufficient research in this area. More people must be trained as specialists, and of even greater importance, the need for, and importance of, rock mechanics research must be recognized and supported by mining companies.

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About the Author

Dr. Robert Stefanko, professor of mining engineering, has been Head of the Department of Mining since 1964. He joined the faculty in 1957 as an instructor, having been a graduate assistant from 1955. He holds the B.S. degree in Naval Science from the University of Virginia, and the B.S., M.S. and Ph.D. degrees in mining engineering from Penn State.

In 1948 he joined the Westmoreland Mining Company, and until 1955 served in several capacities including mine engineer, assistant mine foreman, and purchasing agent.

He established the rock mechanics laboratory in the Department of Mining as well as the undergraduate and graduate course offerings in this area. He has been active on rock mechanics committees in both the AIME and ASTM, and is presently chairman of the scholarship committee, Coal Division, SME-AIME.

In addition to his administrative and teaching duties, he is the principal investigator of four research projects on mine drainage, mine disasters, roof bolting, and seismoacoustical properties of rock.

College News Notes

Dr. B. F. Howell, Jr., professor of geophysics, attended the annual meeting of the Eastern Section of the Seismological Society at the Lamont Geological Observatory of Columbia University, Palisades, N. Y., on October 7 and 8. He presided over one of the sessions and was also Chairman of the Nominations Committee.

At the ninth biennial conference of the International Briqueting Association held in Denver, Colo., on September 2 and 3, Peter T. Luckie, research assistant in mineral preparation, presented an invited paper entitled "The Application of the Pelletizing Process to the U. S. Coal Industry," which he co-authored with T. S. Spicer, professor of mineral preparation engineering. The paper reviews the development of the pelletizing process as a means of handling very fine coal and the future application of this process in the U. S. coal industry.

While traveling in Europe last spring, Lothar Weyher, research assistant in mineral preparation, visited industrial and university research institutions in connection with his research on centrifugal separation methods applicable to the beneficiation of fine coal. Among the places visited was the research center of the Dutch States Mines in Heerlen, The Netherlands, which are widely known for their work on cyclones and the development of other successful benefication devices, such as the sievebend. He also visited the Steinkohlenbergbauverein in Essen, Germany; other research institutes in Germany known for their various investigations on the separation of solids in cyclones; and all four Schools of Mines of Germany.

Dr. Hans A. Panofsky, professor of meteorology, was in Moscow from June 15-22 to attend a conference on "Finescale Structure of the Atmosphere and Its Effect on Radiowave Propagation," at which he presented a paper on "Atmospheric Fine Structure above the Surface Layer," served as chairman of one of the sessions, and also wrote one of the five final summary reports. The conference was sponsored by several international scientific societies, the host being the Academy of Sciences, USSR, which will publish the proceedings in Russian and English.

Dr. Panofsky also attended the Workshop on Weather Satellite Data at Boulder, Colo., from August 25 to 31. This conference was called to enable interested meteorologists to study results of recent research in uses of weather satellite observations and suggest future possible operational uses.

Dr. G. W. Brindley of the Materials Research Laboratory and the Department of Geochemistry and Mineralogy attended the Fourteenth National Clay Conference and the Second Annual Meeting of the Clay Minerals Society in Berkeley, California, on August 23-26, at which he presented a report on "Classification of the Phyllosilicates, including the Layer Lattice Clay Minerals."

At a joint session of the Portuguese Society of Chemistry and Physics and the Geological Society of Portugal held recently at the University of Lisbon, Portugal, Dr. G. W. Brindley presented a lecture entitled "Reaction Processes in Some Oxide Materials." This meeting was termed an historic occasion in that it was the first time the two societies had held a joint session.

John H. Hoke, professor of metallurgy, recently attended the annual meeting of the National Metal Congress and Exposition of the American Society for Metals in Detroit, Michigan, where he was chairman of a technical session devoted to high strength steels, and at which he presented a paper entitled "The Degree and Stress Dependency of the Superplastic Effect in AISI 4340 Steel." In addition, he organized a luncheon meeting for alumni of the Department of Metallurgy who were attending the Metal Congress. There he welcomed them in the name of the department and brought them up to date on recent developments at Penn State.

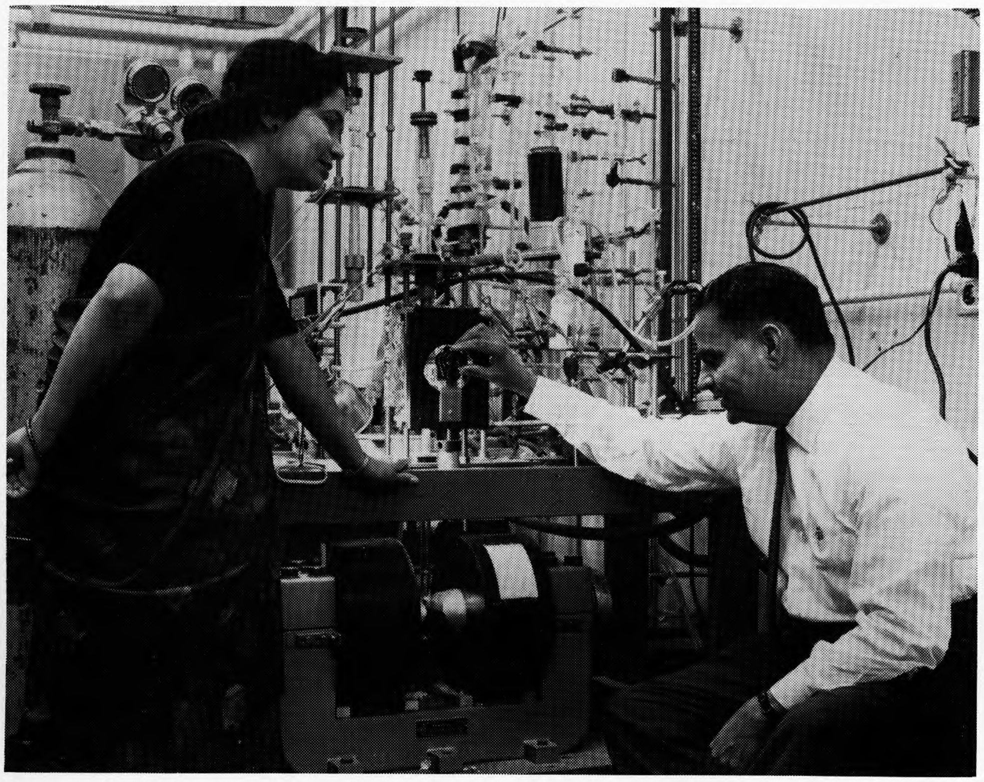
Dr. John D. Ridge addressed the Philadelphia Geological Society on Wednesday, November 17 on the subject of "Mineral Resources and Developing Nations." The talk, given on the campus of Bryn Mawr College, pointed out the necessity of capitalizing a significant fraction of the income received from mineral resources and discussed the methods of insuring a maximum return from the exploitation of mineral raw materials.

Harold J. Read, professor of metallurgy, is the author of a paper entitled "Essais de Durete dans la Finition des Metaux" published in the Bulletin de Documentation of the Centre d'Information du Chrome Dur, Paris, France.

Study of Brittle Materials

The Rock Mechanics Laboratory of the Mining Department of the College of Mineral Industries and the Ordnance Research Laboratory are cooperating on a $15,000 project concerned with the development of testing procedures to obtain basic data on the physical properties and characteristics of brittle materials. The results of this research program will be particularly meaningful in the design and construction of radons, underwater vehicles, and missile components. Dr. Madan M. Singh, assisted by Young Sam Kim, will be in charge of this project.

Cancer Research At Penn State



Laxman N. Mulay, associate professor of solid state science at the University, and his wife, Indumati Mulay, research associate in the Department of Material Science.

In Tokyo this summer at the Sixth International Conference on Medical Electronics and Biological Engineering, two Penn State researchers, Drs. Laxman N. and Indumati L. Mulay, a husband and wife team from the University's Materials Research Laboratory, reported that magnetic techniques developed here have revealed significant information on the differences in the free-radical activity and concentration of paramagnetic ions in certain normal and cancerous tissues.

The applications of three magnetic methods which reveal basic biomedical information about leukemia and other related diseases have been developed at Penn State. The Mulay team, using only tiny tissue samples, found cancerous specimens deviated "significantly" from normal ones. In normal tissues most of the molecules are magnetically in balance; thus, the electrons of the atoms in the molecules of these tissues are said to be paired, or "satisfied." However, in cancerous cells the normal biochemical reactions are disrupted. When many of the molecules in a normal tissue are broken, the parts are magnetically unsatisfied, and these unattached parts are called *free-radicals.*

The Mulays further reported that when they were testing the attractive and repulsive forces of a variety of materials in a magnetic field with a device that measures magnetic susceptability, they discovered that biological tissues gave varying results. While examining human cancerous tissues, they found that wide deviations occurred between these and normal human tissues. Certain types of cancerous cells, which contain more free radicals than normal cells, are more strongly attracted by a magnetic field than healthy cells.

By carefully plucking single cells from biological tissues, the Mulays were able to isolate the cells in a magnetic field under a microscope. The magnetic force on the tissue is measured by the distance from which it is pulled into the magnet. Thus, the varying amount of "pull" exerted on the cell by the magnet indicates some differences between normal and cancerous cells. Many tests on these human tissues and also on tissues from laboratory mice have shown that the technique works. Although this test is only a gross detector, it has some potential for qualitatively "guessing" whether or not a cell is indeed cancerous.

In a second technique reported on by the Mulays, the magnetic susceptibility test, samples as small as four ten-thousandths of an ounce indicated whether or not tissues are cancerous. By this technique the tiny samples are suspended on a fine quartz spring in a quartz test tube between two poles of an electromagnet. Such a spring can measure weight changes of about one part in a million, while the magnet creates a field of about 15,000 gauss.

The third cancer-detection system applied by the Mulays is the use of electron paramagnetic resonance (EPR), a complicated method which is far more sensitive and accurate than the two previously described. EPR measurements indicate the general nature of free radicals present in the cells and point up certain differences in them.

By this method tissue samples are again placed in a magnetic field in a quartz test tube. Radiation is beamed at high radio frequency through the tissues. An unpaired electron then spins around its axis and around the atomic nucleus in much the same way as the earth moves around the sun; and if enough energy is forced into the system, the spin of the electrons is changed. A certain combination of the magnetic field and the radio frequency radiation produces the right amount of energy necessary to counteract the orientation of these electrons. Thus this energy is absorbed by the electrons in the tissue.

The purposes of these studies by the Mulays were, then, three-fold: first, to observe whether any significant differences in the magnetic susceptibility existed between certain types of normal and cancerous cells (the reported results indicate differences do indeed exist); second, to obtain additional detailed information on the free-radical activity and paramagnetic ions in these cells (this phase is a matter for further study); and third, to aid the understanding of the disease by correlating the results of their findings with existing biochemical and medical information.

Dr. Mulay concluded his report to the conference by stating that, "the experimental observations . . . have shown a clear-cut distinction between the particular leukemic and non-leukemic tissues, while the general interpretations and conjectures have opened up a new area for basic studies on the identification of the free-radicals, the paramagnetic ions, their concentrations, and their electronic interactions."

Much of the research being carried out by Drs. Laxman and Indumati Mulay is supported by the American Cancer Society.

Oil Recovery Course

The Department of Petroleum and Natural Gas Engineering at Penn State is currently offering a ten-week course in modern oil recovery techniques for oil producers and petroleum engineers of the Bradford area. The course was arranged by Dr. C. Drew Stahl, head of the department, and professor R. W. Harding, and is being presented by Dr. David A. T. Donohue and Dr. S. M. Farouq Ali, assistant professors.

The first five weeks, presented by Dr. Farouq Ali, were devoted to a review of methods of oil recovery using miscible displacement techniques.

The second part of the course, which is being presented by Dr. Donohue, deals with thermal methods of recovering oil from "depleted" oil fields.

This ten-week course is one in a series of continuing education projects sponsored in recent years by the department of Petroleum and Natural Gas Engineering for the oil producers and engineers of Pennsylvania.

Bell New Director

The duties of director of the Mineral Constitution Laboratories have been temporarily assumed by Dr. Maurice E. Bell, and Mr. Norman Suhr has been appointed assistant director. Dr. Samuel E. Goldich, who was the director from August 1, 1964 to August 31, 1965, resigned to become professor of geology in the Department of Space and Earth Sciences, University of New York, Stony Brook, Long Island. Dr. Bell is also Director of the Mineral Industries Experiment Station.

Salaries At New High

A recent report prepared by the University Placement Service indicates that beginning salaries for June 1965 baccalaureate graduates have reached a new high. The report on salaries for Mineral Industries and several other Colleges is shown below:

COMPARISON OF MONTHLY BEGINNING SALARIES
JUNE BACCALAUREATE GRADUATES, MEN ONLY*

	1965		1964		Per Cent Change	
	Mean	*Median*	*Mean*	*Median*	*Mean*	*Median*
Agriculture	455	447	447	450	1.8	0.6
Business Administration	537	550	518	550	3.7	0.0
Engineering	621	630	602	610	3.2	3.3
Liberal Arts	483	495	488	495	1.0	0.0
Science	557	550	558	557	0.2	-1.2
Mineral Industries	634	640	597	600	6.2	6.7

*1964-65 Annual Report of the University Placement Service

Research For Mine Management

For the past several years the Department of Mining at Penn State has been developing the field of operations research as a decision-making discipline for the mining industry. Two years ago the Coal Research Board of the Pennsylvania Department of Mines and Mineral Industries provided funds for research in decision problem for low-cost mining. This far-sighted support has resulted in the application of operations research methods to solve certain transportation and production problems commonly experienced in the coal mining industry.

However, because OR is still in its infancy and because the gap between it and the scientist has not yet been bridged, sufficient interest has not yet been generated for these methods to be widely used. Consequently, the Coal Research Board suggested and provided partial support to inaugurate a short course to provide mine management with an administrative understanding of OR principles.

On November 7-12, therefore, in cooperation with the CRB, a five-day course in linear programming, one of the many facets of the field of operations research, was given at University Park. There was obviously a need for an administrative understanding of operations research for mine management because, in spite of news coverage given to linear programming, few business people understand how it can be used in their own companies. The purpose of the course, therefore, was to give a balanced and detailed presentation of some of the basic concepts and theories of linear programming, and to show how it can be applied in a variety of situations.

The course was conducted by Charles B. Manula, assistant professor of mining engineering, who was assisted by Richard L. Sanford, Y. C. Kim and Thomas O'Neil, research assistants in mining engineering, and by Jan Mutmansky, National Science Foundation fellow. Among the sixteen people concerned with the mining industry who attended the course, the following states were represented: Illinois, Indiana, Kentucky, New York and West Virginia, as well as Pennsylvania.

Gifted Students Science Seminar

The College of Mineral Industries is currently conducting a Gifted Student Science Seminar for 28 science students selected from Centre County high schools. This program is jointly sponsored by the Office of the County Superintendent of Schools and the College of Mineral Industries.

The seminar, which began on October 2, will last until February 19. During the first eight weeks, lectures have covered the earth sciences; the remainder will be confined to the applied sciences. The seminar will be conducted in the classrooms and laboratories of the College of Mineral Industries. Each of the lecture-demonstrations will be taped and broadcast on the National Educational Television network in the fall of 1966.

Special pamphlets are also being prepared for each lecture-demonstration so that, in addition to the television broadcasts, students will be in possession of pamphlets containing lists of materials, additional demonstrations, questions, and any problems requiring further study in their own classrooms.

The purpose of the seminar is to demonstrate to the students the various areas of research, the many exciting problems needing solutions, and the tremendous career potential in the fields of earth sciences and applied sciences.

MINERAL INDUSTRIES

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. . . dedicated to resident education, research, and continuing education in all fields of mineral discovery, investigation, extraction, and utilization to the end that true conservation—the efficient exploitation of known mineral deposits, the discovery of new deposits, and the development of new techniques for using mineral raw materials not now industrially employed—shall be achieved now and in the future.

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