Young

A Study of Mine Surveying Methods and Their Applications to Mining Engineering
A Study of

Mine Surveying Methods

And Their Applications to

Mining Engineering

L. E. Young, E. M.
Golden, Col.

The Iowa Engineer
1904
A STUDY OF MINE SURVEYING METHODS AND THEIR APPLICATIONS TO MINING ENGINEERING

By L. E. YOUNG

INTRODUCTION.

These notes, problems and observations have been compiled in order to present in useful form for the student much that is today scattered among various texts on surveying and much from practical work that is not included in the average series of lectures on mine surveying.

The surveying of lode and placer claims has been omitted, as the present methods of conducting such work are very different from practice in underground work, and recent legislation has caused considerable confusion in all mineral surveys.

Mine surveying is really one part of mining engineering. The purpose of these notes is to show how mine surveying enters into all the other phases of mining engineering and what methods are best adapted to each kind of work.

It is assumed that the student has a good knowledge of the instruments and methods of plane surveying. He should be skillful in handling and adjusting the various instruments. Instruction in the art of adjusting the transit as used in mining work should be given before underground work is attempted.

DEFINITION.

The following definition is included in the introduction to Johnson's "Theory and Practice of Surveying": "Surveying is the art of making such field observations and measurements as are necessary to determine positions, areas, volumes, or movements on the earth's surface. The field operations employed to accomplish any of these ends constitute a survey. Accompanying such survey there is usually the field record, the computation, and the final maps, plats, profiles, areas, or volumes. The art of making all these belongs, therefore, to the subject of surveying."

Mine surveying is generally defined as the art of making such measurements as may be necessary (a) to determine the location and extent of bodies of coal, ore, etc., (b) to determine the relative positions of points in the mine with regard to each other or to points on the surface.
A STUDY OF MINE SURVEYING METHODS

IMPORTANCE.

A. In all surveys the importance and the accuracy of conducting the work should be directly proportional. The great value of our mineral deposits and their limited extent warrant and demand the greatest care in establishing boundaries and in conducting underground surveys. An example of this fact is often seen in errors in surveying lode claims. A foot increased length on the line of a lode three feet wide and containing ore worth twenty-five dollars a ton, (fifteen cubic feet per ton) represents for each thousand feet in depth on the lode a value of five thousand dollars.

B. Pillars of sufficient size and properly located must be left in the mine either permanently or temporarily in order to protect important passages, to prevent the inrush of water and to protect adjoining property or buildings on the surface.

C. Royalties are often based on the underground surveys. Stopes and working places must be accurately measured to determine the volume of the excavation. From these figures the tonnage removed is estimated.

D. Before any permanent openings are made, complete surveys should be made in order to determine the most advantageous site. The best location for a shaft, slope or tunnel, and the best methods of exploitation, drainage, underground transportation, hoisting, ventilation, etc., depend on the knowledge of the deposit given by careful surveys.

E. In order to avoid breaking into old workings, where there may be quantities of gas or water, good surveys and maps are necessary. Many states require the filing of maps of mines that are about to be abandoned. When driving openings towards such workings, the proximity to dangerous ground can be determined by careful survey.

F. Geological features and irregularities discovered by drill holes or openings, when properly recorded and mapped, may be anticipated.

G. Buildings, tracks, reservoirs, streams, etc., may be properly protected if the openings are properly mapped.

H. Many mine surveying problems occur that demand great exactness; for instance, to determine a point on the surface directly above a given point underground, in order that a bore hole or shaft may be sunk to connect the former with the latter.

I. A system of bore holes or drifts, an examination of samples from the body blocked out and a complete survey will permit of the estimation of the value of a mine or mineral deposit.
J. Much litigation may be avoided if the mine is properly surveyed.

From these few statements the importance of mine surveying is obvious. An inaccurate survey is valueless, in fact a poor survey is often worse than none, in that openings may be driven in the wrong direction to make connections, old workings may be tapped, etc. One of the essential things for a mine surveyor to appreciate is the accuracy demanded of him.

DIFFICULTIES.

Many difficulties characterize mine surveying:

A. The surveyor is frequently called upon to carry a line through low, narrow places where it is difficult to set up the transit, take sights and measure distances. Coal seams twenty-eight inches thick are frequently mined; veins even narrower are mined and often stations must be established and surveys made in openings not more than twenty-eight inches high.

B. Artificial light is necessary in order to illuminate the point of sight and the cross hairs. Such light is generally very poor, and this fact greatly hampers work with the instrument. When the safety lamp is necessary, the candle power is reduced to less than unity.

C. A smoky atmosphere greatly reduces the possible length of sight and often compels the surveying squad to postpone the survey. Sights of over two thousand feet are possible in good air, but when the powder smoke is dense thirty feet is a good sight.

D. In surveying highly inclined openings it becomes necessary to use an auxiliary telescope to read vertical angles, to measure inclined distances, and to calculate horizontal distances and differences in elevation.

E. It is not always possible to make a closed survey, so that the advantage of having a closed check is lost. This necessitates repeating angles and remeasuring distances for all accurate work.

F. The actual underground conditions frequently necessitate the establishing of stations in the roof instead of in the floor and setting up the transit under a point instead of over a point.

G. The survey must be conducted so as not to interfere with mining operations. This requires that the work be conducted rapidly and at the same time accurately.

Methods of conducting underground surveys vary greatly; in England methods are still in vogue which have long since been abandoned in America. The methods in the United States depend largely on the value of the deposit and the proximity of other workings.
NOTES ON HISTORY.

A history of mine surveying would be composed largely of a record of the evolution of mine surveying instruments. Such a record has been recently compiled by D. D. Scott and others and published in the Transactions of the American Institute of Mining Engineers, Volumes XXVIII-XXXI. A few of the more important points given in this record follow.

"Mine surveying, in some form or other, has been practiced from the earliest times; but it has never kept pace with the other branches of surveying, or even with the art of mining itself, and cannot be recognized as an exact science until shortly after the beginning of this century."

1556 A. D.—Agricola, in his De Re Metallica describes the practice of mine-surveying. The instruments used were very crude, the principal one being the stationary compass.

1571. Diggs describes the "theodolitus," also applies the principle of the telescope.

1633. Rossler invented the method of suspending from a cord a compass and clinometer.

1681. Houghton describes the use of strings, plumbs and compass.

1686. Geometria Subterrania, of Nicholas Voigtel (Eisleben, Saxony, 1686) exhibits slight development in methods and instruments for mine surveying.

1710. Strum proposed the astrolabium for the miner.

1775. Kastner designed the quadrant clinometer.

1785. Beyer describes the common hanging compass. Tripod came into use.

1798. Breithaupt introduced mine theodolites.

1820. First American transit manufactured.

1843. Bourne first used high class theodolite in tunnel work.

1850. First American mine transit. Top telescope first used.

1858. Shifting tripod head successfully used.

1873. Coxe describes plummet lamp used in anthracite coal mine.

1874. Coxe describes five hundred foot steel tape used in coal mine surveying.

GENERAL STATEMENT OF INSTRUMENTS AND EQUIPMENT USED.

A. Transit. The instrument should be selected with reference to the work to be done. The regular light mountain transit, equipped with auxiliary telescope and mounted on an
extension tripod is commonly used. For careful work, the instrument should have a complete vertical circle. A complete description of mining transits is given in the volume of Scott and others on “Mine ‘Surveying Instruments.” The transit should be equipped with a reflector and at times with a prismatic ocular.

B. Compass. The compass, by means of which the first surveys were made and which is still in use in many districts, cannot be relied upon for accurate work especially in proximity to bodies of iron or iron ore. Lupton in his “Practical Treatise on Mine Surveying” published 1902, says in regard to practice in English mines: “The dial is the instrument generally used by mining surveyors for taking bearings and angles. The graduated circle is stationary and the needle swings clear of it. Dials are made of various sizes, from a small pocket one up to one carrying a needle eighteen inches long. The circle is divided into degrees, and if the end of the needle is not opposite one of the divisions, the surveyor has to estimate as nearly as he can the fraction of the degree beyond the last unit, thus, ⅛, ¼, ⅜, ⅝, ⅞, and ⅑; the bearing being, say southeast 21½°”.

However, in the United States, the compass survey is practically obsolete, many transits being constructed without the compass. The compass reading serves as a check to detect errors of more than one degree. For making a rough plat of a mine, the compass is, however, of great use. Many so called hand transits which resemble the English dial are used for making such plats.

C. Level and Rod. The ordinary engineer’s or wye level is used underground in determining the elevation of points. When the survey is properly conducted with the transit, vertical distances are measured and it becomes unnecessary to carry elevation by the level. Frequently the level is used in setting timbers, sleepers, machinery, etc. The level should be mounted on a heavy, adjustable tripod for precise work.

The rod used may be the regular five foot one which can be extended to nine feet. The target should be so constructed that it can be easily illuminated. Johnson suggests that “a small steel rod like a knitting needle may be soldered onto the target at the zero line so as to project two or three inches, then a paper and light held behind it properly will enable the target to be set.”

D. Tapes. In mine surveying in the United States the chain is practically obsolete. References are made in recent articles to its use, but the work done with the steel tape is much more accurate. A 100 foot steel tape divided into tenths and hundredths of a foot is most generally used by American engin-
ciers. Mr. E. B. Coxe was the first to introduce the long steel tape or chain tape, at first 500 feet long, afterwards up to 1000 feet. Many tapes, 100 feet long, are graduated to feet throughout their entire length and to hundredths only from 0 to 10 and from 90 to 100. In the anthracite fields tapes 310 feet long have been used. The tape is so graduated that beginning at one end, the marks are 10, 9, 8, 7, to 0 and then increase up to 300 at the other end. Tapes 300 to 1000 feet long are of great advantage in measuring long sights and also in measuring up working places.

The length of tape and the graduation should be adapted to the work. For important surveys, especially in establishing the base line and carrying the meridian into the mine, a very good tape should be used. It is never economy to purchase a cheap tape. Errors are frequently traceable to the use of a poor tape, and the cost or re-surveying any portion of a mine would more than pay for a good tape.

In shaft work the tape should be of such a length that the longest sights and distances can be measured without establishing intermediate points. A 200 or 300 foot tape carefully graduated should always be reserved for shaft work.

In traversing underground where long sights cannot be made, a tape more than 100 feet long is inconvenient. However, when entries or levels are driven straight or "on line" long tapes can be used to advantage.

For "measuring up" stopes and rooms long tapes should be provided—the length being determined by the regular system of opening up the working places. In coal mines the rooms are frequently from 200 to 300 feet long. In metal mines the levels are seldom more than 200 feet apart and the stopes are therefore limited to 200 feet in height. These tapes need not be graduated more than to feet.

Pocket tapes of 10 to 25 feet lengths should be carried by the instrument man and the man who takes the side notes. The instrument man must measure the height of instrument and of the point, and should have a tape reading to hundredths. In taking side notes it is generally not necessary to measure closer than the tenths of a foot.

The standardizing of tapes is very important. If no standard is within easy access of the mine, the tapes should be sent at regular intervals to some instrument maker to be compared with the standard. In repairing tapes, it is very difficult to restore the proper distance between graduations on opposite sides of the break. It pays to send good tapes when broken to those who make a business of repairing tapes.
Mine water frequently attacks tapes locally, thus causing a reduction in the cross-sectional area. The tape hence becomes weaker at such points and, if it does not break, will stretch considerably if subjected to much tension. Such elongation can be detected only by comparison with a standard.

Provision should be made for repairing a broken tape without returning to the surface. Various types of clips or splices can be made for this purpose, or can be obtained from instrument companies. Such precautions may save considerable delay.

Cleaning the tape is very necessary if the tape is to be used in a mine producing acid water. Most mines produce enough water to coat a tape with mud if the tape is not held off the ground. Acid water if not speedily removed will soon weaken the tape, and render it unfit for accurate work. Grit and mud will, by abrasion, injure the tape in several ways. The graduations will soon be worn away and the coiling of the tape on a reel will give the grit opportunity to grind out deep notches. The tape, then, must be carefully cleaned either underground or on the surface. A preliminary cleaning should be given underground, but this should always be succeeded by careful work on the surface. One end of the tape should be attached to a fixed point several feet above the ground and beginning at the end so attached, the operation of removing the dirt and wiping dry should proceed to the unattached end. After the tape has been wiped dry, it should be rubbed with oil. Common kerosene is generally used, but this is hardly of benefit. Sperm and olive oil are recommended.

Reels of various types are used in mining work. It is advisable to keep the tape out of the water and mud, and when not in continuous service it is advisable to reel up the tape and thus preserve it. Such reels may be of wood or metal, and should be so constructed that the tape can be wound up without binding, even when heavily coated with dirt. A convenient form of reel is made of steel, of such design that the tape winds on itself; across the back of the reel is a leather band or holder through which the left hand is passed. Holding the reel in the left hand the chainman easily winds up the tape by means of his right. Care should be taken in removing the tape from the reel as carelessness will result in breaking the end off the tape. It is advisable to carry the tape into and out of the mine on a reel.

Metal handles or clamps may be attached to the ends of the tape or points intermediate in order to facilitate measuring. Many engineers attach leather strips to the ends of tapes instead of using the metal handles. In order to have uniformity of
tension in chaining spring balances may be used. In this way, the tension being known, the amount of sag can be calculated.

The average tape used in mine surveying is graduated only to feet. Some special device or method must be employed in order to read the tenths and hundredths. Commonly in chaining or measuring the tape is pulled up, the front chainman marks the proper distance on the tape by means of his left thumb, then reads the next foot mark toward the zero point, and measures to his thumb by means of a short auxiliary tape. Instead of marking with the thumb a metal clip may be used; this will witness the distance until measured with the small tape.

A convenient scheme is used by many engineers, by the use of which marking clips and small tapes become unnecessary. A strip of wood about one inch wide, one-eighth inch thick, and about seven-tenths of a foot long is prepared. One end is cut square and becomes the zero end. Measuring from this end, tenths are laid off and notches cut as marks. In order to distinguish the zero end, the other end is rounded. Suppose the distance between stations is between twenty-seven and twenty-eight feet. The tape is drawn up, the thumb of the left hand catches the point on tape and the strip of wood is brought up with the right hand and the distance from the point marked by left hand to the nearest foot mark on tape is measured by the stick. The tenths can then be easily read and the hundredths estimated. This decimal of a foot will be either added to or subtracted from the whole number of feet depending on the direction of measurement. The stick can be carried in a pocket and can be easily replaced if broken or lost.

The zero point of the tape may be several feet from the end. In the anthracite fields this length from zero to the end is as much as 10 feet. These 10 feet are graduated regularly to hundredths, the end of the tape being marked 10. From zero to the other end, the tape is marked in feet. In measuring with such a tape the rear chainman first holds the zero point of the tape at the rear station so that the fore chainman can determine the nearest 10 foot mark toward the rear chainman. That is, he determines whether the distance between stations is between 110 and 120 feet or 120 and 130 feet. If between 110 and 120, he draws up the tape until 110 is at the front station, he then calls "chain" to the rear chainman who reads on the extension beyond the zero point the number of feet and hundredths which must be added to 110. Thus auxiliary tapes, markers, etc., may be avoided.

The measurement of distances should be checked in all possible ways. Each party should measure distances twice. When returning through newly surveyed openings, some mem-
ber of the party should be detailed to pace distances and check the measured distances. When it is known that levels, entries and rooms are driven a standard distance apart, calculations should be made underground and measured distances thus checked.

E. Bobs an Stations. The tools and equipment for locating, making and marking stations vary considerably and will be described in detail later. Commonly, plumb bobs suspended from stations in the roof by twine or wire give the point of sight. Three bobs should be provided, one for the instrument, one for the back sight and one for the fore sight. Ample string or wire and other supplies should be provided for each day's work.

Miscellaneous. Note books must be provided for the proper recording of all observations made. Books should be so filed and work so recorded that any member of the engineering corps can find and plat notes, or continue the work of any other member. The notes of a transitman are generally taken as an index of his work. Some field or pocket book should be carried by the party so that calculations may be made in the field if at any time a check on the work is desired or if it becomes necessary to set points properly for directing workmen in driving openings or in locating timber, guides, etc.

A reading glass is necessary for the transitman, a sheet of tracing cloth or oiled paper for those giving sights, a thermometer if there be any marked increase of temperature in the lower workings of a mine over that in the upper workings or of the surface. Corrections in measurement should be made when the temperature is high. An adjusting pin, screw driver, and simple repair kit should be included in the outfit of a party which is going out for several days surveying.

SURVEYING PARTY.

Number. The number of men included in the party depends entirely on the work to be done, the skill of the members, and the time allowed for completing the work. Often, the transitman only is experienced and must take as his assistants so called “helpers” who know nothing of surveying. In order to do measuring the party must consist of at least two. When a mining company has sufficient work to keep one party in the field continually, one or two men may assist the transitman. In the anthracite field, surveying is done by parties of seven divided into two squads—one consisting of the chief and two helpers who locate stations, measure distances and take side notes, and the other party reads and records angles and distances. Parties of more than four are uncommon.
Work of Members of Party. The chief of a party directs the survey, establishes points, takes side notes, and checks distances. He must be able to plan and direct the work and manage men. The transitman may be chief of party. He has charge of the transit, reads and records angles and distances; he may take the side notes. He must be an accurate and rapid worker. Accuracy, however, comes first, as inaccurate work is valueless.

The fore sightman or fore chainman establishes stations, numbers and marks the stations, gives the fore-sight, superintends measuring, records distances, may keep side notes and may be detailed to set up the instrument. He must be a good conscientious worker and should take much pains and pride in his work.

The back sightman gives backsights, assists in chaining, carries any material to be carried, keeps all equipment save the transit in good shape. cleans the tapes, makes plugs, etc., and sharpens tools. He must be a good workman and should have ambition to become the transitman.

Side notes may be taken by the chief of the party when the party is divided into two squads, and by the transitman when there is but one squad. If the fore sightman is competent, this work may be assigned to him. The completeness of the mine map depends largely upon the care with which the side notes are taken, and such work should receive considerable attention. By side notes are meant those additional measurements which are taken off the traverses, by which points in adjacent excavations are located with regard to the traverses. The dimensions and location of openings are thereby determined.

Work of Party. A. The success of the party depends largely upon the chief. He should understand men, have their confidence, encourage them to learn the details and principles of the work. He should be able to plan work so that the entire party shall be busy and if possible have his assistants attend to all details. He can then give his full time to running the party and doing transit work.

B. A good party is composed of men who will do more than the actual work assigned and who realize the importance of the details. Failure to provide daily the proper tools and equipment, may render many hours work valueless or cause considerable loss of time while the necessary equipment is being provided.

C. Surveying work should not interfere with mining operations and vice versa. When properly planned and executed, the work may be carried along entries which are used for haulage without materially interfering with traffic. Smoke will
interfere with the work if the chief has not anticipated it and transferred his work to passages having a clear atmosphere. The work can be properly planned so that the party shall have completed the work in haulage ways or near working places before cars or smoke can interfere.

D. Too much stress cannot be laid upon the importance of subordination of all other members of the party to the chief. The party must work together. The chief should enjoy the most earnest co-operation of his men and should make them appreciate that careful work and strict attention to all details are necessary to good surveying. A few minutes given to explanation of the importance and object of certain operations may in the end save much time. Each man should be made to realize that his welfare is being considered by the chief, that he is not obliged to do unnecessary work, or to remain in strained positions an unwarranted length of time, and, especially, that his time belongs entirely to the chief of squad.

E. A complete and practical system of signals should be devised for underground work. Systems in vogue on the surface are in general impracticable underground. In sighting and measuring it is very important that the man at the instrument or at one end of the tape should be able to communicate with his co-laborer without walking or climbing to him. The movement of a light or special sounds are commonly used to indicate certain orders. However, where a number of lights are continually moving about, as in shaft sinking, the use of the light as the signal is impossible. Again, the voice or a whistle cannot be used in the proximity of noisy machinery. Frequently in doing important work, especially in shafts, surveyors stretch a chord or wire so that by movements of this chord one party below may signal to another above or vice versa. Special systems may easily be devised to fit the occasion.

F. Special care should be taken with all notes. Notes cannot be too full. The surveying party should note geological features, character of mineral, thickness and character of coal or other points which may later on be of value in planning underground operations. It is much more economical to take full and complete notes when making a survey than to be obliged later on to make a special visit to determine these points. By noting faults or horses in the upper workings, these can be frequently anticipated in driving lower or adjacent openings. All readings and measurements should be checked as often as possible. Subordinates should be trained to check readings for the instrument man. The foresightman should carry a notebook and record measured distances even though he do not take the side notes. Many calculations may be made in the
field to check observations without interfering with actual work. Frequently a few minutes spent in this way will save several hours work in correcting errors or making resurveys.

UNDERGROUND STATIONS.

The care with which a station should be established depends upon the character of the survey and whether or not it is to be considered a permanent station. Stations may be divided into two groups—(a) temporary, and (b) permanent.

By a temporary station is meant any station which will probably be knocked out soon after being established or one which is designed to serve only for the survey for which it is put in. A permanent station is established carefully and precautions are taken to have it so located and marked that it may serve with similar points as a base or reference to which subsequent surveys may be tied.

The inexperienced surveyor loses more time by making poor stations and by marking them in a poor manner than by making actual errors in the survey. The surveyor whose work it is to keep a shaft or tunnel properly aligned or to keep the mine man up to date should before beginning a survey check up his newest stations to see that they have not been disturbed. Very often the station mark has been removed, the station has been tampered with, is inaccessible or has dropped out or been completely destroyed. The experienced surveyor sees that he has a number of stations so established that even though one is destroyed, he suffers no great inconvenience.

1. The permanency of a station in the floor or bottom depends upon (a) the marking, (b) the character of material, (c) the hardness of ties, (d) the amount and kind of haulage, (e) the character of the roof, (f) the character of the station itself or (g) the mine water.

a. In all cases the station which cannot be indentified is worthless. To be of value or permanent the station in the floor must be so marked that it can be easily found and identi-

b. A permanent station cannot be established in the floor when the latter is composed of very soft material; or, when there is considerable pressure about the opening, the floor material is forced up thus displacing the station.

c. Frequently stations are established in the ties. A station in soft wood is practically valueless as a permanent mark for it is easily loosened or displaced.

d. Unless protected in some way by a shield or covering, a station in the floor of a roadway along which there is considerable haulage is liable to be knocked out. This is espec-
ially true when the motive power is men or mules; with rope or locomotive haulage the station is more permanent.

e. The character of the roof must often be considered. If the roof is very strong there is probability of the floor rising; if the roof is fragile considerable material falls and must be removed. Stations in the floor of an entry in which there are frequent falls may be knocked out by the men who shovel out the rock.

f. The station to be permanent should consist of a nail driven into a wooden plug firmly imbedded in the floor or of a rivet firmly imbedded in the floor. Nails in ties or in cracks in the floor can hardly be classed as permanent stations.

g. Stations established in the floor are liable to corrosion by mine water. The metal may be entirely dissolved or various materials may be deposited upon it.

h. Stations in the floor when near working places will be loosened or blown out by shots.

The permanency of stations established in the roof depends upon (a) the marking, (b) the character of roof, (c) the character of station, (d) workmanship, (e) mine water, (f) proximity to workings, (g) character of floor.

b. When the roof is fragile, the station may drop out.

g. When the floor is soft, and there is considerable roof pressure, material is forced up from the floor and the roof sinks thus decreasing the elevation of the station or dropping it out completely.

The permanency of a station established in timbers depends upon (a) the permanency and character of the timber, (b) the settling of the timber, (c) the character of the station, (d) marking, (e) the proximity to working places.

a. Stations placed in poor timbers or sets which may be removed cannot be considered permanent, in fact most stations in timber are temporary.

b. Timbers frequently settle considerable, especially when the bottom is soft and no sill is used.

e. Timbers set near working places may be knocked down by shots.

Stations may be established in timbers which must be located in definite positions as shaft timbers.

In certain systems of mining, as longwall advancing, it is almost impossible to keep stations in the roof, which fact is due to the caving of the roof as the work advances. As longwall is used in flat seams, horizontal angles alone must be measured. The sinking of timber and the rising of the floor need not be
considered when no horizontal displacement of the station is noted. Many engineers carry stations in the floor under such conditions.

2. Stations should be so located that (a) the fewest number, necessary for the purpose, be used, and that (b) these be at the most available and useful points.

a. Before locating stations it is advisable to inspect the workings to determine the most advantageous points for stations. Short sights and unnecessary set-ups can often be avoided by thus planning the work. Reference stations should be established at convenient points in back entries so that haulage, etc. may not interfere with the work. At the intersection of important roadways, good witness stations should always be established because points at intersections are often knocked out. Permanent stations should be located where there is little danger of their being disturbed, not always at the most convenient points.

3. Character of Station.

a. "The simplest top station is a shallow conical hole made with the point of the foresightman’s hatchet, which is dug into the top rock and rotated; it is called by some a jigger station. Corps using these entirely have a jigger, consisting of a steel pointed extension rod with an offset holding a paint brush. The rod is long enough to allow the point to be driven into the roof at any height, and its rotation marks a circle with the brush, which is also used to mark the number beside the circle. Centers are set under such stations, and sights are given by another tool—also called a jigger. This is an extension rod, beyond the upper end of which projects a sheet iron shaped like an isosceles triangle, with the upper and smaller angle cut off so as to form an end one quarter of an inch broad, and in this end is cut a U shaped groove. The sights are given and "centers" set by putting a plummet chord in this groove. The advantage of this method lies in the rapidity with which the centers are set, and the sights given, and the ease with which the highest stations are reached. The disadvantages are the impossibility of making the jigger hole perfectly conical, so that the jigger can be set in the same place on two successive sights, and of making the plummet chord hang in exactly the same place."*

b. Common nails may be driven in cracks in the roof or floor. When the nail is driven in the roof a plumb line and bob are suspended. When the nail is driven in the floor or tie, a pencil or rod is placed vertically over the nail at which the instrument is sighted.

*Coll. Eng. XIV, 10.
c. Spads, spuds, staples or screw eyes may be driven into a crack in the roof or into a timber. Spads or spuds are generally made by hammering out the head of a horseshoe nail and punching a hole in the flattened head for inserting the chord. Iron or copper may be used for spads, but iron is generally used because it cheaper. It is not advisable to make a station in a crack, for the same force which made the crack may cause it to open further and the station will then drop out. Such cracks are generally water courses.

For accurate work nails should be used because the plumb line may be suspended from either side of the nail and in short sights the error due to the width of a nail in backsight and foresight will soon become quite appreciable.

d. A spad is driven into a wooden plug in the roof. Holes from 1 1/2" to 6" in depth and of such diameter that the spad will not split the plug driven into the hole are drilled in the roof at the point selected. The smaller the hole the quicker the work. Drilling may be by hammer and drill, twist drill or power drill. When the roof is poor, it must be brushed down until it sounds firm under the hammer. When the roof is too poor, a special type of station may be put in or a timber may be cut in to support the station temporarily and a permanent point may be established near by.

The plug is of wood, of slightly larger diameter than the hole, tapered at one end, sawed off square at the other, slightly longer than the depth of hole, and driven up flush with the roof. When wet the plug expands and fills the hole completely. The wood should be hard enough to stand driving and to hold the spad and should not split when the spad is driven. Good plugs for small holes can be made from broom handles. Plugs and spads should always be made on the surface. The spad should be driven broadside to the line of sight.

e. A hole 3-32" in diameter may be drilled in the roof; a cord or wire placed in the hole can be held firmly by a small wooden plug driven in flush with the roof. A lamp or bob as desired may be hung from the cord or wire.

f. A cylindrical hole may be drilled in the roof. A clip made by bending back upon itself a band of thin steel 3-32" wide having a hole drilled in the center of the clip may be placed in the hole. The clip is so made that the cord passing through the hole in the clip always hangs from the center of the hole in the roof. After the observations are completed, the clip is removed from the hole in the roof. The disadvantages of such a station are important ones. The roof must be good or else uniform holes cannot be driven. All holes should be of small depth and circular in section. The clip cannot always be re-
placed in the holes so that the line hangs in the same position as at first.

g. Stations in the floor may be made by placing a 36" rivet in a hole ½" diameter and 2" deep. The end of the rivet is split and a wedge of wood inserted in this split so that when the rivet is driven into the hole it wedges fast. A mark made on the rivet head gives the point for the station.

h. When the roof is so poor that a station cannot be established in it, three spads are driven in the wall near the roof for the support of the following device.* In the center of a sheet of galvanized iron, cut to form an equilateral triangle, base 1 ½", is punched a small hole through which is hung a plumb bob. To each corner of the triangle is attached a chain by which the entire device may be hung from the three spads in the walls. The chains are of equal length and must not stretch. The spads should be so located that the plate will hang horizontal and the plumb bob in the line of sight. The disadvantages of such a station lie in the fact that three points must be preserved instead of one. The bending of the plate, the twisting of the chain or the bending of the hooks by which the chains are hung from the spads will prevent the hanging of the bob to duplicate the first conditions. In low entries it is difficult to manipulate this device so that the instrument can be easily set up under the bob so suspended. The point of set-up may be marked in the floor and the instrument set up over this point.

4. Marking of Stations.†

a. As previously stated a station so poorly marked that its identity cannot be determined is valueless until it has again been properly located. Temporary stations need not be marked very carefully as they are not designed to be of future benefit to the one who establishes them.

b. In addition to being numbered or marked to distinguish from other stations all stations should be so witnessed that they can be readily found.


†A number of large and well managed mines do not mark the number of stations underground. All stations have a number which appears in the note book and on the maps. There may be cited an instance of a mine operating three shafts over a thousand feet in depth. There have been established over two thousand stations not one of which can be identified by any one unfamiliar with the mine. It required a new surveyor three months to learn the mine so that stations could be found. Again in this same property station 121 may be on the first level and station 122 on the eighth; station 2001 on the ninth and station 2002 on the third. The mine officials appear to be well satisfied with this lack of system.
B. Place. Marks may be made (a) on the station itself, (b) on the roof or walls, and (c) on the timber.

a. It is rather unwise to witness the station on itself; if the station be destroyed there is no mark; a better method can easily be found.

b. In coal mines the roof is generally smooth and the walls rough. In metal mines very often one or both walls are smooth and the roof rough. In tunnels generally the walls and roof are all rough. When walls and roof are equally firm, the smooth surface is to be preferred.

c. Marking on timber depends on the permanency of timber and of the station. It is difficult to paint or mark on rough timber; however, dressed timber gives a good surface for any kind of a mark.

C. Kind of Marking.

a. Paint. Some geometrical form enclosing the station or number of the station may be used. When the station is in the floor a vertical line is drawn on one of the walls opposite and the station number enclosed in some geometrical form. The mark used should distinguish the station from those of other surveys. The color of the paint used depends upon the background. For dark walls use white paint (white lead mixed with linseed oil) and for white walls, as salt and gypsum, use dark paint. Sufficient paint for the day should be carried in a quart tin can. A round bristle brush about one inch in diameter and well wound with wire in order to make it stiff enough for rough work is used in applying the paint to the walls. When the walls are very wet, paint is not to be recommended as it comes off quickly.

b. Chalk. When the instrument man marks stations himself, which is generally when he desires only temporary stations, chalk may be used on dry walls.

c. Nails and washers. At times numbers are made by driving nails into timbers. A washer is used to denote zero. Nails may be driven to outline figures or in rows composed of the same number of nails as there are units in the digit. It is rather inconvenient to use this system when the numbers are large or where there is little timbering.

d. Tags. These are generally discs of brass, zinc or lead, on which is stamped the mark for the station. The tag is punched and through the hole is driven the spud or nail of the station. It may be painted white to make it easily seen. Tags made from sheet metal upon which the number is stamped may be hung from the station. When the station drops out there is no clew to its former position.

e. Figures chiseled in the wall. This mark is very permanent in good rock, and is the best for wet walls.
All marks should represent good workmanship; numbers and letters should be easily legible. In some way they should be distinguishable from marks of other surveys.

D. System of Marking. Marks to be of value must be according to some system. The importance of having a good system can be readily appreciated. When a party is daily establishing stations in various parts of a large mine, unless some method is used in marking stations it will be necessary to have a map of the mine at hand in order to locate a given station. Again instead of the station identifying itself with regard to location, the map must again be used. In large coal mines openings cannot be readily identified unless stations or drifts are intelligently marked according to some system.

a. Frequently, drifts or entries are named and the stations on the drift are numbered consecutively towards the working face. A station then may be marked Swede Drift 9. It is rather awkward and laborious to put the name of the drift at each station.

b. Openings may be lettered and stations numbered consecutively as in (a). A station then would be marked A 6, or M 16, R 21, etc.

c. A section of a mine may be given a letter or a number; as all ground between certain boundaries would be A and stations in that block numbered consecutively as A 1, A 100, etc. Levels of a mine may be lettered or all stations on a certain level given a group number, as all stations on first level would be 100 to 199, on the third 300 to 399, etc.

d. When drifts or openings are turned off at regular intervals these may be numbered consecutively from some given point and with regard to direction. Along a main entry running east and west, side entries north and south are distinguished as first south or tenth north. Stations are numbered consecutively on the main entry without prefix or suffix. On the side entries we may number 10N25 or 2S33 meaning station 25 on the tenth entry to the north and station 33 on the second entry to the south. In this way the station really locates itself. Instead of numbering the stations consecutively, distance from a given point may be used. Suppose a station is 307.46 feet from the main entry on the fifth south, the mark should be 5S3+07.46.

e. The system of numbering stations consecutively as they are put in is very poor practice. By this method station 356 may be in one part of a mine and 357 in another part possible a mile distant.

Various modifications of these systems may be adapted to circumstances.
5. Point of Sight. In surveying underground artificial light is, of course, necessary both at the instrument and the point sighted. Various devices have been used to illuminate the point sighted.

a. Common practice is to use a light as the point of sight. The point of light used depends largely upon the character of the mine and what kind of light the miners use. In metalliferous mines the tallow candle is used, in coal mines an open lamp burning lard oil or the safety lamp. The acetylene and electric lamps are sometimes used by mining engineers. When locating points in rooms or stopes or at the breast of drifts, the light is often sighted at instead of an established point.

b. A rod, nail or pencil properly illuminated may be used for rough sights. When the side telescope is used, the double or lop-sided target may be used instead of the ordinary rod or plumb bob. The double target is so constructed that the point sighted at on the target is not directly under the station but off to one side a distance equal to the distance from the axis of the side telescope to the station under which the instrument is set, or equal to the distance between telescopes. When such a target is used no correction need be made for the side telescope.

c. A plumb line suspended from the station is the common point of sight. The vertical wire of the instrument is set upon the line or upon the point of the bob. In order to facilitate the measurement of distance and to have uniformity in the work, it is quite common to loop the line about a nail or a match so that when the line is stretched taut by the weight of the bob the nail or match will hang horizontal, thus giving a good point upon which to set the horizontal wire. The vertical angle and measurements to the instrument and to the roof and floor are taken with regard to this point. To illuminate the line or bob sufficiently a sheet of oiled paper or tracing cloth should be placed in the line of sight back of the plumb line and back of the paper the light.

d. In (a) it was suggested that the sight be taken at the naked light, Mr. Coxe adapted the plummet lamp which consists of a heavy lamp suspended from two or three chains so that the whole can be easily hung from an established point in the roof. The lamp always hangs at the same distance below its point of support. When the transitman is ready to sight, the lamp is hung and lighted and the flame bisected by the vertical wire, the horizontal wire being set upon the proper point of the lamp.

e. In the three tripod system the point of sight is again a lamp but instead of being suspended from the roof it is supported on a tripod similar in every way to the one on which the transit is set up.
f. Instead of having an illuminated background against which the point of sight will show plainly, the background may be darkened and the line of sight illuminated. This is accomplished by cutting a horizontal and a vertical slit in a sheet of metal and after the sheet has been placed so that the slit will be in the proper line, the lamp placed behind the slit illuminates the slit.

Vertical sheets of metal in the same plane and so mounted that they can be easily shifted have been mounted on a platform and placed behind wires used in shaft plumbing. By this arrangement the sheets may be shifted so that a vertical line of sight may be developed directly back of the wire sighted.

g. Various patent devices for sighting in underground work have been put upon the market. One of the best of these consists of a strip of sheet metal about 2" wide and 12" long. At either end are cut holes so that the strip may be suspended from the station by a cord and from the lower end of the strip the plumb bob is hung. A number of holes are drilled in the strip, the centers being on the line between the upper and lower cords. Half way between the ends of the strip, the hole drilled is about ½" diameter, from the center towards each end the holes diminish in diameter and are far enough apart so that there remains between adjacent holes about ¼" of metal. When a light is placed behind the strip, the strip being at rest, a vertical line of sight appears to the instrument man. He can also sight at the plummet as it revolves, bisecting the ellipse of light in the center. The different sizes of holes will suit long or short distances by allowing more or less light to pass through.

BASE LINE.

1. A base or reference line should always be estimated or selected before any attempt is made to carry the meridian underground. It is always advisable to establish the meridian before doing any underground surveying. If this be not done it will always be necessary to correct bearings or later on to change the entire set of field notes. The importance of having such line is very obvious especially when several openings are made on one property and it is necessary to survey for connections.

2. Such a base line should be marked by permanent stations that will be accessible at all times if possible. In districts in which the ground is covered deep with snow during many months in the year, points must be established where they will not be covered very deep or where they can be found easily. These points should be convenient to shafts or openings so that
sights to the same line can be taken from any opening. When such arrangement cannot be made a trangulation system should be laid out.

3. All underground surveys of adjacent properties should be referred to the same base and the same datum. Unless this is done at once corrections will have to be made when connections between adjacent workings are calculated. Notes should be taken in the same way and azimuth measured always from the south or always from the north.

After the base line or reference system has been established, some point or points should be located in or about the mouth of the tunnel or collar of the shaft. About a tunnel this is sometimes difficult because the ground adjacent will be graded, or covered with waste rock, or the track arrangement may not be permanent. Owing to the hoisting rope, sheave and dumps it is almost impossible to locate a permanent point over a shaft. This is especially true of vertical shafts. Timbers or pipes being taken into the mine often knock out points. The engineer should at once look over the ground and find some point adjacent to the shaft which will not be disturbed.

CARRYING THE LEVEL AND MERIDIAN INTO THE MINE.

In order that underground points may be located with regard to points on the surface it is essential that by some means the meridian be carried into the mine. In other words a survey must be made from the surface through the openings to points in the mine. Such an opening may include measuring the depth of the shaft, plumbing the shaft or carrying the line underground by direct sighting with the transit.

Levels. The depth of a shaft or opening may be determined.

(a) By the aneroid barometer when only a rough figure is desired. Read the barometer at the surface, also noting the temperature; then go underground to the bottom and read the barometer, noting temperature. The barometer reading should be taken several times; after the barometer reading is constant return at once to the surface and again take several readings at the surface. Corrections for difference in temperature between the mine openings and the surface should be made. The mean of the difference between reading taken at the surface and underground is the depth of opening.

b. The depth of a vertical or inclined shaft of uniform dip may be determined by measuring the length of the hoisting rope used in reaching the bottom of the shaft. In order to do
this the number of revolutions of the head sheave during the hoist should be noted. The circumference of the sheave being known the amount of rope wound can be easily calculated, or two marks can be made on the rope, one opposite a fixed point when the cage or skip is at the bottom, another after the cage or skip has been brought to surface, opposite the same point. The rope between these marks represents the depth of the shaft. When the winding drum is cylindrical the rope round and not winding on itself, determine the circumference of the drum, the number of coils or rope, then the amount of rope between the two marks can be roughly calculated. When the rope winds on itself during part of the hoist, correction must be made for the increased diameter due to the rope. When the drum is conical, measure the diameters at each end of the surface on which the rope is wound, determine the number of coils of rope wound during hoisting the length of rope can then be roughly estimated. When the spiral drum or differential drum is used it is necessary to know the equation of the curve of the drum, the number of grooves per foot of face of drum and the number of coils of rope wound. When flat rope is used, the thickness of rope, diameter of reel or reel and rope when the skip is at the bottom, diameter of reel and rope when the skip is at the top should be determined. Then either algebra or calculus may be employed to determine the length of rope.

c. "A steel wire is unwound from a reel on the surface and passed over a pulley, dropping down into the shaft and held taut by a weight at the end. There is a horizontal scale over which the wire passes. The measurement is begun by lowering the weight a short distance and placing a mark on the wire at a point which is at the height of the point from which the depth is to be measured. At the same time a slight mark is made in the wire opposite the zero point of the scale. The wire is then unwound until this mark moves to a point of graduation when this distance of travel is measured on the scale and recorded. Then another mark is put on the wire at the zero point and another part is measured, and thus the measurement continues by segments until the weight has nearly reached the bottom of the shaft. Then a level line from an instrument (underground) will determine a point on the side of the shaft at the height of the first mark made on the wire. Then the last portion of the wire that was unwound is measured on the scale and the total depth is equal to the sum of all the parts measured on the scale. The depth may also be measured when the reel is wound up and the two results compared."*

*Nugent's Plane Surveying, p. 356.
d. The depth of shaft may be measured directly by means of a tape. A nail is driven in the collar of the shaft, the elevation of which nail is known and from which nail is suspended the tape. Then a man with the reel on top of the cage, unwinds the tape as the cage is lowered till the end of the tape is reached. Then he drives another nail, ascends to surface, unhooks the tape and proceeds to the last nail set; again from that point he proceeds as before until the reaches the bottom.

e. An instrument equipped with top or side telescope may be set up over the shaft and the height of instrument being known, the telescope is depressed until the vertical circle shows that the telescope is vertical. A point on the bottom is then established directly under the instrument, but distant from the center the distance between telescopes. In the line of the telescope another point as far as possible from the first point is established on the bottom and the vertical angle to this is read. Both points on the bottom should be at the same elevation. The distance between these points can be measured. We have then a right triangle, which can easily be solved for the long side—the depth of shaft. In order to check this, several lines may be established in the same way and the depth calculated.

Knowing the elevation of the collar and the depth of shaft the elevation of the bottom is determined and proper bench marks are established.

f. To determine the elevation of the bottom of an inclined or crooked shaft, it is generally advisable to run a traverse with the top or side telescope from a known bench mark on the surface. The depth of shaft can then be readily computed.

To carry the meridian down an inclined shaft or slope it becomes necessary to observe (a) the horizontal angle or azimuth (b) the vertical angle, (c) the distance, (d) the height of instrument and (d) the height of the point sighted. For highly inclined openings it becomes necessary to use an auxiliary telescope because of the interference of the main telescope with the plate. Eccentric bearings may be used but most engineers prefer the auxiliary telescope. Such telescopes must be adjusted so that by easy calculations the proper line may be found. The top telescope is mounted so that when the main telescope is horizontal, it is also horizontal and with the vertical wire in the same plane with the vertical wire of the main telescope. The horizontal wire of the top telescope should be so adjusted when sighted say at a rod two hundred feet from the instrument, the main telescope being horizontal, the difference in readings on the rod corresponds to the vertical distance between telescopes.
When the side telescope is used, horizontal wires of the main and of the auxiliary telescope should be in the same plane and when the instrument is sighted at a vertical plane surface about two hundred feet distance instrument, the distance between points in the line of sight of the main telescope and the side telescope should correspond to the horizontal distance between telescopes.

Distances may be measured from the instrument or the station established to either the point of sight or the next station. Most engineers prefer to measure from the axis of the main telescope to the point sighted. It becomes necessary then to make various readings. Notes are often kept in the following form:


An accompanying figure shows for the top telescope the various angles and distances, except azimuth, which should be noted. The distance between telescopes should be a constant. Numerous Greek letters have been eliminated, in order that the difficulties, which are numerous enough for the average student, be not multiplied. The object has been to make the student think in terms of actual observations rather than in abstract letters.

The student should note that in the use of the side telescope when the vertical angle is 90°, no point above or below the instrument can be sighted if it lies within the right cylinder generated by turning the instrument on the horizontal plate. This cylinder will have a radius equal to the distance between telescopes. Under the same conditions a top telescope will also generate a similar right cylinder but this cylinder does not mark the limit of sight of the top telescope. Points directly under the center of the instrument are visible up to a certain limit which is determined by the ratio between the distance between the telescopes, the diameter of horizontal plates and the height of standards. Assume a point directly under the center of the instrument; this is not visible through the side telescope but may be through the top telescope if the vertical angle is not much over 90°. An infinite number of horizontal angles but only one vertical angle may be read for such a point as it is the apex of a right cone, the center of whose base is the center of the instrument. Any point above the plane of the plate of an instrument is visible through the top telescope.

Plumb lines and wires may be used to carry a line from the surface underground through an inclined shaft. When the shaft is sunk on several dips the problem requires considerable care. When the line of the shaft is known approximately, a
wire is stretched from the surface to a point well down the shaft. The bearing of the wire is established by two bobs hung so that the cords just touch the wire on the same side. Two bobs are hung in the same manner underground. When the shaft is on a uniform dip, the wire may be stretched taut; when the dip diminishes the wire may be hung to clear the sag in the shaft. Plumb bobs are hung on the line in the same way. Having established two points underground, the wire may be taken down the shaft and hung in the line of the two stations and two more established further down. Great care must be taken that bobs are always hung on the same side of the wire and that all points are properly aligned.

When two or more inclined shafts are connected underground surveys should be made if possible connecting survey points established at the various levels. When there is but one opening, in carrying the meridian into the mine, great care should characterize the work. All surveying should be carefully done but greater precision is essential to shaft work, especially when but one line can be run, because all subsequent work depends upon the accuracy in location of the shaft stations.

Vertical shafts. When there is but one vertical shaft there is nothing to check the work.

a. When the shaft is not very deep or wet the transit equipped with Auxiliary telescope, may be used. The instrument is set up at the collar of the shaft, back sight is taken on a known point and two points in the line of the instrument are established at the bottom of the shaft, as far apart as possible and both visible from the transit. The azimuth of the line underground can be readily calculated when all the distances are measured. This method is used in some of the deep level shafts of the Rand.

b. For deep and wet shafts it is advisable to hang wires from the surface. When there are two shafts, but one wire is necessary to each shaft. Underground and surfaces traverses are run to connect the wires which should be suspended at the same time. The azimuth of the plane through the two wires can thus be determined. When there is but one opening two wires should be hung from the surface in a line the azimuth of which is known. Copper or steel wire may be used; copper is generally preferred for shallow shafts. Hang an 8 pound bob from a No. 20 copper wire. These wires should be as far apart as possible, should hang free, should not interfere with hoisting and should be so located that the transit can be set up in line with them underground. The wires should be lowered from the surface, a light bob being attached to the wire in order to keep it from catching on timbers, etc. When the wire extends
to the bottom, it should be drawn up so that it will clear the bottom even though it does stretch a little. It is generally advisable to lower the wires one at a time and to draw the first wire taut in the same corner from which it is suspended at the surface in order that the second wire may not be entangled with it. In plumbing the Tamarack shafts 4,250 feet deep, No. 24 piano wire was used. This was lowered by means of a small two cylinder hoist operated by compressed air. The lowering weights consisted of two balloons or frames, ten feet long and two and a half feet in diameter at center tapering to a point at each end. These were made of slats and weighed twenty pounds. A lantern was hung in the center of each so that its progress down the shaft might be observed. It took half an hour to reach the bottom. Eight pound bobs were then attached and the lines brought so far from the center of the shaft as possible. When the wires were in place fifty pound cast iron bobs were substituted for the eight pound ones, when the wires immediately stretched fifteen feet. They were then cut to the proper length and the bobs immersed in pails of engine oil; this resulted in the shortening of the wires twenty-five inches due to the buoyant effect of the oil on the weights. One of the members of the party should inspect the wires to see that they are hanging free. It is always advisable to see that no ventilating currents cause a deflection of the wires. Water, oil or molasses may be placed in the vessel in which the bobs hang.

The distance between the wires and the azimuth of the line through them should be carefully determined. Then set up the tripod underground as nearly as possible in line with the wires and by means of the shifting head place the transit in the line of the wires. The known line on the surface is thus projected underground. Establish a point over the instrument and another point in the line of the wires, at a good distance. Measure the distance between the wires and distances from the instrument to the wires and to the established point.

When the compartment of the shaft is small it is advisable to hang more than two wires. When four are hung, their position should be determined on the surface with regard to some known line. Two points should be established underground, from each of which the other can be seen and also all the wires. Set up at both points, read the angles to the wires and the other point and measure the distances. Calculate the azimuth of the line through the two established points.

Plumbing shafts requires considerable time and often in order to make the interference with mining operations as brief as possible, engineers do not wait for the bobs to come to rest but bisect the arc of vibration. This may be done by tracing on
a sheet of paper the elliptical path of the bob as it swings. The
center of the ellipse can then be taken as the point of sight, or
the extreme points in the arc of vibration may be marked on a
sheet of paper placed on a heavy board, the line joining these
points is bisected and the middle point taken for the sight. Var-
ious other methods may be used in carrying the meridian down
the shaft. The co-called T square method* has been successfully
use on the Comstock lode.

UNDERGROUND TRAVERSING.

By a traverse is meant a series of consecutive courses
whose lengths and bearings, or azimuths, are determined. A
traverse is then a system of connected lines, the second starting
from the first, the third from the end of the second and so on.
A transit is said to be “oriented” when it is set up with the hor-
izontal circle in such a position that if the vernier is made to
read zero the line of sight will be parallel to the meridian. When
carrying on an extended survey it is most convenient to carry
angles by the continuous azimuth. Many engineers prefer to
read angles between lines of the traverse, always turning either
to the right or left. These readings can be easily checked by
repeating the angles. Having established the azimuth of a line
underground, the meridian can be carried to any part of the
excavation and by accurate measurements the position of any
point determined with regard to any other, either underground
or on the surface. For accurate work vertical angles should
always be read and measurements taken from the axis of the
instrument to the point of sight, the height of instrument,
height of point and measurements to show the distances of the
stations from the walls and distances to any irregularities not
sufficient to deflect the traverse. When a line is being extended
in order to determine the proper direction to drive an opening
to connect with another, very few measurements save those es-
sential to the traverse are taken. In mapping a mine all exca-
ations must be noted and measured so that they may appear
properly on the map.

The duties of the various members of the party have already
been noted.

The cross wires may be illuminated by (a) a reflector,—an
elliptical silvered plate inclined at an angle of 45° with the
ring which carries it, and by means of which it is fitted to the
object end of the telescope; (b) by a half cylinder of white
cardboard fastened to the telescope with an elastic band, and
light reflected from it to the cross hairs; (c) by use of a sheet

of white paper rolled into a cone truncated, placed with the 
large end over the object glass, a circular hole cut in the middle 
of the cone and a candle held opposite the hole.

The transitman sets up under a known point; the back- 
sightman illuminates the point under a known station. The 
transitman clamps the vernier on the known azimuth of the 
line determined by his instrument and the backsight; plunges 
the telescope and sets on the backsight and clamps the lower plate. 
(Some engineers prefer to set the vernier at 180° less than the 
reading for the last foresight on the main traverse and back- 
sight without plunging the telescope.) Then he plunges, sights 
on the new point established in the meantime by the foresight, 
clamps the lower plate and reads the azimuth of the line through 
the point of transit and the new point. For accurate work he 
should repeat the angle. Then the instrument man reads the 
vertical angle and measures the height of instrument, while the 
foresightman measures the height of point and together with 
the instrument man or backsightman measures from the axis 
of the instrument to the point sighted. The distance is known 
as the "measured distance" or "slope distance."

The three tripod method of traversing has been used some- 
what but is not considered very practical in that it requires 
three tripods and requires that the party shall contain a man, 
in addition to the transitman, who can set up an instrument so 
that it can be used for often a considerable length of time. It 
is totally impracticable for traversing along roadways in which 
traffic frequently interrupts the surveying party. The equip- 
ment for this work comprises an ordinary transit, three exten-
sion tripods so constructed that the transit can be unclamped 
and removed, leaving the leveling screws on the tripod, and two 
plummet lamps which may be set and clamped upon the tripod 
when the transit is removed. These lamps carry spirit levels so 
that they can be leveled. The steps in the operation are these: 
Suppose the transit to be set up under a known point; a back-
sight is given by plumb bob; the elevation of the station being 
known; the height of instrument is determined. The foresight-
man sets up under the next point, centering and leveling as with 
the transit; having properly set up, the tripod being set very 
firmly, the lamp is lighted and the foresight given. When the 
point of sight on the light is the same height above the plate 
as the telescope, the height of instrument need be taken only by 
the foresightman. Having measured distances and read the 
angles the transitman takes the transit off the tripods, takes the 
third tripod from the backsightman, and carries tripod and tran-
sit to foresight. The foresightman removes his plummet from 
the tripod in place, places it upon the tripod brought up by the
transitman and goes ahead to establish the next station. The transitman simply sets his instrument upon the plate already centered and leveled and is ready to backsight. The transitman does not have to bother setting up, but it generally pays to have him check the set up before making any sights; so the real purpose of the three tripods is not gained.

In working with the top and the side telescopes, or with angles above 60° trouble is apt to occur from the increased and magnified effects of personal and instrumental errors. These errors may be divided into classes (a) variable errors, and (b) constant errors.

a. Variable errors. I. Centering the instrument. A sight of 50 feet with a vertical angle of 85° gives a horizontal distance of 4.35 feet. In a circle of that radius an arc of .0013 feet subtends an angle of one minute, which means that a displacement of .0013 feet in position of the instrument bob would give an error of that amount.

II. Leveling the instrument. If the plate is one minute from the horizontal an error of eleven minutes in azimuth may occur with the vertical angle of 85°.

b. Constant errors may be due to inclination of the standards, errors in collimation and the eccentricity of the telescope axis.

The work should be carried on and the notes so kept that any other surveyor can come in and take up the work at any point.

SURVEYING THE MINE.

The survey of the mine as a whole has for its object the production of a map to show essentially the underground workings. For flat veins, seams or beds, a horizontal plan is generally the only map made. However for highly inclined veins in order that all features of the work may be readily observed it is not uncommon to make three or four sheets,—a horizontal projection, a vertical projection, a vertical section, and a projection of the vein itself. In common practice the survey of the mine means nothing more than a determination of the amount and position of excavation.

To survey the mine properly it is essential that some general plan be first laid out and that, so far as possible, this plan be closely followed. In traversing drifts, irregularities should be noted so that if of importance they will appear on the map. all openings should be noted.

In surveying coal mines, the angle at which rooms are turned off should be measured, the rooms properly located with regard to the entry, all dimensions carefully taken and all open-
dings correctly located. When openings are closed, gobbed or bratticed they should appear so in the notebook. Even though such features are not to be mapped, the surveyor should make his book a record of actual conditions, in the mine when the survey is made.

In surveying a longwall mine, it is necessary to show the roads that are open and the working face. Points about 40 feet apart are located and the face is then drawn in the notebook. The traverse may be carried along the face but this is generally very dangerous and points established are so near to the working face that they will be blown out by blasting.

In surveying large stopes it is often impossible to use the transit. Special methods must then be adapted. The various types of clinometers and needles on cords have been successfully used. Hand compasses or hand transits are then of great assistance. A few hours' work with the Brunton will show its applicability to this grade of work. The method of off-setting with tapes is commonly used in metalliferous mines.

There is considerable difference in the method of conducting a survey when one is in the regular employ of a company and when one is doing only custom work. More permanent stations should be established in the former case than in the latter.

The field book should be a regular and accurate record of the work of the surveying party irrespective of the continuity of the work, or several books should be used so that a continuous record may be kept in one book of the work in one mine or one section of the mine. Notes should be so well taken that they can be worked up "cold," that is, any time after the survey is made by any one. It is advisable to keep the map work up close to field work. Very often surveys must be made at regular intervals. Where such is not the case, and the surveying party does the mapping, each day's work should be completed before another is begun. That is, all calculations of traverse should be made the same day the field work is done. This often works hardship to the instrument man, but after systematizing his work he will find it easy and will want to do it. Mapping can be reserved for odd days.

Side notes can be kept best by using the right hand page of the field book for sketches, the left hand for angles, distances, etc. Sketching and all notes should begin at the bottom of the page and follow up the page. The center line of the page should be taken as the line of traverse. Sketch to a convenient scale, and do not crowd the notes. Always take enough measurements and sketch carefully. Some engineers do not attempt to show to scale distances from the traverse, but put in dimensions so that the notes can be easily interpreted.
PRELIMINARY TO BEGINNING UNDERGROUND OPERATIONS IT IS ONSEREOUS THAT THE LOCATION AND EXTENT OF THE DEPOSIT TO BE MINED SHOULD BE DETERMINED. WHEN THERE IS AN OUTCROP, THIS CAN GENERALLY BE MORE EASILY ACCOMPLISHED THAN WHEN THERE IS NO SURFACE INDICATION.

STRATIFIED DEPOSITS. FLAT SEAMS OF COAL ARE OFTEN SO CUT BY STREAMS THAT AN OUTCROP MAY BE TRACED FOR MANY MILES. A TRAVERSE MAY THEN BE RUN ALONG THE OUTCROP TO DETERMINE THE BOUNDARIES OF THE COAL. OFTEN THE OUTCROP OF AN OVERLYING MEASURE IS TAKEN AS AN INDICATION OF COAL AND IT IS THEN COMMON TO RUN A SO-CALLED "CROP LINE" ALONG THE OUTCROP. WHEN THE MEASURES ARE INTERSECTED BY STREAMS LARGE TRACTS OF COAL ARE OFTEN PLATTED IN THIS WAY. WHEN THE TRACT IS NOT COMPLETELY SEVERED FROM THE ADJOINING AREA, IT BECOMES NECESSARY TO PUT DOWN BORE-HOLES. THESE WILL SHOW THE DEPTH OF THE COAL HORIZON AND TOGETHER WITH THE CROP LINE WILL SERVE TO LOCATE AND BOUND THE TRACT. WHEN THE MEASURES ARE INCLINED AND OUTCROP IN A FLAT COUNTRY, THE OUTCROP SHOULD BE TRAVERSED AND BORE-HOLES SHOULD BE PUT DOWN TO INTERSECT THE PRODUCTIVE MEASURES. THE DEPTH OF THE HOLES AND THEIR POSITION WITH REGARD TO THE OUTCROP BEING KNOWN, THE PRODUCTIVE AREA OR ACREAGE CAN BE PLATTED.

WHEN THE MEASURES ARE OVERTURNED OR VERTICAL AT THE OUTCROP AND THEN SLOPE OFF TO HORIZONTAL IT BECOMES MORE DIFFICULT TO ESTIMATE ACREAGE AND, FINALLY, THE TONNAGE. FAULTS FREQUENTLY DISPLACE MEASURES SO THAT CALCULATIONS ARE UNRELIABLE. THE FAULT PLANE, THROW, ETC., MUST BE POSITIVELY ESTABLISHED BEFORE ANY ESTIMATES OR PLATS CAN BE MADE. IN MANY DISTRICTS IN THE CENTRAL STATES, THE COAL MEASURES ARE HORIZONTAL AND COVERED WITH GLACIAL DEBRIS. THE COAL HAS AT PLACES BEEN COMPLETELY ERODED, AT OTHERS IS COVERED WITH BUT A FEW FEET OF ROCK AND AT OTHERS BY SEVERAL HUNDRED. THE CONTINUITY OF THE COAL CAN BE DETERMINED ONLY BY VERY NUMEROUS DRILL HOLES, AS MANY AS SIX HUNDRED TO THE SECTION BEING COMMON PRACTICE.

OUTCROPPING VEINS SHOULD BE TRAVERSED, THEIR STRIKE AND DIP DETERMINED, AND THEIR INTERSECTIONS AND ANY DISTURBING FAULT PLANES CAREFULLY LOCATED. WHEN THERE IS NO OUTCROP, DRILL HOLES MAY BE PUT DOWN TO INTERSECT VEINS. KNOWING THE LOCATION, DEPTH AND ANGLE OF THESE HOLES TO INTERSECT THE VEIN, THE POSITION OF THE VEIN IS DETERMINED AND THE MINERAL ACREAGE MAY BE APPROXIMATELY DETERMINED.

MASSES OR LENSES OF ORE APPEARING ON THE SURFACE SHOULD BE SURVEYED AND DRILL HOLES LOCATED AT REGULAR INTERVALS. THE HOLES BEING VERTICAL, THEIR DEPTH AND LOCATION BEING KNOWN AND PLATTED
the volume in the mass may be calculated and the tonnage estimated. When masses or lenses do not outcrop; drill holes should be put down to intersect the mineral. The depth at which the drill enters and leaves the ore body being noted for each hole and each hole being properly located on a contoured map, the volume of the mass can be determined.

Alluvial deposits should be carefully mapped and drill holes so located and mapped that the volume of material as well as the extent and depth of rich strata may be determined.

The importance of surveying in the work preliminary to mining operations can be readily seen. No legitimate mining enterprise is attempted without a fair knowledge of the extent of the body upon which operations are to be carried on. A complete contoured map is always of great advantage to the engineer who is locating a deposit.

DRILL HOLES.

It is frequently assumed that bore holes are straight; that is, if started vertical, they continue so, or if started on a known angle they continue on that angle. This is seldom the case, for the holes are deflected from their course. This is more likely to occur in vertical holes with the diamond drill than with the percussion drill. However with the percussion drill when the rods are not very long, the rod tends to work to one side and may soon be deflected from the vertical. The falling weight, however, has a tendency to straighten the hole. When the diamond drill is used for an inclined hole it is almost impossible to maintain the desired angle because the drill rods are of a smaller diameter than the bit and will lie against the bottom or side of the hole and by this deflection the face of the bit is inclined from the proper bearing. In order to ascertain the course that has been taken by a bore hole it is necessary to make a survey just as it is necessary to survey a tunnel. Many difficulties must be overcome, and to this end many ingenious devices have been adapted. Nolten’s instrument consists essentially of a glass cup in which is placed hydrofluoric acid. When the cup is placed in a bore hole in an inclined position, the acid will attack that part of the glass below the level of the acid. A line will then mark the angle of inclination of the glass cup. While the acid is being lowered into the hole the acid will shake about and will leave no clear mark upon the glass; when it has reached the required depth, if it is allowed to remain unmoved for half an hour, the acid will etch a permanent record of the inclination of the glass and also of the tube in which it is fixed. In order to record the direction in which the hole is proceeding, in case it is not perfectly vertical, another instrument is com-
bined with this one and fixed in the same tube. This instrument consists of a compass needle free to revolve in a horizontal plane on a vertical pivot, and of a watch which can be set to operate a lever, so that the needle can be clamped at the exact time at which the watch is set. When lowered into the hole, the needle after being allowed to come to rest is clamped, and will show the direction of inclination because the compass is fastened to the tube.

Ordinary gelatine is easily melted when immersed in hot water and solidifies again at 70° F. When melted it takes several hours to stiffen. A clinometer and compass placed in a tube containing melted gelatine and lowered into a bore hole will show the direction and inclination if the gelatine is allowed to cool.

Various other devices may be used. It has been found that in a depth of 370 feet a bore hole had deviated 37.5 feet in a horizontal direction from the vertical. It cannot be assumed, then, that bore holes are vertical when deep deposits are being prospected. In order to block out the ore body, holes must be platted in their true position. Frequently a diamond drill is set up underground and holes at various angles are used to explore the adjacent ground. Also in driving drifts towards abandoned mines it is necessary to carry holes ahead and to the sides of the drifts in order to avoid breaking into bodies of water or gas.

**LOCATING OPENINGS AND MINE PLANT.**

In locating and blocking out ore bodies various openings are necessary. Samples must be taken in order to determine the quality of the ore. Openings provide the means for getting such samples and for determining the quantity of material that can be mined. Such openings must be carefully located. By means of bore holes samples can be obtained from ore bodies at considerable depth. Shafts, tunnels and drifts better serve this purpose but the cost being much greater these generally give way to the bore holes for systematic and extended exploration.

The extent and depth of the ore body being determined by careful surveys of the exploratory openings, the sites for permanent openings and buildings are surveyed. A contoured map is always of great service in laying out the mine plant. Mine openings should be so placed that surface water will not run into the mine—that a very high building will not be necessary to secure fall enough to run the product of the mine to the mill or into railroad cars, and that there is sufficient dump room. When upon the side of a mountain, openings must be placed out of the paths of rock and snow slides. The surface plant
being located, the underground workings may be laid out. When a flat coal seam is to be mined, large companies generally make a plan showing how openings are to be driven and how working places are to be located. When seams dip considerably, it becomes necessary to establish roadways on grade. Generally these can be laid out on paper. When the conditions affecting the method of working are known, ore bodies may be blocked out similarly. That is, if we know a vein is regular and dips at a certain angle, levels and stopes may be platted and workings made to conform with this plan. Such plans are, of course, ideals and may not be attained, but it is always well to have in mind such ideals and then endeavor to carry out the system planned. If the tract has been properly explored without the use of drifts, tunnels and shafts, openings may be so located that with a minimum amount of dead work a maximum tonnage may be produced at a low operating expense. Faults, irregularities, old stream channels, poor coal, poor roof and old workings may be avoided. Some companies in Pennsylvania require all openings to be driven straight and rooms to be driven at a given angle irrespective of local conditions. In laying out the mine workings on paper, proper pillars should be left for shafts, roadways, boundaries and buildings. Failure to determine the position of buildings on the surface with regard to mine openings has often been responsible for disasters. Witness the cave in at the Negaunee mine which incapacitated the hoists for two shafts, thus preventing the immediate removal of debris in order to release the miners.

The mine surveyor then is largely responsible for the laying out of the mine and arrangement of the mine plant.

SHAFT SINKING.

In sinking large shafts the surveyor generally plays an important part. The shaft must be kept vertical or upon a given pitch. When the shaft is sunk on the lode regardless of change of dip, it becomes necessary to place frequent rollers or pulleys to carry the hoisting rope. Many companies today in sinking large shafts decide upon a given angle for the shaft and sink regardless of walls. The surveyor must then not only keep the work progressing in the proper direction but establish points by which the proper vertical angle may be maintained.

Record of the depth must be given regularly and points located so that the plats or stations may be cut at the proper intervals. When sinking has progressed to a lower level and the plat has been cut the timbermen require the surveyor to
locate for them by elevation the sleepers to carry the skip rails. In order to do this the surveyor proceeds as follows: The transit is set up over the rail at a known point, the shortest distance is measured from the axis of the telescope,—when the angle of the shaft is large the top telescope,—to the sleeper; at about 100 feet back a leveling rod with the target set at the distance just measured at the instrument is placed on the sleeper and held at right angles to the sleeper; the telescope is then sighted on the target and the vertical angle read; this should be the established shaft angle. If it checks properly, the rod reading is recorded and the rodman goes down the shaft to the point at which marks for setting sleepers are desired. He places his rod along the stubs or shaft timbers so that the rod makes a right angle with the established line of the shaft. The transitman has the rodman place the target, clamped, as already noted, in the line of the telescope when set at the proper vertical angle. The zero of the rod then determines the proper point for the top line of the sleeper.

Along shafts which are not straight as previously noted, pulleys, sheaves or rollers must be properly placed. It frequently falls to the lot of the surveyor to determine the proper points for such rollers. The proper line for the rope must then be determined if possible analytically; generally, however, a few experiments will show where the pulley is needed.

TUNNELLING.

In driving a tunnel for prospecting purposes or for transportation, the surveyor must give the direction, distance and grade. The direction may be established by three points placed on lines. One of these points should be a permanent station and not less than thirty feet from the breast, the other two about six feet apart and one not less than ten feet from the breast. By hanging plumb lines from these stations the workmen can properly align their work. Unless precautions are takn the walls will not be driven straight. The walls of the tunnel should be equidistant from the established line, or some given distance. Timbers should be set on line.

"In very long tunnels excavated under high mountains more elaborate methods have to be adopted for locating the center line. The theodolites employed must be of large size; in ranging the center line of the St. Gothard tunnel, the theodolite used had an object glass eight inches in diameter. Instead of the ordinary mounting a masonry pedestal with a perfectly level top is employed to support the instrument during the observations. The location is made by means of triangulation. The various operations must be performed with the greatest ac-
curacy, and repeated several times in such a way as to reduce the errors to a minimum, since the final meeting of the headings depends upon their elimination."

"The triangulation was compensated according to the method of least squares. The probable error in the fixed direction was calculated to be 0.8" of arc. From this it was assumed that the probable deviation from the true center would be about two inches at the middle of the tunnel, but when the headings finally met this deviation was found to reach eleven inches."*

The cross section of a large tunnel** may be taken by a method of polar co-ordinates. A light brass protractor in a vertical plane is mounted on a tripod; to this protractor is secured a light measuring rod, graduated to tenths, which slides upon a rest on the face of the protractor. Points in the cross section are measured by setting the plane of the protractor at right angles to the axis of the tunnel and then sliding the rod out until it touches the wall. Read the length on the rod and record the angle, and so on for any number of points on the circumference of the tunnel section.

In order to properly drain the tunnel and that a uniform grade in favor of loaded cars may be maintained, the surveyor should regularly establish grade points for the foreman.

MINE WORKINGS.

In well planned mines, the surveyor must almost daily establish points for the shift boss or foreman in order that rooms, stopes, raises or breakthroughs may be driven as planned. In some states breakthroughs must be driven at a minimum distance apart. The surveyor must keep the mine so surveyed that he can quickly establish such points. It is good practice to set points for the center line of openings. Generally it is necessary to give such points at first only temporarily as stations established so near a working face will be disturbed; after the work has proceeded sufficiently permanent points may be put in.

CURVES AND CONNECTIONS.

It is often necessary to drive a curved entry in a mine in which rope or motor haulage is used and especially where cars must travel rapidly from the side entries into the main entry. These curves are often quite sharp and are described with regard to their radius rather than to curvature in degrees. The method of laying out these curves differs from railroad

practice only in that all points cannot be established at one time. Points should be set daily by which the miners can drive. Points should not be more than ten feet apart.

One of the most important phases of mine surveying and probably what requires most care is a survey for openings to connect two given or assumed points. Numerous problems will arise upon which will depend the reputation of the surveyor. The principal precautions that should be taken are (a) the adjustment of the instruments, (b) the complete survey should be made by one squad, (c) all stations should be permanent if possible, (d) all measurements and readings should be checked. The surveyor may be called upon to establish the line for

(a) a railroad tunnel driven on grade from both ends,
(b) a railroad tunnel driven from both ends and from shafts sunk along the line of the tunnel,
(c) a mining tunnel to connect with a shaft or vice versa,
(d) a drill hole to intersect mine workings,
(e) a cross cut to connect workings on adjacent veins,
(f) a raise to connect a given point on a level and a shaft or another level, and
(g) air courses to connect working places.

OPENINGS TO INTERSECT VEINS.

In many of the important mining districts engineers have been called upon to solve various problems which require the application of that division of geometry generally known as descriptive geometry. Certain assumptions must be made in all cases but the results obtained prove of considerable value in that no greater error can occur when conditions as noted continue, and the results of such solutions are generally better than guesses.

In the Cripple Creek, San Juan and Clear Creek districts, shoots and zones of ore occur adjacent to the intersections of veins. Practical miners say that “invariably” will ore be found at these “junctions” and that it is always advisable to drive to such points. Many openings are put down in quest of such intersections when it is supposed that they exist and many feet of work show that often the miner has “stayed with the ore” when he might have taken a short cut and saved much money and labor.

The following assumptions should be made in working out problems graphically: (a) The surface is assumed to be a horizontal plane. (b) Veins are planes of uniform dip; intersections of veins are straight lines; thickness of veins is not to be considered. (c) Shafts on veins will be straight. (d) Ex-
cept when the grade is specified, tunnels are horizontal, also drifts. (e) Dimensions of shafts and tunnels should not be considered, that is, openings are considered to be straight lines (f) All inclined shafts to be the shortest possible. In the solution of problems in practice, the scale used should be such that the errors of platting do not materially change the results.

It is very difficult; in fact almost impossible except in stratified measures, to solve problems of faulting. In all cases certain assumptions must be made. If actual conditions are not known and the continuity of the vein or seam is not known, any solution cannot be accepted. In all cases results of such solutions can be given as only probable or possible. Change of dip or strike, faults or other irregularities may easily render such solutions valueless.

Many of these problems the engineer can solve analytically and can check the graphical method. Having determined the proper solution for any problem similar to those given the surveyor has then only to establish points and from time to time check up the alignment of the opening driven to make the connection.

**GEOLOGICAL IRREGULARITIES.**

As previously noted all irregularities should be noted and mapped. Fault planes, horses, rolls, water courses, etc., if properly mapped in one level and drift may be anticipated in driving new openings. Intersections of veins may be opened up in lower levels without undue loss of time if they have been carefully located in the upper workings. The dip and strike of veins should always be noted even though there be not any values in sight. In surveying tunnels all veins that are cut should be mapped and, if possible, identified and described. Failure to note all the veins cut has in many cases resulted in much useless dead work. The character of walls and roof should be noted, as well as the thickness of the vein.

**DRAINAGE.**

The surveyor is frequently called upon to establish a drainage system for a mine. In flat seams, he must then, if he has not already done so, run a line of levels and determine the proper points at which to establish small sumps from which the mine water shall be conducted to the main sump. Sometimes it is possible to drain all the water into the old workings. A complete map of old workings is necessary in order that the volume of water that can be stored may be determined.
Dams should then be placed where they may have good pillars to hold them in place. Several of the large coal companies carry all water in ditches in the back entries. Some of the Michigan copper companies handle all the mine water through one shaft. This necessitates that there be an opening connecting the mines so that water can run freely from any point to the drainage shaft. Recently at Cripple Creek a tunnel has been driven in order to drain a number of mines. This tunnel was driven on line and grade to tap flooded workings. There were three shafts on the line of the tunnel and in all, six points of attack. The importance of an accurate survey can be readily seen.

Impervious strata should be noted in drilling in order that the system of mining may be properly adapted to conditions. This is also important in locating sumps. The water level of a district or mine should be determined and mapped and this can best be accomplished only when complete records are kept of all surveys and conditions at the time of survey.

When mine openings are driven through old stream channels, as in the coal fields of some of the central states, it is at times possible to discharge the mine water into the old channels. However during the wet season of the year these channels become filled with water and flood the mine. It is generally advisable to line the openings so that water cannot pass through.

HAULAGE.

Important road ways should be driven on grades which are adapted to the system of haulage. The grade of tunnels has already been spoken of. In mining in flat seams very frequently rolls are encountered and these must be cut out. On pitching seams roadways should be driven on grade. For rope haulage the grade need not be regular, but if possible all irregularities should be eliminated. The surveyor is called upon to establish points so that the work may progress in the proper direction, to put in curves where necessary and to establish grades.

MAPPING.

Two systems are used in mapping mines, total latitudes and departures, and by means of the protractor. Important courses as in the main entries and shafts should always be platted by latitudes and departures and checked by the protractor. Work with the protractor progresses much more rapidly than with latitudes and departures but it is not very accurate.
The size of sheet necessary for mapping the mine surveyed and the probable extensions that can be economically made from the main opening should be laid out in squares five to ten inches on a side depending on the scale.

Coal mines are seldom made smaller than one inch to one hundred feet. Metalliferous mines may be made to almost any scale; generally a large map say one inch equal to thirty feet is drawn to show stopes, rooms, etc., while another, one inch equal to sixty, one hundred or two hundred feet, will show the shafts and drifts. Several states require that map be made a given scale.

For beds, horizontal or nearly so, a plan is sufficient. The following quotations state briefly good practice for metalliferous mines: "The survey is properly shown by at least three maps: first, the plan or projection on a horizontal plane; second, the longitudinal section, generally the projection on a vertical plane coinciding as near as may be with the general direction of the levels; third, the transverse section or projection on a vertical plane at right angles to the longitudinal one. The maps should have a title giving the name of the mine and location by mining district, county and state; also there should appear the name of the surveyor, date of survey, meridian used, and scale. The map should be on cloth backed paper or tracing-cloth, and may show on the plan the position, number, and elevation of the permanent stations with the bearing and length of the lines joining them or the coordinates of the stations, according to the system used. The advisability of showing these data on the map depends on the use that it to be made of them and must be decided according to the nature of the case."*

The best practice today requires that all notes should be copied from the field books and filed together with all calculations so that at any time reference may be made to any part of any survey. Calculations should be made by the use of logarithms and so arranged that any one can check the work.

The record book may be ruled in the following form extending across one or two pages:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Johnson's "Theory and Practice of Surveying."
Side notes should be preserved in the field book and may be inked in in order to make them more legible.

Certain schemes once adopted should be continued. An inspection of maps from various districts will show how varied is the practice. One company will place the date of a survey at the last station made by that survey on each shaft and opening; another will use a letter or number to represent a survey; another will use colors on the maps, a distinguishing color for each survey. Practice in showing worked out ground is even more varied. The common methods are as follows: (a) Printing on the map the phrase "worked out" over such portions of the mine; (b) by coloring the portions different from the permanent openings and pillars; (c) by hatching the boundaries of worked out portions; (d) by dotting with inks.

Several of the largest companies photograph their maps each year in order to keep a permanent and convenient record of the progress. In such cases it is necessary to mark each year's work so that it will show on the plat.

Frequently mine maps must be produced in court as evidence. In all cases such maps should be so complete and so carefully prepared that no questions can arise in regard to the accuracy of the work of the engineer. Special maps and diagrams should be made on a large scale in order to better illustrate specific points in question.

Models may be made to show parts of the mine, the complete workings, and the relative position of openings, excavations and property lines. Models should be on such a scale that dimensions can be readily appreciated. Only openings may be shown, or, the entire territory and ground included may be represented by wood or glass. Sedimentary deposits should be represented by sheets of glass or wood which can be easily handled and placed together to show actual conditions. A skeleton of sheet metal, wire or tubing may represent the various openings. Sheets of glass may be used to represent the veins and excavations shown in colors on the glass. Vertical or horizontal sheets of glass may be used and after the shaft has been located on these the adjacent workings may be be projected.

CALCULATION OF VOLUMES AND ASSAY PLANS.

The estimation of volumes and tonnage of ore in place or in stopes is one of the most important parts of a consulting engineer's work, and he must adopt a system of work which shall be rapid and at the same time sufficiently accurate for his purpose. A good engineer cannot be satisfied with anything but absolute accuracy, but generally sufficient time is
not available for the most accurate work. Chapter XIII. of Johnson's Surveying is given to a consideration of the most accurate methods for the measurement of volumes, to which work the student is referred. Practicing engineers persist in the use of approximate methods, among which the most popular is the one known as the "mean end areas formula" which Johnson condemns.

In behalf of the prismoidal formula its extreme accuracy is urged, while in behalf of the mean ends formula its simplicity and rapidity in use are undeniable. In mining work it is not possible to get frequent cross sections. In estimating ore bodies, unbroken blocks larger than 100' x 100' should not be considered when it is known that the ore body is not regular. Winzes, raises and drifts should be driven to divide the ore body into small blocks. Each mine has its special problems and no fixed rule can be stated, only this, always underestimate the tonnage in blocks of ore. In all cases an accurate map, about one inch to thirty feet, should be used and measurements of the vein and ore body taken every five feet for accurate work. Such measurements should be noted on the map at the point corresponding to the place where the measurements were taken. Samples should also be taken at these points. Methods of sampling cannot be discussed in this paper. Almost all the mines of the Rand keep assay plans. An assay plan of a mine is any map, — not necessarily a plan, — which shows accurately the dimensions and value of the ore bodies at such intervals along drifts, winzes, upraises, shafts and stopes that an estimation of the value of the ore in the mine is possible. Where the dip is steep it is more convenient to use the longitudinal section, because the levels on the plan would be too close together to allow the figures to be distinct, but the horizontal projection is more generally used because the sampling follows the irregularities of the vein which do not appear on the longitudinal section. The best projection, however, is that of the vein itself.

Various terms are used in stating the amount of ore in a mine. Practice varies so much, however, that it is not for such a paper as this to review what is recommended in different mining sections. The recent edition of "The Sampling and Estimation of Ore in a Mine" by T. A. Rickard is suggested for a careful study of recent practice.

The following terms are defined by various writers:

Ore developed, — that which is accessible for measurement, sampling and full examination on all sides.

Ore developing, — ore exposed on one side, on two sides, or on three sides.

Ore expectant, — that which will probably be exposed in
the later explorations when it has been shown that the ore shoot is of fairly uniform dimensions and value.

To enter into actual calculations a block of ore must be exposed on three sides. When exposed on three sides, if the ore body is fairly regular, the extremities of the lines not connected may be considered as the limits of the ore and a plane projected through these points. When cut on only two sides, again a line may be drawn enclosing the triangle and the excluded ore body taken as probable ore. The calculations are based on the theory of averages. The geometrical mean is determined for thickness of vein and value of the ore in ounces. The so-called foot-ounce method is thus developed. That is, suppose samples be taken as follows:

<table>
<thead>
<tr>
<th>Width</th>
<th>Assay</th>
<th>Foot—ounces</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4 feet</td>
<td>2.35 oz. per ton</td>
<td>10.34</td>
</tr>
<tr>
<td>6.2 feet</td>
<td>2.45 oz. per ton</td>
<td>2.79</td>
</tr>
<tr>
<td>7.6 feet</td>
<td>2.42 oz. per ton</td>
<td>4.71</td>
</tr>
<tr>
<td>4.0 feet</td>
<td>2.80 oz. per ton</td>
<td>3.40</td>
</tr>
<tr>
<td>22.2 feet</td>
<td>4.27 oz. per ton</td>
<td>21.24</td>
</tr>
</tbody>
</table>

The assay per foot of width is .96 oz. per ton. This method may be applied to any number of samples, samples being taken a uniform distance apart. This method has been worked out by calculus and demonstrated by Mr. Hoffman.*

In the calculation for tonnage the cubic feet of ore are converted into tons on the basis of a certain specific gravity. It is well to determine the specific gravity of a large sample of ore and determine the number of cubic feet necessary to make a ton of ore, instead of guessing the number of cubic feet to the ton.** The summation of the tonnage in the numerous blocks of ore will give the total tonnage in the mine.

**From "The Sampling and Measurement of Ore Bodies in Mine Examinations," by Edmund B. Kirby.**
The tonnage of coal in a tract may be similarly estimated, it being unnecessary to consider the analysis of the coal. As a rough approximation one thousand tons is estimated for each foot of thickness per acre for a horizontal bed. The specific gravity of the coal should be considered when accurate figures are desired.

"Loose ore piled on dumps in pieces from head to gravel size will have from 35% to 50% of interstitial spaces, the percentage being greatest if the lumps are somewhat equal sized. Thus a dump with 40% of spaces, and composed of ore averaging 12.7 cubic feet per ton in place, will measure 21.2 cubic feet per ton."

The mining engineer may be called to direct underground operations of various kinds and in almost every instance careful and successful work depends in a measure upon good surveying and mapping. Tunnels for water works, submarine tunnels, submarine pipe lines, etc., call for good maps and generally the mining man is called upon to do the work. Such varied work requires careful application to duty and attention to details which are often neglected in surface work.

**BIBLIOGRAPHY.**

**TEXT BOOKS ON SURVEYING.**

Brough—"Mine Surveying."
Carhart—"Plane Surveying." Chap. VIII.
Davies—"Surveying and Leveling." Book X. Sec. III, IV.
Johnson—"Theory and Practice of Surveying." Chap. XI.
Lupton—"A Practical Treatise on Mine Surveying."
Nugent—"Plane Surveying." Chap. X.
Raymond—"Plane Surveying." Chap. XII.
Scott and others—"Mine Surveying Instruments." T. A. I. M. E.

**PERIODICALS.**

Abbreviations—
A. I. M. E.—Transactions of the American Institute of Mining Engineers.
A. S. C. E.—Transactions of the American Society of Civil Engineers.
Coll. Eng.—Colliery Engineer.
E. & M. J.—Engineering and Mining Journal.
Min. Rept.—Mining Reporter.
S. of M. Q.—School of Mines Quarterly.

REFERENCES.

Base Line—
   Establishing underground base line,

Bobs—
   Kind and weight of,

Carrying Meridian into Mine—
   See Connections, Plumbing, and Shafts.

Connections—
Through two or more shafts, Coll. Eng. Vol. XVI, 53.

Curves—
On mine roads,
   M. & M. Vol. XXIII, 280.
Depth of Shaft—
   Measuring,

Inclined Shafts—
   Corrections for errors in,
   Measuring through crooked shafts with plumb line,
   Surveying, without attached telescope,
   M. & M. Vol. XIX, 433.
   S. of M. Q. Vol. XVI, 146.

Lamp—
   Improved form of plummet,

Plumbing, of Shafts,
Hoosac tunnel method,
Comstock Lode method,
Montana method,
Croton Aqueduct method,
   A. S. C. E. Vol. XXIII, 22.
Severn Tunnel method,
Sperry method,
   A. I. M. E. Vol. XXIV, 29.
Tamarack shaft,
   M. & M. Vol. XXII, 247.
In iron mines in Pa.,
   A. I. M. E. Vol. VII, 139.
General methods,
   A. I. M. E. Vol. XXI, 792.
   E. & M. J. Vol. LXXV, 749.

Stations—
   In poor roof,

Surveying Methods—
   General,
   Coll. Eng. Vol. XIV, 10, etc.
   In coal fields of Pa.,
   Coll. Eng. Vol. XIV, 197, etc.
   In iron mines of Va.,
   A. I. M. E. Vol. XX, 96.
   In the Rocky Mountains,
Telescope—
  Adjustment of side, A. I. M. E. Vol. XXIV, 28.
Volume—
  Of small drifts and stopes, M. & M. Vol. XXI, 344.
Wires—
  Location of four or more, Coll. Eng. Vol. XIV, 92.

PROBLEMS.

The following are suggested in order to teach the student graphical and trigonometric methods for solving mine surveying problems.

Problems involving descriptive geometry to determine the intersections of veins, the location of openings to cut intersections of veins and to locate openings when veins are faulted.

In all cases certain assumptions must be made:

a. Except in problems 4 and 8, the surface is assumed to be a horizontal plane.

b. Veins are assumed to be planes of uniform dip. Intersections of veins are assumed to be straight lines. Except in “b” of Prob. 3, thickness of veins is not considered.

c. Shafts on veins will be straight but inclined.

d. Except where the grade is specified tunnels are assumed horizontal, also drifts.

e. Dimensions of shafts and tunnels should not be considered, that is, openings are considered to be straight lines.

f. All inclined shafts to be the shortest possible except in Prob. 8.

In the solution of important problems found in practice, the scale used should be such that the errors of plotting do not materially change the results.

PROBLEM 1.

a. Locate vertical shaft on line “a-b” to cut the intersection of veins. Find depths of shaft and distance on “a-b” from “A”. 
PROBLEM 1.

b. At 300' from "A" on "a-b" is a vertical shaft 200' deep. Find pitch of inclined shaft and distance on incline from bottom of shaft to intersection of veins. 
   Draw to scale 1"=300'. Take ground line E and W.

PROBLEM 2.

a. Locate vertical shaft to cut intersection of veins. Find depth of shaft and the distance and bearing of point to sink, from "o".
   b. At "o" vertical shaft is sunk to cut vein EF. From this point inclined shaft is sunk on EF to cut intersection of the three veins. Find depth of vertical shaft, also bearing and length of incline, also the pitch of inclined shaft. 
   Draw to scale 1"=300'. Take strike of "a-b" as ground line.

PROBLEM 3.

a. Locate by distance from "o" point on "a-b" to sink shaft. This shaft inclined and the shortest possible to cut intersection of veins. Find length, pitch, and bearing of shaft.
   b. Call intersection "r". Part bounded by "xor" is ore. Taking "xor" as mean section and 6' as average thickness, compute No. tons of ore. Heaviness=170 pounds per cu. ft. Find length of "or" "xr".
   Draw to scale 1"=300'. Take strike of "cd" as G.

PROBLEM 4.

a. Horizontal distance from tunnel mouth, (Elevation 9653'), to outcrop of vein, (Elevation 11745'9), is 6000'. Vein strikes N 30° E and dips 63° to the NW. Tunnel is driven N 25°W horizontal. Find length of tunnel to cut vein. What depth on vein, will tunnel cut vein, knowing that 1700' NE from outcrop elevation is 12345'.9' and taking hillside as plane of the three points given.
   b. Same as "a" tunnel on 2.5% grade.
   Draw to scale 1"=2000'.0. Take G E & W.

PROBLEM 5.

a. Locate vertical shaft on Royal to cut intersection of veins. Find depth of shaft and distance and bearing of point to sink from "o".
   b. Locate incline on Lotus. Find depth, etc. Same as "a".
   c. Locate incline on Minnesota. Find depth, etc. Same as "a". Scale 1"=300'. Take G E & W through "o".
PROBLEM 6.

a. On the Lotus 200’ N W from “o” an inclined shaft is sunk 300’ in length. From the bottom of shaft a drift extends on vein N 75° W. At what distance from shaft should a crosscut be started to cut intersection of Royal and Minnesota. This crosscut to be at rt. angles to drift. Find length of crosscut.

Draw to scale 1"=300’. Take G E & W through “o”.

PROBLEM 7.

a. Locate vertical shaft to cut intersection of veins. Find bearing and distance from “o”.

b. Vertical shaft is sunk at x’ to depth of shaft in “a”. At bottom of shaft crosscut is run to cut the intersection of veins. Find bearing and length of crosscut.

c. Incline started at x’ to cut intersection of veins. Find length, pitch and bearing.

d. Locate inclines on: Gopher, Mt. Boy and Yuma, to cut intersection of veins. Find lengths, distances and bearings from “o”.

Draw to scale 1”=300’. Take G E & W through “o”. Point x’ is 300’. N 30° W from “o”.

PROBLEM 8.

a. From “o” outcrop bears N 10° E and dip of vein is 45°. 800’ up the hill the point “o’” has an elevation 300’ higher than “o”. Find strike of vein.

b. From “o’” shaft is sunk on vein. From “o” tunnel is driven on vein. Find point of intersection and lengths of shaft and tunnel. Shaft perpendicular to outcrop.

Draw to scale 1”=300’. Take G E & W.

PROBLEM 9.

a. Find point to sink by bearing and dist. from “o” to cut intersection of veins. Call point “x”. Find depth.

b. At “x”, due west of “o” 5100’, S 67° 45’ W 7850’ from “o” vertical drill holes are put down cutting a fault plane at: 1000’, 600’, 1000’, resp. It has been determined that portion above fault plane has moved perpendicular to strike in a south-easterly direction along fault plane 500’. Find point to sink as in “a”. Faulting took place, then country eroded to present level condition.

Draw to scale 1”=3000’. Take G E & W through “o”.
PROBLEM 10.

a. On intersection of Pilot and Mary inclined shaft is down 600'. On intersection of Orphan No. 1 and Orphan No. 2 inclined shaft is down 550'. As the air in both places is bad, we wish to start an inclined upraise from one shaft to connect with the other; this connection to be the shortest possible. Locate points in both shafts so work may be carried on at both ends. Find length, pitch and bearing of the connection. Reverse traces on Orphan 1 and 2. Compare. Draw to scale 1"=300'. Take G E & W through "o".

PROBLEM 11.

A vein dips 60°, an entry is driven N 40° W in the vein on a 5% grade. What is the strike of the vein?

PROBLEM 12.

A drift on a 3% grade is driven N 40° E in a vein whose strike is N 60° E. Required the dip of the vein.

PROBLEM 13.

A vein dips 45° to the west and strikes N 12°30' E. A drift on the vein is driven N 16°30' E. Required the grade of the drift.

PROBLEM 14.

A vein dips 54° to the east and strikes N 18°45' W. What is the bearing of a drift on the vein driven on a 3% grade?

PROBLEM 15.

I. The strike of a vein dipping to the S. W. 75° is S 45°15' E. From a given point of outcrop, elevation 3629.4' the mouth of a tunnel bears S 40°10' W and distant 3000' on a vertical angle of -21°08'. The tunnel is driven straight, horizontal and N 12°15' E. Required the distance from the mouth of the tunnel to the point at which it intersects the vein. Assume the tunnel on a 2% grade. What is the shortest distance from the tunnel portal to the vein?

PROBLEM 16.

A vein (a) dips 55° to the northwest and strikes N 35°10' E. A second vein (b) strikes N 35°10' E and on the surface (assumed to be level) is distant from the (a) vein 800'. How far from the vein (a) should a vertical shaft be put down to pierce the intersection of the veins (1) if (b) dips 30° to the northwest; (2) if (a) dips 75° to the southeast and (b) 55° to the northwest. What will be the depth of shaft in all cases?
A STUDY OF MINE SURVEYING METHODS

PROBLEM 17.

A vein dips 43° to the northwest, strikes N 33°15' E, elevation of outcrop 914.6'. At an elevation of 869.2' and distant from the outcrop 1000', an inclined shaft dipping 75° and bearing N 56°45' W is sunk to intersect the vein. (a) Required the depth to which the shaft must be sunk. (b) Assume the pitch of the shaft the same but the bearing S 89°14' W; what will be the depth of shaft?

PROBLEM 18.

The surface has a uniform slope of 10° to the north. A vein strikes east and west and dips 40° to the north.

(a) How far north of the outcrop must one go to sink a vertical shaft which shall cut the vein at a depth of 700'. (b) What will be the bearing of drifts on the vein driven from the bottom of the shaft on a 3% up grade? (c) How far can they be driven so as not to approach nearer than 100' to the surface?

PROBLEM 19.

The vein described in problem 18 is intersected at a depth 1000' by a vertical shaft. From the bottom of the shaft a slope on the vein extends due north 600'. An entry is driven on a 4% grade to the southwest from the bottom of the slope for a distance of 4000'. Required the depth of vertical shaft necessary in order to connect the end of the entry with the surface?

PROBLEM 20.

The horizontal distance between two vertical shafts is 1000', the difference in elevation of the collars of shafts is 291.4'. The depth of shaft sunk from the higher point is 647.2'; from the bottom of this shaft a crosscut (a) is driven towards the other shaft on a 1% grade, 436'. The second shaft is 350' deep. Required the length and grade of crosscut (b) from this shaft to meet the breast of (a).

PROBLEM 21.

Suppose that the lower shaft described in 20 bears S 19°40' W of the other and that the crosscut (a) is driven S 40° W. Required the direction, grade and length of (b).
PROBLEM 22.

A vein dips 60° to the south and strikes N 70° E. Consider the outcrop of the vein as 3650’ elevation. 500’ distant from the outcrop and at an elevation of 3601’ a vertical shaft is sunk to intersect the vein. From this shaft the mouth of a crosscut tunnel bears S 60° E, 2000’ on a vertical angle of — 30°. The tunnel is driven N 33° W. on a 2% grade to intersect the vein. Required the length of slope on the vein necessary to connect the shaft and the tunnel.

PROBLEM 23.

Using the top telescope:

(a) Elevation = 876.42’
+ V. A. = 52° 29’
M. D. = 76.49’
— H. I. = 2.58’
+ H. Pt = 3.45’
r = 0.301’
M. D = Distance from axes of main telescope to point of sight.

Required V. D., H. D. and elevation.

(b) Elevation = 761.59’
— V. A. = 69° 55’
M. D. = 87.23’
+ H. I. = 4.28’
— H. Pt = 3.91’
r = 0.301’

Required V. D., H. D. and elevation.

(c) Elevation back sight station = 647.91’
Backsight + V. A. = 59° 20’
M. D. = 63.48’
— H. I. = 4.21’
— H. Pt = 3.19’
r = 0.301’
Foresight — V. A. = 57° 19’
M. D. = 56.93’
+ H. Pt = 3.21’

Required elevation of foresight station.
PROBLEM 24.

Using the side telescope:

Elevation of backsight station 426.81’

Backsight
+V. A. = 46°21’
+H. Pt = 3.19’
vernier 19°24’
+H. I. = 2.26’
M. D. = 98.23’

Foresight
+Vernier (angle right) = 176°48’
-V. A. = 56°48’
+H. Pt = 4.16’
M. D. = 76.24’

Required elevation of new station.

PROBLEM 25.

It is impossible to place staging in a shaft and the second level is not visible from the first level. In order to save time underground, three points in the shaft visible from both levels are established. The following notes are taken (using the top telescope):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100 a</td>
<td>298°</td>
<td>35°04’</td>
<td>-89°20’</td>
<td>3.91’</td>
</tr>
<tr>
<td></td>
<td>100 b</td>
<td>202°32’</td>
<td>37°74’</td>
<td>-87°41’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 c</td>
<td>237°40’</td>
<td>36°58’</td>
<td>-88°10’</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>100 a</td>
<td>297°18’</td>
<td>54°43’</td>
<td>+54°03’</td>
<td>3.60’</td>
</tr>
<tr>
<td></td>
<td>100 b</td>
<td>293°57’</td>
<td>51°82’</td>
<td>+52°26’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 c</td>
<td>299°39’</td>
<td>53°13’</td>
<td>+53°06’</td>
<td></td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\alpha &= 3.33' \\
\beta &= 1.99'' \\
\alpha - \beta &= 3.39'' \\
\end{align*}
\]

Required the distance and bearing of 200 from 100.
AND THEIR APPLICATIONS TO MINING ENGINEERING
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>3</td>
</tr>
<tr>
<td>Definitions</td>
<td>3</td>
</tr>
<tr>
<td>Importance of Mine Surveying</td>
<td>4</td>
</tr>
<tr>
<td>Difficulties</td>
<td>5</td>
</tr>
<tr>
<td>Notes on History of Mine Surveying</td>
<td>6</td>
</tr>
<tr>
<td>Instruments and Equipment Used</td>
<td>6</td>
</tr>
<tr>
<td>Surveying Party</td>
<td>11</td>
</tr>
<tr>
<td>Underground Stations</td>
<td>12</td>
</tr>
<tr>
<td>Base Line</td>
<td>22</td>
</tr>
<tr>
<td>Carrying the Level and Meridian Into the Mine</td>
<td>23</td>
</tr>
<tr>
<td>Underground Traversing</td>
<td>29</td>
</tr>
<tr>
<td>Surveying the Mine</td>
<td>31</td>
</tr>
<tr>
<td>Geognosy</td>
<td>33</td>
</tr>
<tr>
<td>Surveying Drill Holes</td>
<td>34</td>
</tr>
<tr>
<td>Locating Openings and Mine Plant</td>
<td>35</td>
</tr>
<tr>
<td>Shaft Sinking</td>
<td>36</td>
</tr>
<tr>
<td>Tunneling</td>
<td>37</td>
</tr>
<tr>
<td>Mine Workings</td>
<td>38</td>
</tr>
<tr>
<td>Curves and Connections</td>
<td>38</td>
</tr>
<tr>
<td>Openings to Intersect Veins</td>
<td>39</td>
</tr>
<tr>
<td>Geological Irregularities</td>
<td>40</td>
</tr>
<tr>
<td>Drainage</td>
<td>40</td>
</tr>
<tr>
<td>Haulage</td>
<td>41</td>
</tr>
<tr>
<td>Mapping and Models</td>
<td>41</td>
</tr>
<tr>
<td>Calculation of Volumes and Assay Plans</td>
<td>43</td>
</tr>
<tr>
<td>Problems</td>
<td>48</td>
</tr>
<tr>
<td>Bibliography</td>
<td>46</td>
</tr>
</tbody>
</table>