# PRECISE MINE SURVEYING

by

DONALD LESLIE MASSON

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APPROVED:

Redacted for Privacy

Professor of Mining Engineering

Redacted for Privacy

Head of Department of Mining Engineering

Redacted for Privacy

Chairman of School Graduate Committee

Redacted for Privacy

Associate Dean, Graduate Division

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# PRECISE MINE SURVEYING

## INTRODUCTION

The field of precise mine surveying is one that is of interest to all mine surveyors. Standard text books describe methods and practices suitable for routine mine surveying and acknowledge that refinements of these methods are desirable for precise work (1). Engineering departments of large mining companies make improvements to and adaptations of existing methods to meet local conditions and special problems. As these improvements and adaptations are generally unpublished, engineers of different companies may have to solve similar problems independently.

The writer has had occasion to make a number of long surveys for the purpose of shaft connections. Some of these required accuracy of a high degree as it was contemplated making these connections by means of raises below the proposed shafts. The following indicates the need for accuracy in this work. A three compartment shaft may have an outside dimension of seven by seventeen feet. An error of location of the connecting raise of more than a few inches may make it necessary to slab the walls to allow the timber to be placed in exact alignment. Shaft timber must be aligned exactly for the proper functioning of the cages and skips. Slabbing increases the cost of shaft sinking by an appreciable amount. In heavy ground, an error of location of more than a foot may weaken the shaft walls so that timbering, cementing and maintenance costs would be increased. An error of several feet

(1) Staley: Introduction to Mine Surveying. Pg. 23, 99, 200

may make shaft maintenance difficult or in some cases may render the shaft unserviceable. A larger error might not only make the raise useless but might weaken the ground so that the whole project would have to be abandonded. A quarter of a million dollars is not unusual for the cost of sinking a shaft to moderate depth together with the necessary equipment and surface structures. Deep shafts may cost several times this amount. An alternative to driving the raise full shaft size is to drive a pilot raise of five by nine feet in cross sectional dimension. This must be slabbed to the full size of the shaft and increases the total sinking expense. An error of location of the shaft may permanently weaken the walls of the completed shaft. Any refinement of the standard practice of mine surveying that can be accomplished at a reasonable cost is justified if the final results are more accurate.

## GENERAL

Underground conditions at the mine of the Compania de Real del Monte y Pachuca located at Pachuca, Hidalgo, Mexoco are such that it is more difficult than usual to check underground surveys with the surface triangulation system. The mine is the largest silver mine in the world and has been operated continuously since before the time of Columbus. The present workings are a combination of ancient, winding drifts with the more recent development of modern mining practice. In large areas of the mine there are no openings connecting with the surface that can be utilized for checking with the triangulation system. Long levels are driven from interior shafts and are orientated by shaft plumbings. In the southern part of the Real del Monte district an extensive network of levels has been developed from the Dolores and La Rica shafts. Sometimes it is possible to check the transference of bearing and coordinate of the various levels by a two shaft plumbing. Many times the opportunity for such a check could not be made without a prohibitive expense. In general the surveys could not be closed. For this reason unusual precautions were taken to minimize errors and their effects.

In the latter part of 1941 it was decided to sink the Monterrey shaft five kilometers southwest of the Dolores mine. At the time that the decision was made to sink the shaft the method of connection was not decided upon. One possibility was that the shaft would be connected by means of a raise from an extension of the South Pacific drive on the four hundred level of the Dolores mine. Another possibility was that development levels from the proposed shaft would be connected to the extension of the South Pacific drive. It was necessary that the surveys be accurate in elevation and coordinate location to meet the requirements of both methods of connection. In December 1942 it was decided not to make the connection but by that time the necessary surveys had been made.

Plate number II shows some of the primary traverses in the area before the Monterrey shaft survey was run. Surveys in the area had been carried from the Hermosa and La Rica shafts. They were not considered sufficiently accurate for the proposed connection.

The mine ventilation system required a number of large fans. These caused air velocities up to eighty feet a second in the constricted sections of the development workings through which the surveys were carried. High humidity and powder fumes introduced problems of visibility. Additional problems for the surveyor were introduced by rock and air temperatures. The writer, as assistant superintendent of the department of mining engineering had occasion to solve some of these problems.

## EQUIPMENT

Transits used for mine surveying in the United States are generally a modified surface type transit reading by vernier to one minute. These are satisfactory for routine work where extreme accuracy is not of primary importance. For precise work transits designed for mine surveying give better results. Those used by the Compania de Real del Monte y Pachuca for precise underground surveying were the English made Watts standard mining tacheometer. This model read by vernier to twenty seconds on the horizontal circle and to thirty seconds on the vertical circle. It has both a coarse and a fine centering device that permits exact centering without requiring releveling. With the coarse centering device the transit can be centered as accurately as the surface type transit can be with the conventional type of shifting center. The fine centering device consists of two sets of opposing thumb screws placed at a ninety degree angle from each other. By means of these the transit could be centered to any point within the range of the device by movements of opposing screws.

The centering thorn on the Watts mining tacheometer made exact centering under a point more nearly possible than with the conventional centering punch mark found on surface type transits. As all mine surveying from permanent points necessitates transit stations in the back of the mine workings, any device that will make exact centering under a point easier is an advance in mine transit design. A study of a number of traverses and a series of calculations together with discussions of traversing errors with the chief engineers of several large mining companies has convinced the writer that imperfect centering of the transit is one of the greatest sources of small errors in horizontal angular measurement. Illustration I shows the method of centering using a thorn. Due to the relative position of eye, the plumb bob and the thorn it is possible for the engineer to judge whether or not the thorn is centered directly under the plumb bob point. It is more difficult to estimate the exact position of the plumb bob point with relation to a punch mark as the eye is on approximately the same plane as the mark and plumb bob point and

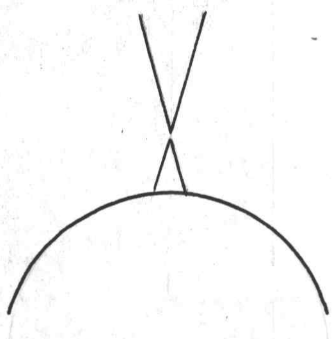

Illustration I

there is considerable parallax.

A special diaphragm, etched on glass, was supplied (see illustration 2). This diaphragm has advantages over those generally fur-

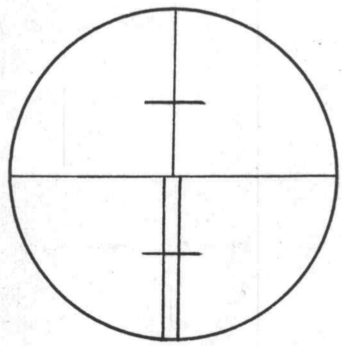

Illustration 2

nished with conventional surface type transits. The alignment of the upper half of the vertical crosshair with the plumb bob string is the same as with any other vertical crosshair. For distances of twenty meters or more the plumb bob string appears in the lower half of the diaphragm as a continuation of the upper vertical crosshair if the alignment is perfect. A slight error in alignment is readily noticed and can be corrected. As the distance between the transit and the plumb bob string is lessened the string appears wider than the vertical crosshair. An estimation of the spaces between the edges of the plumb bob string and the two lower crosshairs is of assistance in bisecting the string with the upper crosshair. This is especially desirable in shaft plumbing work where distances between the transit, the plumbing wires and the plumb bobs are generally short.

One source of error in angular measurement is an engineer's mistake in the use of the clamp and tangent screws of the transit, mistaking the upper for the lower or vice versa. The upper and lower tangent screw heads on the Watts mining tacheometers are shaped differently which enables the engineer to differentiate between them by feel. This prevents the mistake of using the wrong tangent screw with a resultant error.

High velocity air currents introduced problems of centering and taping. The eight and ten ounce plumb bobs normally used in mine surveying were found to be too light for use under the conditions encountered in this survey. Tests with these in the air currents encountered showed that there was a difference in location of the plumb bob point at the height of the transit of more than a centimeter in its position when the plumb bob was shielded and in its position when the plumb bob was not shielded. As this difference was excessive and would have introduced serious errors in the survey if not corrected, heavy mercury plumb bobs were obtained. These were satisfactory; lateral displacement was found to be negligible when they were tested in the same manner as the lighter weight plumb bobs were.

Canvas shields eighteen inches wide and seven feet high were mounted on frames and used to protect the plumb bobs from air currents wherever possible. Wider shields were found to cause too great an obstruction in the drifts with the result that eddying currents of air moved the plumb bobs. Canvas shields similar to these but having a window covered with transparent plastic were tried in the measurement of horizontal angles in an effort to obtain better protection of the plumb bobs. These were discarded as it was found that conditions of visibility prohibited their use. Shorter shields which protected the plumb bob and transit head only were not tried but might have caused less eddying as they would not have interfered as much with the normal air flow.

The tape used was a Lufkin one hundred meter steel tape one eighth of an inch wide. Tape clamps and tension handles of standard design were used throughout the survey. Thermometers of a conventional type were suspended as close to the tape as possible. The writer believes that a tape thermometer would have given more accurate results as there was an appreciable difference between the rock and the air temperatures in some sections of the mine. The taping was done at rail level. No tests were run to determine the accuracy of the measurements of the temperature of the tape. An error of two degrees would not have made an appreciable difference in the correction of the tape for temperature.

The transit used for triangulation was made by Berger. It had an eight inch horizontal circle and measured by vernier to five seconds. The vertical circle measured by vernier to thirty seconds.

## METHOD OF PROCEDURE

For convenience of description the survey is divided into the following operations: surface leveling, underground leveling, shaft measuring, surface triangulation, the underground traverses, tape standardization and the calculations. Actually the work progressed in much the same order except that the tape was standardized after the shaft measurements in the Dolores shaft. If conditions interfered with the work of one operation, field work was continued in the next until such a time as work in the first operation could be resumed.

## SURFACE LEVELING

Due to the rough topography it was impractical to run accurate levels in a direct line on the surface, although approximate levels were carried over the proposed power line to the Monterrey shaft. Ten bench marks were established near the road connecting the Dolores and the Monterrey shafts. Three engineers, C. J. Barber, J. H. O'Connor and D. L. Masson, each using a slightly different method, ran the surface levels from bench mark to bench mark and then back for a check. Barber and O'Connor omitted bench mark four by running from bench mark three to bench mark five through an old quarry instead of following the road.

Barber ran the levels by a modification of the method used by the United States Coast and Geodetic survey[2] using a Wilde level and a four meter self reading rod, reading all three stadia hairs. An attempt was made to keep the foresight distances roughly equal to the backsight distances by means of stadia. In some cases the foresight

(2) Avers: Manual of First Order Leveling pg 3-9

and backsight distances varied considerably.

O'Connor used a Kueffel and Esser wye level and a four meter self reading rod. His backsight and foresight distances were chosen at random.

Masson used both the Wilde level and the Kueffel and Esser wye level. He used a two meter Philadelphia type rod, using the target and reading the vernier to a tenth of a millimeter. His backsight and foresight distances were made approximately equal by taping. Rod readings were not taken within eighteen centimeters of the ground to avoid variable refraction.

All rodmen used rod levels. No corrections were required for refraction since the backsights and foresights were approximately of equal length. Table I gives the results of the surface leveling.

TABLE I

SURFACE LEVELS

| Engineer | Difference Elevation △ 301 A to B. M. 8 | | | Variation out - in | Variation ÷ $\sqrt{K}$ | Dev.*of the Ave. from the Mean |
|---|---|---|---|---|---|---|
| | Out | In | Ave. | Meters | mm. | mm. |
| C.J.B. | -46.1322 | 46.0682 | -46.1002 | 0.0640 | 24 | 23.5 |
| J.H.O. | -46.116 | 46.147 | -46.1315 | 0.031 | 12 | 7.8 |
| D.L.M. | -46.1323 | 46.1467 | -46.1395 | 0.0144 | 5 | 15.8 |

*Deviation of the average from the mean.

The table reads: C. J. Barber measured the difference in levels between triangulation station 301 A to bench mark 8 as -46.1322 meters, from bench mark 8 to triangulation station 301 A as 46.0682 meters. The average difference in elevation between bench mark 301 A and bench mark 8 is -46.1002 meters. His variation between the two sets of levels is 0.0640 meters. His variation divided by the square root of the distance in kilometers is 24 millimeters. The deviation of the average of his levels from the mean of all the levels run was 23.5 millimeters. The other lines read in a like manner.
K is the distance leveled in kilometers 6.9557 (stadia measurement)
The U.S. Coast and Geodetic Survey[2] states that the allowable variation for first order leveling is 4.0 mm $\sqrt{K}$.
The mean difference in elevation is -46.1237 meters. This was accepted as correct.
The probable error of the mean is ±0.0085 meters (Bessels formula)[3]

$$r^{o} = \frac{0.6745}{n\,(n-1)}\sqrt{v_1^2 + v_2^2 + v_3^2 + \ldots . v_n^2}$$

$r^{o}$ is the probable error of the mean
n is the number of observations
v is the variation of the observation from the mean

## UNDERGROUND LEVELING

Using the same methods with two meter Philadelphia type rods the results given in Tables two and three were obtained in underground leveling. Considerable difficulty was experienced in leveling on the 400 level due to fumes from blasting and a fog caused by high humidity which limited the length of foresights and backsights. When conditions were too unfavorable it was necessary to suspend field work until the visibility was better.

(2) Henry G. Avers op. cit. pg 6

(3) Marks: Engineering Handbook pg 121

## TABLE II

### UNDERGROUND LEVELS 300 LEVEL - DOLORES MINE

| Engineer | Difference in Elevation B. M. 300 to rail 1690 counter shaft | | | Variation out - in | Variation ÷ $\sqrt{K}$ | Dev. of the Ave. from the Mean* |
|---|---|---|---|---|---|---|
| | Out | In | Ave. | Meters | mm. | mm. |
| C.J.B. | 8.9615 | -8.9440 | 8.9528 | 0.0175 | 13 | 10.0 |
| J.H.O. | 8.9440 | -8.9360 | 8.9400 | 0.0080 | 6 | 2.8 |
| D.L.M. | 8.9348 | -8.9362 | 8.9355 | 0.0086 | 6 | 7.3 |

This table reads in a similar manner to Table I.

K is the distance leveled in kilometers.

The mean difference in elevation is + 8.9428 meters. This was accepted as correct.
Probable error of the mean is ± 0.0027 meters (Bessels formula).

## TABLE III

### UNDERGROUND LEVELS 400 LEVEL - DOLORES MINE

| Engineer | Difference elevation B. M. 404 T to B. M. 404 M | | | Variation out - in | Variation ÷ $\sqrt{K}$ | Dev. of the Ave. from the Mean* |
|---|---|---|---|---|---|---|
| | Out | In | Ave. | Meters | mm. | mm. |
| C.J.B. | 6.841 | -6.855 | 6.848 | 0.014 | 9 | 23.6 |
| J.H.O. | 6.827 | -6.833 | 6.830 | 0.006 | 4 | 5.6 |
| D.L.M. | 6.7970 | -6.7936 | 6.7953 | 0.0034 | 2 | 29.1 |

*Deviation of the average from the mean.

The table reads in a similar manner to Table I.
K is the distance leveled in kilometers (2.5 approximately).
The mean difference in elevation is +6.8244 meters. This was accepted as correct.
The probable error of the mean is $\pm$ 0.0067 meters (Bessels formula).

## SHAFT MEASUREMENTS

A one hundred meter tape, subsequently checked with a standard tape (see section on tape standardization) was used to transfer the elevations down the shafts. Due to operating conditions the shaft measurements were taken prior to the standardization of the tape. A tension of eight and a half kilos was arbitrarily taken for the first measurements. The same tension was used in later shaft measurements, because the distances in the Dolores and Monterrey shafts were approximately equal, and small errors in measurement would be compensating if both measurements were taken in a like manner.

The tape was suspended vertically in the shaft with the tension applied at the lower end by a tension handle. Points were marked on provisional braces in the shaft so that, although the tape did not touch them, readings could be taken simultaneously at both ends. The verticality of the tape was checked by the shaft timbers which were plumb. After taking one set of readings the tape was moved vertically a short distance and the readings repeated. The surface elevations were transferred to the tape, and from it to the permanent bench marks by spirit levels, reading the suspended tape directly. The tape was used as a long leveling rod. The air temperature was taken at each end of the tape and the readings averaged. For temperature and tension corrections refer to the section on calculations. Table IV summarizes the results obtained in shaft measuring. The measurements of the Dolores and 1690 countershafts were repeated on different days by different field parties.

TABLE IV

SHAFT MEASUREMENTS

| Engineers | Dolores | 1690 Ctr. | Monterrey |
|---|---|---|---|
| D.L.M., J.H.O. | -290.0826 | -60.5177 | |
| C.J.B., F.R. | -290.0761 | -60.5181 | |
| D.L.M., F.R. | | | -284.2403 |
| Average | -290.0794 | -60.5179 | |

F. R. is Francisco Ruelas
Dolores shaft measurements were from △ 301 A to bench mark 300.
1690 countershaft measurements were from the rail at the collar of the shaft to bench mark 404 T.
Monterrey shaft measurements were from the bench mark 8 to bench mark 11 on the two hundred and eight five meter level, the level from which the contemplated raise for connection of the shaft was to have been driven.

As the final connection was not made a check of the accuracy of the work of leveling and shaft measurement was impossible. In another survey for shaft connection at the Paricutin shaft by the Cia de Real del Monte y Pachuca, the writer, using the same methods of leveling and shaft measurement, was able to close his levels to 0.0005 meters. The Paracutin shaft connection had unusual problems of temperature as the rock temperature was 135 degrees fahrenheit.

The measurements were carried down the Tula shaft approximately 370 meters, through about two kilometers of winding drift, about forty five meters up the 5 North raise, through about five hundred meters of drift for the connection. The surface levels were carried about 1700 meters on the surface and then down the Paricutin shaft. Some compensating errors must have been present but the results indicate an accuracy suitable for precise mine surveying.

## TRIANGULATION

After preliminary reconnaissance the triangulation stations were selected as shown in Plate number I. Due to the rugged topography there was little choice in the location of triangulation stations, several of which were old ones of the triangulation system established by the company and approved by the Mexican government for the location of mining claims in the Real del Monte and Pachuca mineral districts. In addition to the angular measurements a base line was prepared and measured. This was for purposes of a check as the original triangulation base line had been measured twenty years before this survey. There was no doubt as to the accuracy of the primary triangulation system but it was decided to make a check to determine whether or not the primary triangulation stations had been moved.

The triangulation was oriented by ties to the Purisima and Dolores shafts for reasons given under the section on Orientation. As shown in Plan I, the triangulation net included two quadrilaterals and two short traverses, one at the Purisima shaft and one at the

Dolores shaft. Dolores shaft is located inside a high stone wall and the most feasable way of tieing in the station at the collar of the shaft with the triangulation system seemed to be by a short traverse. Purisima shaft is located in a wood of large oak trees. Local conditions precluded cutting down enough trees to enable the station at the collar of the shaft to be tied in directly with the triangulation net. A short traverse was required to tie in the shaft plumbing of the Hermosa shaft. Only one angle in the triangulation was less than thirty degrees an angle measuring $25^{\circ}34'27.7''$. All stations were occupied; there were no calculated angles.

Two engineers, working independently, measured all triangulation angles by repetition.

O'Connor first set the A vernier at $00^{\circ}00'00''$ and repeated the angle four times with the telescope erect; he again set the A vernier at $00^{\circ}00'00''$ and repeated the angle four times with the telescope inverted reading both verniers each time. He made similar observations with the A vernier set at $120^{\circ}00'00''$ and $240^{\circ}00'00''$ making a total of six measurements of four repetitions each, the average of which was adjusted for station adjustment to $360^{\circ}00'00''$.

Masson read both verniers and repeated the angle twelve times, alternating telescope erect and inverted; the initial A vernier was first set at $00^{\circ}00'00''$. This procedure was repeated, making two readings of twelve repetitions each. If the results of the two measurements varied by more than seven seconds the angle was remeasured with the A vernier first set at $90^{\circ}00'00''$. The average angle was adjusted for station adjustment.

Angular measurements were rejected if there was any uncertainty as to their accuracy, but were not rejected because of minor variations from other measurements. Some trouble was experienced because of signal poles being moved; if there was any question about this the measurement was rejected.

The angular measurements were weighted by the number of repetitions; average values were calculated. Thirty nine angles were measured with an average of ninety six repetitions an angle. The maximum number of repetitions was two hundred and eight; the minimum sixty.

The line of sight between certain stations had to pass close to the ground or close to trees and other objects since it was impractical to erect towers, and since large trees could not be cut, due to local conditions. Due to the elevation above sea level, from nine thousand to over ten thousand feet, and to the intense sunlight of the tropics, lateral refraction made it extremely difficult to check certain angles. To minimize the effect of lateral refraction, heat waves, and the uneven expansion of the transit due to heat, angles were measured as far as possible early in the morning and on cloudy days. Relatively steep vertical angles greater than fifteen degrees were unavoidable in certain triangles. The sum of thirty nine angles as determined by both engineers varied by $00^{\circ}00'20.8"$ or $0.53"$ per angle.

The writer observed two cases of lateral refraction that were of unusual interest. One afternoon he was measuring triangulation angles at $\triangle 16$ following a heavy tropical thunder shower. The sky was cloudy and the air was cold. As he finished measuring the angles at the station, he observed the clouds were breaking and that in a few minutes the weather would soon be sunny. He set his crosshairs on a range pole signal about a kilometer away. Then, without touching the transit, he observed his range pole. As the sunshine broke in the area the crosshair seemed to creep off of the range pole. When the area was in sunshine the horizontal circle was read, the crosshair set on the range pole and the angle read and calculated. The angle was about a minute. Unfortunately as the angle was of no importance to the survey the exact value was not saved. The writer had not moved his feet nor touched the tripod or transit. There was no wind. The level bubbles were perfectly centered. The only explanation seems to be that of lateral refraction.

Another morning the writer arrived at the same triangulation station before sun up. He set up his transit and while waiting for his helpers to erect a range pole he centered his crosshair on the backsight about a kilometer and a half away. His helpers delayed erecting their range pole because it was necessary to cut some brush to insure visibility. In the meantime the sun rose. When conditions were ready for angular measurement, the backsight was checked. The crosshairs were off the range pole. The amount was not measured but by estimate the angle of lateral refraction was similar to the first case cited.

For the sixteen triangles in the net the mean triangle closure error was 3.59". The quadrilaterals were adjusted by the method of least squares; while all triangles were adjusted to 180°00'00". Angles were calculated to tenths of seconds. The maximum angular adjustment was 2.7", the minimum 0.1", the average 1.2". Because of the relatively short distances involved the spherical excess was not calculated.

The check base was established between △ 1915 and △ 1916, on a flat piece of ground in the lower part of the village of Tezuantla. The distance between bases was measured twelve times with the standardized hundred meter tape (see section on standardization of tapes) using tension handles to insure the correct tension of seven and a quarter kilos. Intermediate points consisted of crosses cut on lead plaques firmly fastened to stakes driven solidly in the ground. The tape was supported by stakes set on line every five meters and leveled to uniform grade. The maximum grade between intermediate points was less than five and a half per cent. For corrections of temperature, grade and reduction to the elevation of the Santa Julia base refer to the section on calculations.

In case the range of the measurements of a draft exceeded three millimeters, the draft was remeasured and variations above this limit were rejected. All measurements were made on a cloudy day, none being taken in the direct sunlight. The mean of the twelve measurements was 415.5215 meters, reduced to the elevation of the Santa

Julia base, and was accepted as correct. The calculated distance from △15 to △16, two primary triangulation stations, as determined by the above measurement and the present triangulation is 1 304.9892 meters as compared with 1 304.9886 meters as given by the original triangulation. This is a difference of 0.0006 meters or one part in 2 175 000.

## UNDERGROUND SURVEY

Transit stations for the underground traverse were placed in the drift back, timber being avoided wherever possible. So far as practicable, stations were a minimum of twenty meters apart, and the line of sight was kept roughly a half a meter from timber and the wall of the drift or other objects to avoid possible lateral refraction.

The writer believes that one of the most important phases of any survey underground is the proper selection of stations. A simple series of calculations was made showing the possible errors of bearing due to a centering error of one millimeter. Where both the foresight and the backsight are over twenty meters the effect on the bearing is small. The shorter one or both of these distances, the greater the effect of the error. It is likewise important that the transit be set in a location where the surveyor can work without being in a cramped position. Accuracy is difficult when the surveyor has difficulty in moving around and in manipulating his transit due to space limitations. In this survey two engineers, Masson and O'Connor selected stations in the best locations possible before commencing the underground field work.

All underground traverse angles were measured independently by two engineers using Watts transits. With the A vernier first set at 00°00'00", O'Connor repeated each angle twice with the telescope erect and twice with the telescope inverted; he then read the explement in the same way. If the sum of the two differed from 360°00'00" by more than fifteen seconds, he repeated the procedure and averaged those values which checked within fifteen seconds.

Masson repeated each angle eight times, alternating the telescope erect and inverted, with the initial A vernier set at 00°00'00"; the explement was read in the same way. If the sum of the two angles differed from 360°00'00" by more than ten seconds the procedure was repeated. Values which checked to ten seconds were averaged. Whenever either the backsight or foresight distance was less than twenty meters, compensating centering was employed. Mercury plumb bobs were used to minimize the effect of air currents.

Compensating centering as used in this survey consisted of centering the transit with the telescope in one position. The angle was measured as described. The transit was then moved and recentered with the telescope turned a hundred and eighty degrees. The explement was then measured.

Both engineers used canvas shields to protect the plumb bobs from high velocity air currents. Much of the angular measurement and taping was done on Sunday when the ventilation fans could be stopped.

The angle values as determined by each engineer were compared and all those which failed to check each other by fifteen seconds were remeasured. About ten percent of the angles failed to check by twenty seconds, over twenty percent failed to check by fifteen seconds. Those which checked by less than fifteen seconds were weighted by the number of repetitions and averages calculated. In the case of angles which failed to check by fifteen seconds the measurement was repeated by one of the engineers. In all instances except at the Tapona countershaft, where the ground was moving due to mining operations, the repeated angle checked one or both of the previous measurements by less than fifteen seconds. This remeasured value was averaged to the original measurement from which it differed less. Angles were calculated to the nearest second.

Angles as measured by both engineers were compared to ascertain if there were constant differences in angular measurement. The sums of sixty angles chosen at random varied from each other by 72" or an average of 1.2" per angle.

A number of transit stations were unavoidably placed in timber. As these stations were near working stopes and as timbermen were repairing drifts sets on both the three hundred and four hundred levels it was found that in certain sections the transit stations had moved in the period of a month that intervened between the two surveys. It was decided that if the sum of a consecutive number of angles as measured by each engineer did not vary by more than 15" $\sqrt{N}$ in which N was the number of angles in the series, the series would be accepted as correct. For these series each engineer calculated and checked the bearings and co-ordinates of his survey. Absolute bearings and coordinates as computed by each engineer were averaged after each series.

All taping was done using the same tape and procedure used in taping the check base at Tezuantla, except that each draft was measured six times instead of twelve. The tape was supported every five meters by strips of wood of uniform thickness placed on the rails. The slope of the tape was checked by spirit level whenever definite level data was not available and in some cases the existing level data was checked. All measurements were taken between the points of two mercury plumb bobs suspended from the transit stations. Care was taken that the plumb bobs were stationary during measurements, canvas shields being used to protect them when necessary. Temperatures ranged from sixty to eighty five degrees fahrenheit. For corrections of temperature, slope and reduction to the elevation of the Santa Julia base refer to the section on calculations.

From the wire in the Dolores shaft on the three hundred level to base 194 on the four hundred level the average distance between transit stations was 51.8 meters. The maximum distance between transit stations was 135.271 meters, the minimum 15.272 meters. However, shaft plumbings and auxiliary surveys for the transference of bearing from one level to another necessitated the use of shorter distances. There were few measurements of more than a hundred meters as measurements longer than the tape necessitated placing an intermediate point with a transit. There were ninety four transit stations including plumbings in a direct line between the Dolores wire on the three hundred level and base 194 on the four hundred level. An additional sixty five transit setups were made for shaft plumbings and transfer of orientation from one level to another.

The following table summarizes the comparison of measurements by this method and of previous measurements made in routine mine surveys.

TABLE V

COMPARISON OF TAPING

| Point - Point | Present taping | Previous taping | Variation meters | Variation 1 meter in | Remarks |
|---|---|---|---|---|---|
| △301 △301A | 84.689 | 84.622 | 0.067 | 1 264 | Surface |
| △15 △16 | 1 304.9892 | 1 304.9866 | 0.0006 | 2 175 000 | (1) |
| 17 drafts | 732.797 | 732.628 | 0.169 | 4 336 | (2) |
| 1028/11-1045/9 | 1 233.999 | 1 233.248 | 0.751 | 1 643 | (3) |
| 1056/2 1061/3 | 349.795 | 349.716 | 0.079 | 4 428 | (3) |

(1) - For △15 to △16 see section on check base.
(2) - The measurement of the sum of seventeen drafts of this check survey was compared with previous measurements of the same drafts. Previous check and routine mine surveys made by various engineers.
(3) - These comparisons were made of the calculated distances between two transit stations on straight stretches of the South Pacific crosscut. The previous survey was a routine mine survey.

If the method of taping described in these notes is correct, then the difference in earlier taping may be due to a combination of the following reasons:-

1. Too much tension is applied to the tape when the tension is not measured. This would stretch the tape with a consequent short measurement.

2. Old tapes used in check and routine mine surveys may have permanent elongation after continued use. This would give a short measurement.

3. Temperature corrections are not made in routine and ordinary check surveys. Under the conditions of this survey most of the temperatures were above the temperature at which the tape is standard (sixty eight degrees fahrenheit). This would make an uncorrected measurement shorter.

4. Precautions are usually not taken to have the plumb bobs absolutely stationary while taping. When the plumb bob is moving slightly engineers may have a tendency to accept the shorter of two measurements.

For comparison of check of underground taping by this method refer to pages 20 and 24.

A comparison was made of the calculated distances between the wires in the Dolores-Purisima shafts (Traverse number two) and the Purisima-La Rica shafts (Traverse number one) as determined by triangulation and by previous underground traverses.

The following table summarizes the results:-

TABLE VI

COMPARISON OF TAPED DISTANCES - EARLIER TRAVERSES

| Point - Point | Distance by Triangulation | Distance by Traverse | V a r i a t i o n Meters | 1 meter in. | Remarks |
|---|---|---|---|---|---|
| Wp - Wd | 1 403.506 | 1 403.229 | 0.277 | 5 067 | Traverse N°2 |
| Wp - Wr | 750.250 | 750.183 | 0.067 | 11 175 | Traverse N°1 |

Wp is wire in the Purisima shaft.
Wd " " " " Dolores "
Wr " " " " La Rica "

STANDARDIZATION OF THE TAPES

Using a transit to obtain alignment, three bases A,B, and C, were placed in a line on the floor of crosscut N 2175E, three hundred level, Tapona. The bases consisted of iron pins set in concrete to the level of the drift floor with a cross, cut with a sharp chisel on each pin to mark the station. The floor of the drift between monuments was leveled as smooth as practicable to support the tapes.

A fifty meter standard tape, National Bureau of Standards number 6973, certified to have a length of 50.0000 meters when supported on a flat horizontal surface at a tension of 7½ kilograms, was used to measure the distance between these bases. Tension was applied by means of a tension handle. The tape was read simultaneously at both ends by engineers J. H. O'Connor and D. L. Masson. Six sets of observations were made for each measurement, the engineers changing ends of the tape after the first three readings.

The results of the measurements are summarized in the following table:-

TABLE VII

MEASUREMENTS WITH THE STANDARD TAPE

| Point - Point | Mean Measurement | Maximum Variation | Maximum deviation from the mean |
|---|---|---|---|
| A - B | 49.45567 | 0.0006 | 0.0003 |
| B - C | 49.40006 | 0.0003 | 0.0002 |
| A - C | 98.85573 | | |

The hundred meter tape was then standardized. The tape was fastened firmly at base A so that the tape reading was 98.90000. Tension was applied on the tape at base C by means of the tension handle until the end of the tape read 0.0443. The tape was read four times by one engineer, then the engineers changed ends of the tape and the observations were repeated five times more. The mean of the nine observations indicate that the tape gives a correct measurement of 100.0000 meters when supported on a flat horizontal surface with a tension of 7.277 kilograms, or for practical purposes 7¼ kilograms. No correction was made for temperature or grade, which were constant for both tapes. The temperature was seventy two degrees fahrenheit throughout the tests.

The measurement was repeated with the same tape using a tension of 9.0 kilograms. The average of six measurements was 98.849467 meters or 0.00626 meters less than the correct measurement. Assuming that for a limited range of tension the elongation is proportional to the tension applied, then the tension correction to be used with this tape at other than the tension of 7¼ kilograms should be $\pm$ 0.0000361 meters per meter of taped distance for each kilogram variation in tension from 7¼ kilograms. If the tension applied is greater than the standard tension the correction should be added to the measured distance; if less, subtracted.

## ORIENTATION

All the important surveys made in the Real del Monte district since 1929 are based directly or indirectly on a check survey between the La Rica and Purisima (Hermosa) shafts on the four hundred level (four hundred and ten meter level in La Rica.) This survey, made by Fredell and Goldberg in 1929, was oriented by three plumbings in both shafts, and was adjusted so as to close between the two shafts. (Traverse number one on Plate II.)

Subsequently, this survey was continued on the four hundred level to Dolores shaft, (Traverse number 2) which had been plumbed from the surface, giving a closing error of only 0.068 in Lat., 0.001 in Dep. This survey had been continued to the Santa Margarita counter shaft, (Traverse number four) and back through the Vizcaina vein to close at La Rica shaft (Traverse number three) and also through the Santa Ines vein to close at the Guardaraya crosscut (Traverse number fifteen).

The Santa Margarita counter shaft had been plumbed to the five hundred level and the check survey carried on that level to both the Colon South counter shaft (Traverse number eight) and the Regla counter shaft (Traverse number nine). In the former the survey was tied by plumbings to surveys carried from La Rica shaft on both the four hundred and five hundred and fifty meter levels (Traverses numbers six and seven) both of which had been oriented from Traverse number one. At Regla counter shaft the check survey was carried to the four hundred level by plumbing and closed on to a continuation of the traverse between La Rica and Colon South counter shaft on that level (Traverse number ten).

From Regla counter shaft the survey had been continued through the North Pacific crosscut to winze 1700E (now counter shaft 1690E), Tapona vein, (Traverse number eleven) where it had been tied to a traverse on the three hundred level from Dolores shaft (Traverse number twelve). The last mentioned traverse had been oriented by careful plumbing of Dolores shaft from Traverse number two.

All the traverses had been balanced so as to close and had been made without using a standard tension on the tape, and without making temperature corrections. These traverses are shown on Plate II. From the end of the North Pacific crosscut the survey had been carried as a routine mine survey to the South Pacific drive.

The total coordinates of the underground survey and the surface triangulation are based on the permanent transit stations (bases) 26 and 27 (Traverse number two) near the four hundred level shaft station, Dolores shaft. The orientation of the underground survey is based on the bearing between these bases (S 12°28'30"W); while the triangulation is orientated by these bases and bases 1 and 2 at Purisima shaft (Traverse numbers one and two).

Engineers Fredell and Becerra (4-26-36) plumbed the Dolores shaft from the surface (△301A) to these bases 26 and 27. This plumbing was accepted as correct and the coordinates of △ 301A recalculated to be 9 936.344 latitude, 20 945.597 departure. Engineers O'Connor and E. Villasenor plumbed the Purisima shaft to bases 1 and 2 (Traverses number one and two) and the coordinates of base 304 were recalculated to be 9 936.344 latitude; 20 945.597 departure. The orientation of the triangulation was determined by the new coordinates of 301A and 304. The bearings of △ 15 and △ 16 (see check base) as determined by this orientation and triangulation are S 67°33'12.5"E as compared to S 67°33'00.1"E as given by the primary triangulation, a difference of 12.4".

An attempt was made to check this orientation by plumbing the La Rica shaft from bases of traverse number one on the four hundred level, La Rica (Masson - O'Connor, 11-15-42). Due to some undetermined reason, possibly taping errors in the earlier check surveys, the orientation did not check by 00°00'29.9". In the final orientation of the triangulation the La Rica check was disregarded.

Traverse number two was continued to the Tapona countershaft, a distance of 993.277 meters from the wire in the Dolores shaft as measured on the three hundred level, and the countershaft plumbed to the three hundred level. For preliminary calculations the plumbing of the Dolores shaft between the four hundred and three hundred levels (5-17-36) by Fredell, Viescas, and Madrazo had been accepted, coordinates and bearing of the present three hundred level traverse were carried by traverse to the Tapona counter shaft and tied in to the one wire plumbing previously mentioned. The adjustment of the three hundred level traverse to the coordinates of the wire in the Tapona counter shaft of the four hundred level traverse necessitated a swing in bearing of $00^{\circ}04'01.4''$ by increasing the azimuth of the new survey. In an effort to account for this large swing in bearing, a comparison of the angles of this survey with those obtained by Barber in 1937 was made. This indicated that one or both of the bases on the three hundred level at the Dolores shaft has moved. The value of angle B 186 - B 187 - 914/3 as determined by O'Connor was $172^{\circ}06'13''$, by Masson as $172^{\circ}06'19''$. However, Barber in 1937 measured the angle $172^{\circ}08'46''$. It is probable that one of the bases had moved as base 187 is near a stoped area on the Santa Brigida vein. A check of the four hundred level at the Dolores shaft by O'Connor and Masson by surveying from old stations of traverse two did not find any movement of bases 26 and 27.

Masson and O'Connor then plumbed the Dolores shaft between the three hundred and four hundred levels and recalculated the traverse on the three hundred level. Based on this plumbing, the bearings of the traverse to the Tapona countershaft, three hundred level had to be adjusted by decreasing the azimuth $00^{\circ}00'07''$. The distance between wires as measured on the three hundred level and as measured on the four hundred level varies by 0.033 meters or a difference of 1 in 30 000. (See comparison of measurements with previous surveys, Table VI).

The following table summarizes the results of plumbings from the four hundred level, bases 26 and 27 to the three hundred level, bases 186 and 187, Dolores Shaft:

TABLE VIII

DOLORES SHAFT PLUMBING

| Date | Bearing 186-187 | Method | Engineers |
|---|---|---|---|
| 5-5-1936 | S $47^{\circ}$ 47' 49" E | 2 wire alignment | Fredell, Viescas |
| 5-17-1936 | S $47^{\circ}$ 47' 59" E | Collimation | and Madrazo |
| 12-28-1942 | S $47^{\circ}$ 43' 51" E | 2 wire alignment | O'Connor, Masson |

The bearing as calculated from the closed survey from bases 26 and 27 through the four hundred level, the three hundred level, the Tapona counter shaft, and the Dolores shaft is S $47^{\circ}43'58''$E which checks the plumbing of 12-28-1942 by $00^{\circ}00'07''$ and indicates that one of the bases in question has moved.

Three bases 300, 301 and 302 were established on the three hundred level in solid ground and tied into the present survey. The following table summarizes the engineering data for these bases:-

TABLE IX

ENGINEERING DATA, BASES 300, 301, 302

| Base-Base | Bearing | Distance | Latitude | Departure |
|---|---|---|---|---|
| 300 | | | 9 854.387 | 21 048.078 |
| 300 - 301 | S 67° 48' 03" E | 45.489 | 9 837.200 | 21 090.195 |
| 301 - 302 | S 68° 36' 59" E | 46.474 | 9 820.255 | 21 133.470 |

The survey was then continued on the three hundred level using the adjusted bearing and coordinates to the 2140E raise on the Tapona vein where a one wire plumbing was tied in to transit stations on the four hundred level.

Two permanent bases were tied in on the three hundred level near the present ventilation fan, bases 188 and 189 and compared with the coordinates and bearing determined by Barber in a previous check survey (1937) of the three hundred level. The bearing of the new unadjusted survey for these bases was S 61°23'45"E as compared with the bearing of S 61°22'34"E as determined by Barber. There are thirty three setups between the two bases; E was determined to be 12.34" for the expression e N where e is a constant and N the number of setups.

The 1690E countershaft was plumbed for bearing and coordinates by Masson the three hundred level and O'Connor and Ruelas on the four hundred level (10-29-1942). Due to a distance of approximately two meters between the transit and foresight, two meters between the transit and wire, and three meters between the foresight and base on the four hundred level the accuracy of the transferrence of bearing is questionable. The traverse was carried to the 2140E raise and tied in to the one wire plumbing there. The traverse on the four hundred level was then swung by decreasing the azimuth by $00^{\circ}03'39''$ and the bearing and coordinates recalculated. The distance between wires as measured on the three hundred and four hundred levels varied by 0.013 meters or 1 in 33 000. (Refer to the section on comparison of measurements.) The adjusted bearing between bases 190 and 191 on the four hundred level at the Tapona countershaft was then compared with the bearing as determined by the traverse from Regla (Traverse eleven) and found to check to $00^{\circ}00'20''$.

The adjusted survey was then carried from 2140E raise to bases 192, 193 and 194 placed as near as possible to the face of the South Pacific crosscut at the time of the survey. The bearing between transit stations 1061/11 and 1075/1 as determined by routine mine survey is S $43^{\circ}55'00''$E as compared with the check survey bearing of S$43^{\circ}54'29''$E. The difference in bearing as surveyed is 51", or 31" plus an initial difference in bearing of 20" at bases 190-191. For the expression $e\sqrt{N}$, e is determined to be 7.01". The coordinates of 1061/3 as determined by routine mine survey are 6 905.758 latitude, 23 582.420 departure as compared with 6 903.468 latitude, 23 582.484

departure as determined by this check survey.

MONTERREY SHAFT DATA

The present orientation of the 285 level of the Monterrey shaft is based on a two wire plumbing by the alignment method by engineers Masson and Ruelas (3-28-43) using an initial bearing based on 1918 and 753 as determined by the triangulation for this survey.

The bearing of base 300 to base 301 on the 285 level as determined by this plumbing is S 47°02'03"W. The following table gives the engineering data for these bases:-

TABLE X

MONTERREY SHAFT DATA

| Point | Latitude | Departure | El. of Point | El. of rail at point |
|---|---|---|---|---|
| B 301 | 6 185.721 | 24 304.997 | 2 418.5528 | 2 416.0411 |
| B 300 | 6 216.487 | 24 338.029 | 2 418.9112 | 2 416.0299 |

CALCULATIONS

The metric system has been used throughout these calculations for lineal distances and coordinates. All temperatures are recorded in degrees fahrenheit. All tape tensions are in kilograms.

All calculations were made independently by O'Connor and Masson, using seven place logarithm tables. All triangulation calculations were carried to the nearest tenth of a second, all angles for the underground survey to the nearest second. All taped distances were calculated to the nearest tenth millimeter, but for the final calculation the nearest millimeter was used. All calculations for absolute latitude and departure were carried to the nearest millimeter both for the triangulation and the underground survey. All bearings were calculated by azimuths.

All horizontal distances were reduced to the elevation of the Santa Julia base by the formula $C = Sh/4$ (U.S.G.S)(4) where C is the correction, S is the measured distance, h is the height of the measurement above the Santa Julia base and 4 is the radius of the earth plus the elevation of the Santa Julia base above sea level. The Santa Julia base is the base line for the triangulation system of the district previously referred to. The radius of the earth was taken as 6 378 206.4 meters. No measurements were taken below the elevation of the Santa Julia base. The elevation of the Santa Julia base was calculated to be 2 382.7 meters, the average of the accepted elevations of 1 and 2.

All taped distances were corrected for temperature by the correction factor furnished by the manufacturer of the tape, 0.00000645 meters for one degree fahrenheit difference in temperature from sixty eight degrees fahrenheit for each meter of taped distance. If the temperature was more than sixty eight degrees fahrenheit the correction(5)

(4) C. V. Hodgson: Manual of First Order Triangulation pg 146

(5) Private communication from Lufkin Tape Company

was added, if less it was subtracted.

All slope distances were reduced to the horizontal by the formula $C = h/2S$ for grades less than 5½% where C is the correction to the taped slope distance, h is the difference in elevation between the two points and S is the slope distance.[6]

The tension correction for shaft measurements was made by a method recommended by the manufacturer of the tape,[5] also by "Elementary Surveying" by Breed and Hosmer.[7] One half of the weight of the tape was subtracted from the tension necessary to give the correct measurement when the tape was supported on a flat horizontal surface (seven and a quarter kilos, refer to the section on tape standardization.) The tension thus calculated (6.894 kilos) was subtracted from the tension used (8½ kilos.) The resultant difference in tension between that used and that which should have been used was multiplied by a correction factor and the observed vertical distance corrected by this amount. The tension factor was determined to be 0.0000361 meters per kilo difference in tension per meter of taped distance for the tape used (refer to the section on tape standardization.) The shaft measurements in the Dolores and 1690 shafts were repeated on different days by different field parties and the average of the four measurements was taken as correct.

(6) Charles Edward O'Rourke: Engineering Handbook pg 301

(7) Charles B. Breed and George L. Hosmer: The Principles and Practices of Elementary Surveying: John Wiley & Sons, New York seventh edition 1938 p 433

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(4) C. V. Hodgson: Manual of First Order Triangulation. U.S. Coast and Geodetic Survey, Washington. 1935. p 146

(5) Private communication Lufkin Tape Company

(6) Charles Edward O'Rourke: Engineering Handbook. McGraw Hill Book Co., New York. 1932. p 301

(7) Charles B. Breed and George L. Hosmer: The Principles and Practices of Elementary Surveying: John Wiley & Sons, New York. seventh edition 1938. p 433

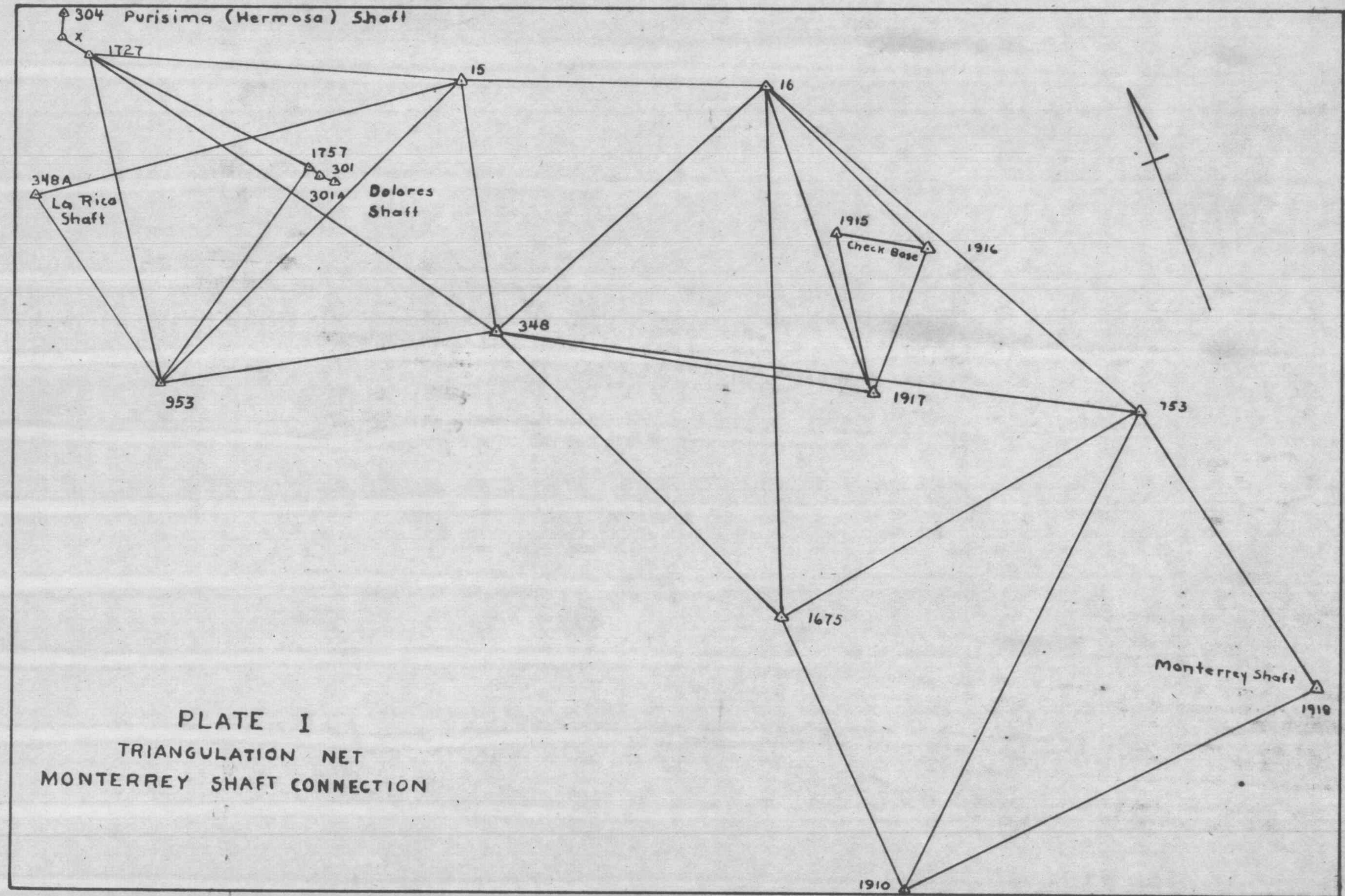


PLATE I
TRIANGULATION NET
MONTERREY SHAFT CONNECTION

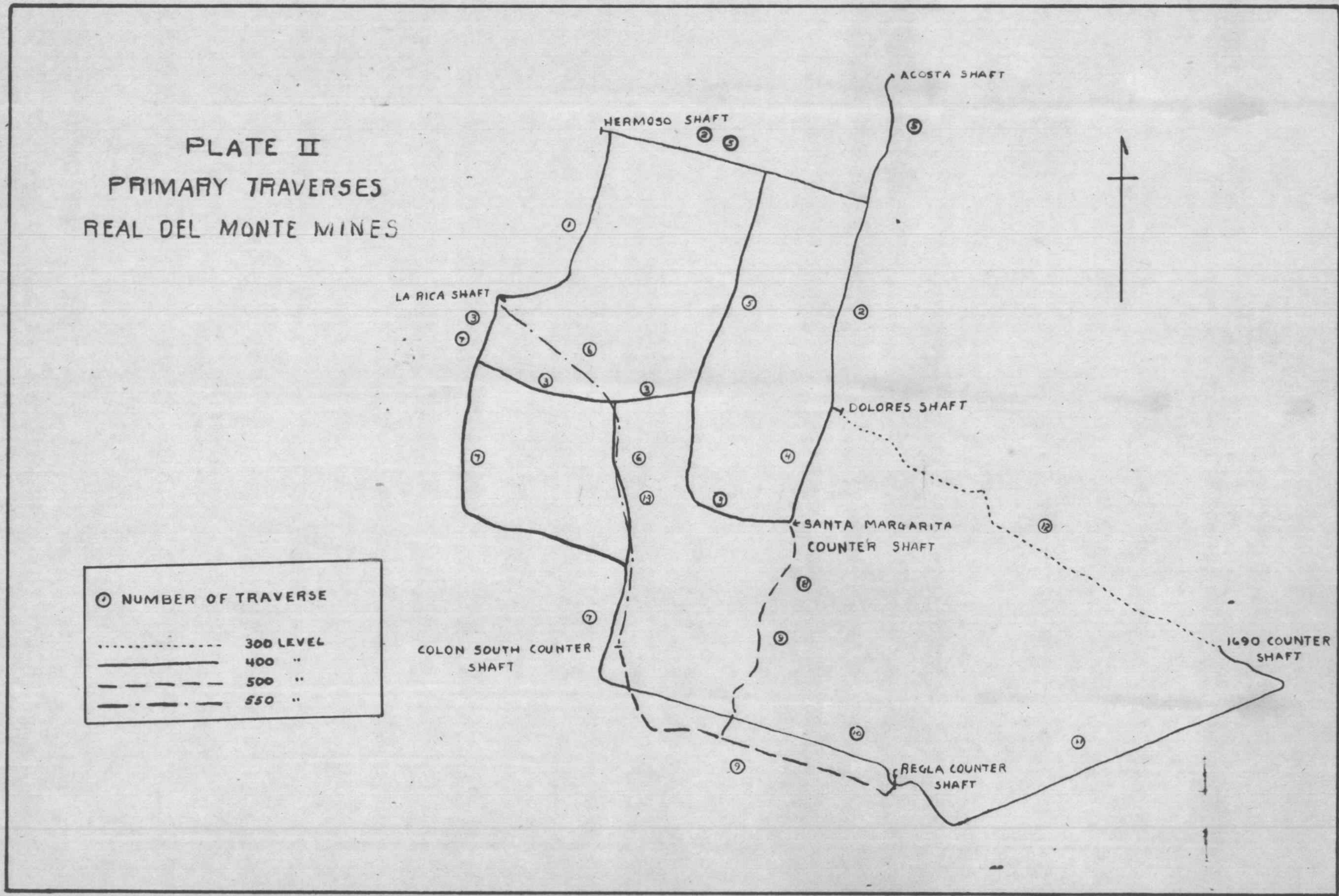
PLATE II
PRIMARY TRAVERSES
REAL DEL MONTE MINES
ACOSTA SHAFT
HERMOSO SHAFT
LA RICA SHAFT
DOLORES SHAFT
SANTA MARGARITA
COUNTER SHAFT
COLON SOUTH COUNTER
SHAFT
1690 COUNTER
SHAFT
REGLA COUNTER
SHAFT
NUMBER OF TRAVERSE
300 LEVEL
400 "
500 "
550 "

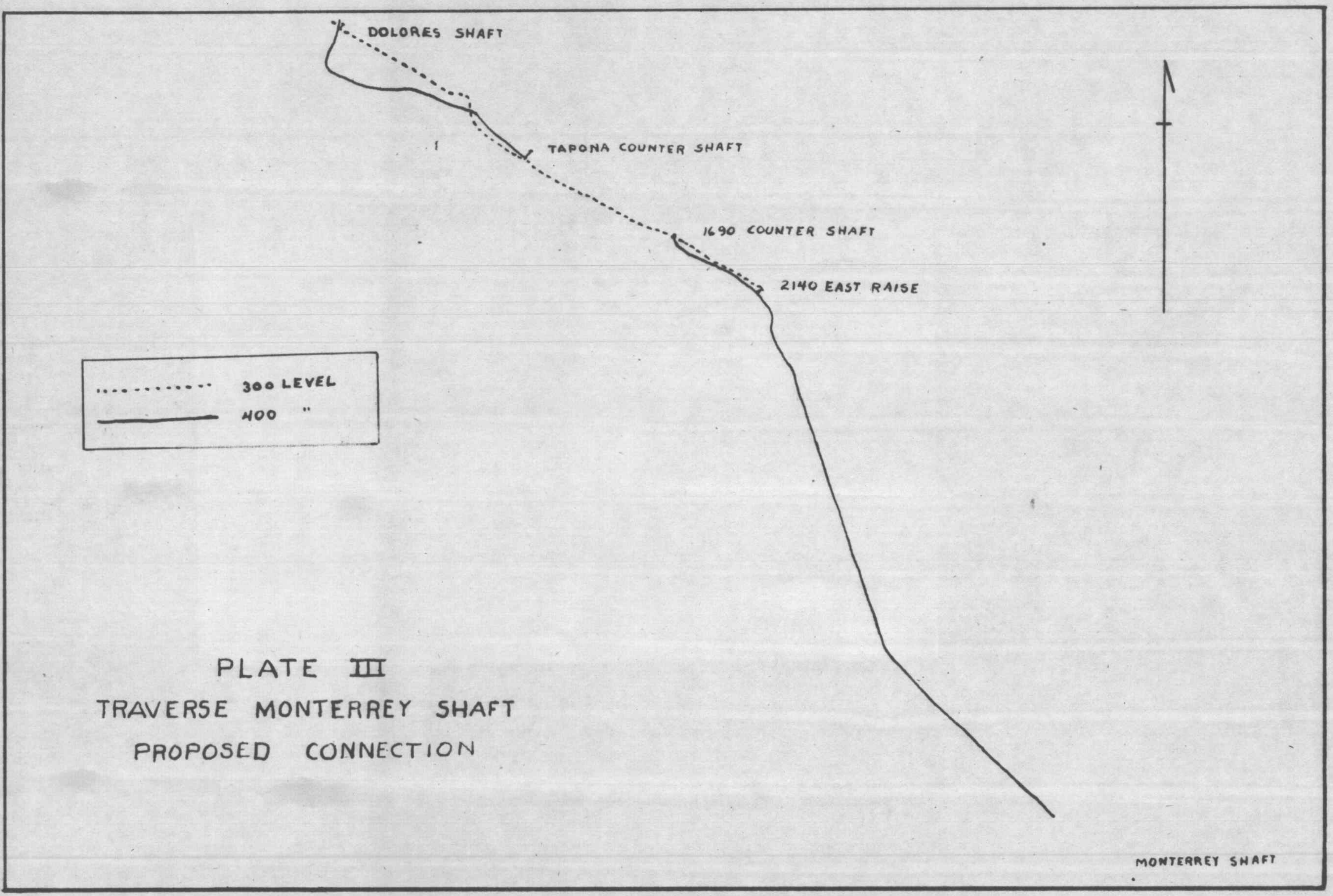


PLATE III

TRAVERSE MONTERREY SHAFT

PROPOSED CONNECTION