Results Obtained by the Schlumberger Method of Electrical Prospecting.

By

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CONTENTS.

INTRODUCTION.

Ore deposits easily discovered by surface prospecting are gradually being exhausted, therefore there has been developed a new scientific doctrine "Applied Geophysics" which attract us to the discovery of orebodies by the different physical and chemical characters of minerals and rocks in hidden fields.

Since in 1830 R. W. Fox[1] found the phenomena of electrical activity in a metalliferous deposit in Cornwall, W. Skey,[2] G. F. Becker and Carl Barus,[3] A. C. Becquerel,[4] W. Ostwald,[5] F. Braun,[6] I. Bernfeld,[7] H. A. Buehler and V. H. Gottschalk,[8] E. T. Allen,[9] Roger C. Wells,[10] N. Abraham[11] and F. Young[12] studied the nature of the electrochemical reactions and their generation, and a great stride has been made both in the theory of electrical prospecting and its practical application.

As regards the theory of electrical prospecting, Roger C. Wells's experiments are to the point, but justification of its practical value lay in the fact that the following authorities developed their method and apparatus, and testified to the benefits resulting from its application.

Although Draft and William's experiments[13] in 1890 were accepted as the pioneer work for practical prospecting, their method was of little value.

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(1) R. W. Fox, Philos. Trans., 399 (1830), 39 (1835).
(2) W. Skey, New Zealand Inst. Trans. and Proc., vol. 3, 232 (1871).
(3) G. F. Becker and Carl Barus, U. S. Geol. Survery, Mon. 3, 309 (1882).
(4) A. C. Becquerel, Compt. rend., vol. 64 to 67, (1868).
(5) W. Ostwald, Zeitschr. Physikal. Chemie, vol. 6, 75 (1890).
(6) F. Braun, Annalen der Physik und Chemie, vol. 44, 507 (1891).
(7) I. Bernfeld, Zeitschr. physikal. Chemie, vol. 25, 46 (1898).
(8) H. A. Buehler and V. H. Gottschalk, Econ. Geology, vol. 5, 28 (1910).
(9) E. T. Allen, Econ. Geology, vol. 5, 387 (1910).
(10) Roger C. Wells, U. S. Geol. Survey, Bull. 548 (1914).
(11) N. Abraham, Physik. Zeitschr., 145 (1919).
(12) F. Young, Phil. Mag., vol. 40, 149 (1920).
(13) Eng. and Min. Journal Press, vol. 111, 782 (1921).

Since in 1912 C. Schlumberger[14] carried on prospecting for Sain-bel pyritic deposits and anthracite deposits in the Alpine districts, his method has been utilized by Sherwin F. Kelly[15] at various metal mines in the United States and in Canada.

After in 1913, G. Bergström[16] had drawn up for the first time lines in Sweden, electrical prospecting has been largely developed there by Hans Lundberg[17] and Kąrl Sundberg.[18] The former experimented in about sixty different ore fields in Sweden, Norway, Finland and Spain, and found great deposits of chalcopyrite and pyrite in the Skellefteå district; while the latter took part in this investigation successfully in Sweden and Norway.

H. R. Conklin[19] made his experiments in many ore fields in the United States, which were proved correct by the presence of the conductor, being in six cases pyrite and one case galena by drilling.

Elbof[20] invented his method in Europe and in June 1924, the first work in America was begun. In Australia, this was used for oil finding lately.

H. Lowy,[21] Daniel G. Chilson[22] and Pastor invented the apparatus for locating orebodies dy radio. H. Lowy carried on his experi-

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(14) C. Schlumberger, Eng. and Min. Journal Press, vol. 111, 782, 818 (1921).
(15) Sherwin F. Kelly, Eng. and Min. Journal Press, vol. 114, 623, 673 (1922). and vol. 119, 1014 (1925).
Trans. American Inst. Min. and Met., No. 1261-M (1923).
Trans. Canadian Inst. Min. and Met., Vol. 27, 166 (1924).
(16) G. Bergström, Sveriges geologiska undersökning, Årsbok (1913).
(17) Hans Lundberg, Jernkontorets Annaler, 203 (1919).
Sveriges geologiska undersökning, Årsbok (1922).
Mining Magazine, vol. 29, 113 (1923).
Eng. and Min. Journal Press, vol. 117, 584 (1924).
(18) Karl Sundberg, Mining Magazine, vol. 31, 346 (1924).
Trans. American Inst. Min. and Met. Eng., No. 1463-I. (1925).
(19) H. R. Conklin, Eng. and Min. Journal Press, vol. 104, 339 (1917).
(20) Eng. and Min. Journal Press, vol. 118, 596 (1924).
(21) H. Lowy, Annal. d. Physik, 36 (1911).
Cent. f. Miner. Geol. u. Paläon, 579 (1911).
(22) Daniel G. Chilson, Eng. and Min. Journal Press, vol. 118, 733 (1924).

ments on the Sinai Peninsula and at Friedrichschafen, and Daniel G. Chilson discovered large deposits at depth in the gold fields of Nevada, U. S. A.

In our country, the C. Schlumberger electrical prospecting method was introduced in 1922 by Prof. Fumio Oda, Kyushu Imperial University, and since then all Japanese mining engineers took an interest in the method and recognised its practical importance.

It is the purpose of my paper to record the results obtained from electrical prospecting which I carried out at the Yanahara, Besshi, Nagamune and Ashio Mines in Japan. Some of the factors affecting the occurrence of orebodies that I believe worthy of consideration by prospectors are discussed somewhat in detail; however, other points, the significance of which can not now be determined, require more field study and experiments in the laboratory and for that reason are here brought to the attention of my coworkers.

THE ELECTRICAL PROSPECTING APPARATUS USED.

The apparatus used by the writer for the experiments was the Schlumberger* electrical prospecting instrument, which is intended to locate any deposits by the examination of the distribution of the electrical potential on the ground surface of the proposed regions, with potentiometer and non-polarizing electrodes. There are two methods of measurement with this apparatus: first, that depending on the weak electric current which is naturally generated by the spontaneous polarization of the orebody in question; and second, that depending on the transmission through the prospecting district, of the electric current which is supplied from other electric source.

The first method with which the writer carried out the investigations, was also sucessfully used by Sherwin F. Kelly in America and by Murray Hughes[23] in Northern Rhodesia.

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* Schlumberger and Sherwin F. Kelly described in minute details the potentiometer and non-polarizing electrodes.

(23) Murray Hughes, South African Min. and Eng. Journal, Jan. 10 (1925). Sherwin F. Kelly, Eng. and Min. Jourual Press, vol. 119, 1014 (1925).

The potentiometer is mounted on a tripod which consists of one stationary electrode and two insulated legs. One pole of the potentiometer is connected to this stationary electrode, and the other pole is connected, through a long flexible copper wire, to the other searching electrode.

If there is a potential difference between two points of earth, an electrical circuit is completed, a current passing through the earth—the searching electrode—the copper wire—the potentiometer—the stationary electrode—the earth.

It is of vital importance that the electrode for this purpose be non-polarizing. When moist soil comes into contact with two metallic electrodes, connected by wire, an electromotive force which is sufficient to mask the phenomena to be studied, is generated by the chemical reactions between them.

After being used for some time, the porous earthenware cups of the non-polarizing electrodes supplied by the maker lost the uniformity in their chemical texture owing to the acid action of a saturated solution of copper sulphate, and were broken into pieces by rough usage. Having no spare cups, the writer used wooden cups instead of the earthenware ones, and satisfactory results could be obtained by this new type of electrode.

RECORDS OBTAINED FROM MY EXPERIMENTS.

I. THE YANAHARA PYRITE MINE.

The crew consisted of the writer, two assistants and two surveyors and the work was carried out in March 1925.

(1) Description of the mine.

The Yanahara mine is situated about 15 km. S. S. E. from the town of Tsuyama in central Chugoku, and about 30 km. N. N. W. from the railway station of Wake on the Kobe and Shimonoseki line. The Yoshii River runs through the mining district.

The area of the concession owned by the Fujita Mining Co. is 2,900,000 sq. met.

The geological structure[24] of the district is very complicated. The country rocks of the deposit consist of slates, sandstones and biotite hornfels of mesozoic formation, on which various kinds of igneous rocks intrude, ranging from the time of the late mesozoic to early tertiary.

Magnetite, pyrrhotite, chalcopyrite, zincblende, etc. are occasionally associated, but the deposits are usually characterized by the scarcity or lack of chalcopyrite, consequently the district is being mined for pyrite ores of the highest grade. Gangue minerals are generally very rare.

The pyritic massive ore deposits in this mine were formed by the hydrothermal replacement of various rock types, such as diabases, quartz-porphyries, hornfels-rocks, slates and others, of these the rocks of sedimentany origin being usually less favorable for the metasomatic process and often leaving a large "horse stone" enclosed in the pyritic ore masses.

The four highly mineralized properties in this mine are the Yanahara, the Hisaki, the Yasumiishi and the Shimotani, of which the Yanahara and the Hishki areas are best prospected and exploited, the Yanahara pyritic ore mass is the largest one, and has an irregular form about 190 meters in length (E.—W.) and 90 meters in width (N.—S.) at river level, and over 100 meters in depth.

(2) Characteristic features of the prospected area.

The district where electrical prospecting was carried out is situated near the right bank of the Yoshii river in the north end of the Hisaki area and about 280 meters distant from the main exploited deposits.

Many years ago, a former possessor of this mine prospected this district by the Kawabata shaft as shown in PL. I. He sunk a vertical shaft about 27 meters deep and found the pyritic ore, but the prospecting shaft mouth is only 2 meters above the mean water level of the river, so it was unfortunately buried by a flood which brought the shaft to an end, owing to the lack of pumping devices at that time. Owing to this circumstance, no prospecting work was carried on here up to the present time.

(24) T. Kato, Japanese Jour. of Geology and Geography, vol. 1, Nos. 3-4 (1922).

As shown in PL. I, the topography of this district shows a flat and bare river bank. So both the prospecting work and stadia surveying could be carried out without any difficulty.

The investigated area is about 7,050 sq. met. which is only 0.24 percent of the total concession. In this prospecting work, the writer got 13 equipotential curves, i.e. about 243 millivolts.

(3) Equipotential chart.

Referring to PL. I it will be noted that the equipotential curve outlines rather accurately the shape of the massive orebody in question. Between the negative center and the river, the equipotential curves are parallel and contiguous mutually, while in the south western part, they are parallel but separate. In the north west the equipotential curves become irregular, and two of them run away. Lack of time prevented close measurement in this part.

Take a cursory view of the whole, every equipotential curve is similar to the next one, like the contours of a regular round hill. Judging from the equipotential chart, it seems probable that the buried orebody in this area is the pyritic massive deposit which is similar to that already exploited in the Yanahara area; and in the eastern part near the river, the orebody has a slightly more steep inclination than the other parts.

The results from this experiment for an orebody showing no outcrop in an already partly developed region indicated that this method of electrical prospecting would prove to be valuable in locating orebodies that might otherwise be missed.[25]

(4) Electrical profiles.

After the field investigations of the equipotential curves, further studies upon the nature of the deposit in question must be carried out in the office.

The following profiles are made in order to get clearer ideas of the deposit.

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(25) Sherwin F. Kelly, Eng. and Min. Journal Press, vol. 114, 625 (1922).

The horizontal distances were measured off as abscissae, and in the upper half of every profile, the height of the ground surface, and in the lower half, the potential differences as ordinates. The potential of each point is calculated with respect to the absolute negative center in the measured property, and negative potentials are plotted upward, while positive ones are plotted downward.

The slope of the ground surface of the region under consideration is gentle and only 1 : 8 in Fig. 1 and 1 : 16 in Fig. 2. It may be assumed that the surface is flat and the influences of the relative heights from the ground surface to the orebody are neglected.

Referring to Fig. 1, it will be noted that the potential curve along the E. W. line which passes through the negative center is very gentle and broad. The potential curve has only one gentle and broad peak corresponding to the position of the negative center.

In Fig. 2, the potential curve is plotted along the N. S. line. The form of this potential curve is the same as that shown in Fig. 1.

If any profiles which passing through the negative center in any direction were plotted, then the potential curves are generally like the gentle and broad curves in Figs. 1 and 2.

This fact[26] represents that the pyritic orebody in this property is deep seated and there is no other orebody except the one which was prospected by the Kawabata shaft as before mentioned, and a passably large massive one like the orebody which had already been exploited in this mine.

II. THE SEKIZEN AND YOKEI AREAS, BESSHI COPPER MINE.

(A) The Sekizen Area.

The crew consisted of the writer, three assistants and three surveyors and the work was carried out in May 1925.

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(26) Sherwin F. Kelly, Trans. Canadian Inst. Min. and Met. vol. 27, 173 (1924).

(1) Description of the Area.

The Sekizen area is a part of the concession of the Besshi Copper Mine, distant 9 km. S. E. E. from the main deposit and has not yet been worked, owing to the obscurity of the deposit. A thorough geological survey of this property has not been carried out, but judging from the information gathered from the prospecting by levels, the geological conditions of the Sekizen area may be regarded as the same as those of the main deposit, therefore here will be given a brief description of the latter.

The Besshi Mine has been worked by the Sumitomo Mining Co. since its discovery in 1690. The mine is situated on the watershed range of Shikoku which is from 900 to 1,200 meters above sea level, and about 8 km. S. from Niihama station on the Takamatsu and Kikuma line. The mine is connected with Niihama by the private railway of this company.

The area of the concession owned by this company is about 25,825,000 sq. met.

The general geology of this mine shows that it chiefly consists of highly schistose crystalline rock systems, called the Sambagawa Series which probably corresponds to the Algonkian formations.

The country rocks are consist of chlorite-, graphite-, piedmontite-, and amphibole-schists, of which the former two are mostly developed. Quartz-schist runs along both sides of the deposit which in some cases passes into sericite- or piedmontite-schist. Beside them, several dykes of serpentine penetrate into the formations.

A vein of cupriferous pyrite runs between the above rocks, striking at 120°, dipping at 45° northward in the upper level and 60° in the lower horizon.

The vein has been found as much as 1,400 meters along the strike and 1,700 meters dipwise, its thickness being 0.9 to 10 meters.

In the orebody two swells seem to course from the upper west part to the lower east corner, sloping at 45°.

There are several step faults in the eastern part.

The ores may be classified into three kinds:

1° Massive pyrite, containing 3 percent Cu.

2° Banded ores with country rocks, containing 4 percent Cu.

3° Enriched ores, containing more than 6 percent Cu.

(2) Characteristic features of the prospected area.

The deposit of this property is an independent small one and nearly resembles the main one as before mentioned, but its dip is southward.

As in the property under consideration, cryptomeria and Japanese cypress grow luxuriantly, great difficulty was experienced in searching the equipotential points as well as in carrying out the stadia surveying.

Several years ago, this area was prospected with three adit levels as shown in PL. II. The nature of this deposit did not warrant successful mining.

The searched over area is 4,650 sq. met. which is only 0.018 percent of the total concession. In this prospecting work, the writer got 30 equipotential curves, i.e. about 510 millivolts.

(3) Equipotential chart.

The equipotential curve outlines are complicated near the outcrops, but generally elongated along the strike of the orebody.

On the right bank, much potential difference was measured than on the left bank. This fact agrees with the results of the prospecting with adits.

In the neighbourhood of the adit mouth of the longest level, the ore distribution, strike and dip of this orebody are irregular. Chalcopyrite and pyrite have disseminated into the eruptive rocks, so the deposit has no regular strike and dip like that of the main deposit. The thickness of these mineral veins is only 0.1 to 0.3 meters containing 1 percent copper.

Before the commencement of the work, weeds were cut down and several roads were made parallel or perpendicular to the strike of the vein.

The negative center of this property was searched on these roads, and was found near the outcrop A. From this point the writer started the measurements and got the equipotential chart as shown in PL. II.

The equipotential curves I, II and III enclosed the outcrop A and their forms are nearly round. Near the negative and positive centers, whether they may be the absolute or local centers of the prospected region, the several curves are enclosed and round, as XIV, XIII and XXIX', XXVIII' curves near the local positive centers, and those locations are (L.–50, D. 75) and (L. 95, D. 210) respectively. One can fined this fact easily in all the equipotential charts in these appended maps. The other curves are deformed and elongated along the strike of the orebody.

Referring to PL. II, there are heaps of deposed débris from those levels on both banks of the river. As the natural potential distribution is artificially disturbed, so the measurements are not carried on there.

As expected, the obtained equipotential chart agrees with the known conditions of the deposit. Thus it will be cosidered that the equipotential curves outline more or less regularly the horizontal projection of the orebody in question.

(4) Electrical Profiles.

The profiles Nos. 1, 2 and 3 in Fig. 3 are plotted through the 30° line which is perpendicular to the general strike of this vein. In Fig. 3, the potential of each intersecting point of the 30° line and of the equipotential curves is calculated with respect to the negative center near the outcrop A.

Referring to Profiles Nos. 1 and 2, the potential curves have gentle peaks which correspond to the position of the outcrop. These broad and gentle peaks are like those in Figs. 1 and 2 in the Yanahara Mine, but in this case these peaks are due to the local conditions, namely, the outcrop, very shallow deposit and scattered metallic surface débris in this property. Therefore from these peaks, we can not expect that the orebody is large as that of the Yanahara Mine.

It will be noted in Profiles Nos. 1 and 2, the potential curves on the left hand side of the peak are generally steeper than those of the right hand side. The potential curves show that the orebody dips to the south. The above supposition may be taken as a further illustration of the following fact. As shown in PL. II or Figs. 3 and 4, there are two adit levels on the right bank and the longer northern level is situated about 4.5 meters above the shorter southern one, and mineral veins can be found in both levels. Therefore from the geological standpoint and evidences from the exploited levels, we can assume that the dip of this orebody is southward.

In Profile No. 2, the small peak near the 42 meters (140 feet) line affords an excellent example of the effect of metallic surface débris and small outcrop on the profile. The writer experienced in the Yokei area exactly the same thing as the before mentioned fact.

In Profile No. 3, the potential curve is very flat compared with those of Profiles Nos. 1 and 2, and the total potential difference is very small. It may be noted that the value of the existing orebody is very small on the left bank, in other words, there is no important orebody in this area. The same judgment may be made with respect to Fig. 4.

Fig. 4 shows the potential curve along the general strike line of the deposit. This profile manifests the relation of the electrical activity of the orebody and the thickness of the overburden. When the thickness of the overburden is from a few to 16 meters, the potential curve swells out gently, but when over 30 meters, the potential curve is nearly flat, so the determination of the orebody becomes very difficult and inaccurate.

(B) The Yokei Area.

The experiments on the Yokei property were mainly conducted by K. Endo and T. Ishihashi, mining engineers of the Sumitomo Mininig Co.

After finishing the prospecting work at the Sekizen area, the Yokei property was investigated in June 1925.

(1) Characteristic features of the prospected area.

The prospected area is situated 6.5 km. S. E. from the main deposit.

The conditions of the geology and deposit of this region are the same as those of the main property, but having smaller size and poorer copper contents. The topographical conditions are exactly like those of the Sekizen property and also great difficulty for measurements and surveying was experienced. Outcrops had already been found at the points *b* and *c*. The outcrop *a* was found by the electrical prospecting.

The old underground workings are illustrated in PL. III. At both ends of those levels, the orebody became too poor for economical working. After searching 33,580 sq. met. in this area, 20 equipotential curves, i. e. 340 millivolts of potential difference were measured.

(2) Equipotential chart.

In order to locate the negative center in the western part of this region, the measurements were carried out along the 25° line No. 2 which passed through the outcrop *b*. Near the outcrop *b*, the peak of the potential was found, then further searching was tried along the perpendicular line to the 25° line No. 2. At last, the negative center was found at the point (L. 3,630, D. 980) on the 25° line No. 1.

Near the outcrop *a*, the equipotential curves were distorted as shown in PL. III. There is no surface indication except the known outcrop *b* in this property. In order to determine the cause of this phenomenon, the ground surface was dug at several parts and at last the outcrop *a* was found only 0.3 meters under the surface. The negative center lies on the connecting line of the outcrops *a* and *b*. The blue dotted line shows the imaginary intersecting line of the ground surface and the orebody whose dip was assumed with respect to the known inclination of the orebody appeared in the first and second levels. Referring to PL. III, it will be noted that the outcrop line *abc* runs generally parallel to the imaginary line, slightly deflecting to the north. Hence above the first level, the true inclination of the orebody is a little steeper than the assumed one.

In the eastern part, the potential lower than the negative center in the western region, was found above the enriched part in the first level. As the metallic débris of the excavated minerals were scattered about the iurface of the northern part near the equipotential curve I, so the artiscial potentials were generated here, then the measurements on this place may be vitiated, therefore further measurements were not carried out and the negative center could not be found in this area.

After these measurements, equipotential curves were traced on the surface of this property as shown in PL. III.

In this case, the outlines of the equipotential chart are generally elongated along the strike of this orebody.

(3) Electrical profiles.

In Fig. 5, all profiles are plotted along the 25° line which is perpendicular to the general strike of this orebody.

In Profiles Nos. 1 and 2, the potential curves have comparatively high and sharp peaks corresponding to the position of the outcrop line *ab*. Judging from the statement of Sherwin F. Kelly,[(27)] the orebody in such a condition may be narrow and shallow.

The potential curves are more gentle in the left hand part (the northern part) from the peaks than in the southern part. Profiles show that the orebody dips to the north and this result agrees with the known direction of the dip of this orebody.

Profile No. 3 is less satisfactory for the investigation of the natures of this orebody.

The potential curve in Profile No. 4, rises gently near the position where the first and second levels are driven. Moreover this tendency of a rising curve is also the effect of the metallic surface débris on this profile.

III. THE NAGAMUNE AND MUNEO COPPER MINES.

The investigation was carried out in November 1925.

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(27) Sherwin F. Kelly, Trans. Canadian Inst. Min. and Met. Vol. 27, 173 (1924).

General description of the mines.

Tha Nagamune and Muneo mines are situated on the watershed range of Shikoku and about 23 km. E. from the Besshi Copper Mine, and about 17 km. S. from the Kawanoe station on the Takamatsu and Kikuma line. Between Kawanoe and these mines, mountains rise one upon another. Communication and transportation between them are very inconvenient.

The general geology and deposit of these mines are very much like that of the Besshi Copper Mine already deseribed.

(A) THE NAGAMUNE MINE.

(1) Characteristic features of the prospected area.

Since its discovery in 1923, the mine has been under operation on a small scale.

In the northern part of the property where electrical prospecting was carried out by the writer, there are several small parallel veins striking at 90°, i. e. E. W. and dipping at 18° to 22° N. Two of those veins are now exploited on the strikewise as shown in PL. IV.

In the southern part of the property, there is a vein, which is distant about 70 meters S. from the parallel veins as before described, and its strike is just the one mentioned before, but the dip is a reverse one, i. e. 20° S. owing to the effect of folding. The vein was worked about 100 meters along its strike but the irregular distribution of the ore caused by the folding, obliged the excavating work to be given up lately.

(2) Potential chart.

As the potential difference between any two points in this field is much too small and the potential distributions are very irregullar, the writer could not trace equipotential lines on the ground surface.

After the negative center was found upon the outcrop, investigations were made through the whole property with the following method. The writer divided the whole field into rectangles, one side of which was parallel to the general strike of the veins, i. e. the E. W. line, and the other side was perpendicular to the former one, i. e. the N. S. line. 21 points each distant from the other about 4.5 meters, are marked oń every E. W. line staked out on the ground and on the N. S. lines, 25 points, about 6 meters apart, are also staked out.

The writer measured the potential difference between the negative center and all the staked points, these having been located by stadia surveying, as shown in PL. IV.

(3) Electrical profiles.

Profiles Nos. 1 to 6 in Figs. 6 and 7, were plotted along the N. S. line perpendicular to the general strike lines of the veins of this mine.

As No. 3 N. S. line passes through the outcrops as shown in PL. IV, so Profile No. 3 which is plotted along the above line, has very sharp and high peaks on crossing the outcrops. One marked peak represents the negative center in this property and the other one corresponds to the outcrop. Except the two marked peaks before mentioned, the other potential curves of Profiles Nos. 1 to 6 generally have the same up and down tendency.

From the transit stations Nos. O to II, the potential curves rise gently. This fact depends on the vein whose one part has been already exploited as shown in PL. IV.

No. 5 N. S. line runs along the river as shown in the topographical map of this property. The measuring station (A-4) is situated on the river bank. There is a heap of metallic débris on the opposite bank of this station. The heap of débris was carried away several times on occa-ions of floods on this river. The metallic surface débris may be scattered on the bank near this station. Profile No. 5 has a high and sharp peak near the right end of Fig. 7. This peak is due to the resultant electrical activity of the mineral vein, metallic débris and running water.

We can find a vivid up and down in the potential curves between transit stations Nos. XII and XVII. There are two parallel veins in this part distant about 13 meters. The owner of this mine considered that the two parallel veins whose outcrops were found in the. N. E. quadrant of PL. IV, were only one folded vein. As a result of further investigations, the writer found a comparatively low potential near the measuring station (XVII—12). This fact induced the writer to believe that the veins which were formerly considered as one folded vein, should be regarded as two parallel veins. On digging through about 4 meters of covering soil near the station (XVII—12), where the owner did not imagine any orebody existed, a narrow chalcopyrite vein was uncovered, proving that my opinion just mentioned was correct.

The potential curves have a marked general tendency, rising up so as nearly to approach the transit station No. XXIII. This may be shown by the effect produced by a very narrow vein buried in the ground. Lack of time and the unfavorable topogrophical conditions prevented the writer from carrying out further investigations in this part.

As to the deposits of this type it seems quite probable that another method of prospecting would be more preferable.

(B) THE MUNEO MINE.

After finishing the prospecting work at the Nagamune Mine, the Muneo Mine, the adjacent concession, was investigated in November 1925.

The proposed property is situated about 4 km. N. W. of the Nagamune Mine.

In this property, no outcrop of the vein could be seen. After the negative center was discovered exactly the same investigations were made here.

For fear of trespassing on the other concession and from lack of time, the writer observed but 180 sq. met. and could not thoroughly carry out the investigations of this mine. Therefore the equipotential chart is not completed.

PL. V shows the topographical map and equipotential chart of this property.

IV. THE SUNOKOBASHI AND RENKEIJI AREAS, ASHIO COPPER MINE.

The prospecting work was carried out in July, August in 1925, and nearly ten men were engaged in prospecting and stadia surveying every day.

(1) Description of the Sunokobashi and Renkeiji Areas.

The Ashio mine is situated about 175 km. N. of Tokyo. The area of the concession owned by the Furukawa Mining Co. is 16,000,000 sq. met. The Sunokobashi and Renkeiji areas are a part of the concession of the Ashio Mine, and has been worked in old days and at present the prospecting levels entered from the main workings reaches to just beneath the area under consideration.

Judging from the information already gained from both surface and underground features, the geological conditions of the Sunokobashi and Renkeiji areas may be regarded as the same as those of the main deposit which is now extensively worked.

The country[28] rocks of this mine consist of the middle Chichibian slates and quartzites which were intruded by the plazioliparite, a volcanic rock, more than 3 km. in diameter.

Nearly all of the deposits are veins and they occur for the most part in liparite, although a few found in sedimentarries.

There are two principal series of veins, one striking at 30° to 60°, called the Yokomabu Series, and the other striking at 95° to 100°, called the Shinsei Series. They intersect each other, forming the so called conjugate system of veins. There are more than 380 lodes, and among them 35 of the former series and 12 of the latter are now being worked. They are from 120 to 1,830 meters long and 0.3 to 5 meters thick. The chief vein minerals are chalcopyrite and pyrite, but zincblende, arsenopyrite, galena and pyrrhotite are also of frequent occurrence. Some of the depo-

(28) Masayuki Otagawa; Trans. American Inst. Min. and Met., No. 111-M (1922).

sits in sedimentaries are irregularly arranged masses called "Kajika," to which is owing the main production of this mine since in 1917. Up to the present time the principal Kajika which have been dsicovered are as follows:

Name of Kajika deposit	Date of discovery	Dimensions in meters			Country rock
		Length	width	Depth	
Tengu	1916	40	11	84	quartzite
Deai 300 shaku	1917	68	28	240	quartzite
Deai 650 shaku	1919	200	18	106	quartzite
Deai 780 shaku	1920	100	8	180	quartzite
Kosei	1908	37	9	500	liparite
Ninenhi	1914	15	6	900	liparite
Tsuruhi	1915	60	5	3	liparite

The majority of Kajika is metasomatic massive deposit along planes of folding in quartzite and dips at 30° to 50° N. N. E. The Kajika ores are chalcopyrite with neither gangue nor pyrite. The sulphide ores contain 30 to 50 percent of copper, and the average is generally more than 15 percent. The boundaries of the deposits are not well defined.

(2) Characteristic features of the prospected areas.

As far back as 300 years, Kajika deposits were known and worked in the Sunokobashi area near Tsudo adit where the central office of this mine is situated. At that time they were mined or rather excavated in an open cut. Although quartzite can be easily excavated with the present mining technique, the excavation of quartzite was so difficult in old days that Kajika deposits in quartzite were not fully exploited. At present we can find many old workings in the Sunokobashi and Renkeiji properties. Since many years, the veins in liparite which are softer than quartzite have been mainly mined.

Since 1916, the Tengu Kajika was found in quartzite, the mining engineers of this mine have done their best in prospecting the Kajika deposit in quartzite, discovering the Deai 300 shaku Kajika, the Deai 650 shaku Kajika and the Deai 780 shaku Kajika.

As shown in PLs. VI and VII, the district where the investigations were made, is a rugged precipitous cliff of quartzite, liparite and slate, hard to climb, so the writer prospected the comparatively flat regions along the river Shibukawa. The area under consideration is 26,000 sq. met. which is only 0.16 percent of the total concession of this mine.

About 110 units of potential difference, i. e. 1,320 millivolts of potential were measured in this investigation.

(3) Equipotential chart.

PLs. VI and VII show the potential charts which were prepared on the Sunokobashi and Renkeiji properties respectively.

(3–a) The Sunokobashi Area.

In the Sunokobashi area, the negative center was sought for along the bank of the Shibukawa river and was found at the point XXXI N. C. (L. 8580, D. 2473) near the outcrop in this river. From this negative center, the measurements of the equipotential curves were started toward the region of the higher potential.

Near the shrine gate, the highest peak of the potential was found, then further investigation of the equipotential curves was carried out toward the points of the lower potential.

Having found a potential lower than that of the negative center XXXI. N. C., the quest for equipotential curves was stopped, and the negative center was pursued to be determined. The negative center of the whole property was located at the point -VIII N. P. (L. 8560, D. 2545). Further measurements of equipotential curves were carried out through the whole property, and the equipotential chart shown in PL. VI was obtained.

The absolute negative center of the Sunokobashi area is –VIII N. P. point. Four other local negative centers were found in this property and their locations are as follows:

Negative Center	Location	
	Latitude	Departure
XXXI N. C.	8580	2473
III N. C.	8655	2545
I N. P.	8560	2660
–I N. P.	9009	2392

Among those five negative centers, four with the exception of XXXI N. C. before mentioned, were located in quartzite near the contact of liparite and quartzite. Much more potential difference was measured in the southern part than in the northern part of this property. In the southern part from latitude 8560 line, country rock is quartzite, but liparite develops in the northern part.

Generally Kajika deposits are richer in quartzite than in liparite, and the site for the prospecting by boring, was usually selected in this region. The equipotential curves were much distorted and many more negative potentials were sought for in quartzite than in liparite near the contact of the two rocks.

Near the local negative center –I N. P. (L. 9009, D. 2392), there are many old workings in which there remains much chalcopyrite and pyrite. Near that point, there is a fault, striking E. W.

At the point (L. 8635, D. 2540) near the local negative center III N. C., a bore hole was drilled by diamond boring, having a direction S. 15° E. and an inclination of S. E. 80°. Referring to Fig. 8, the record of the strata passed through, there is no sign of Kajika deposits, only the show of several thin veins of chalcopyrite and pyrite.

(3–b) The Renkeiji Area.

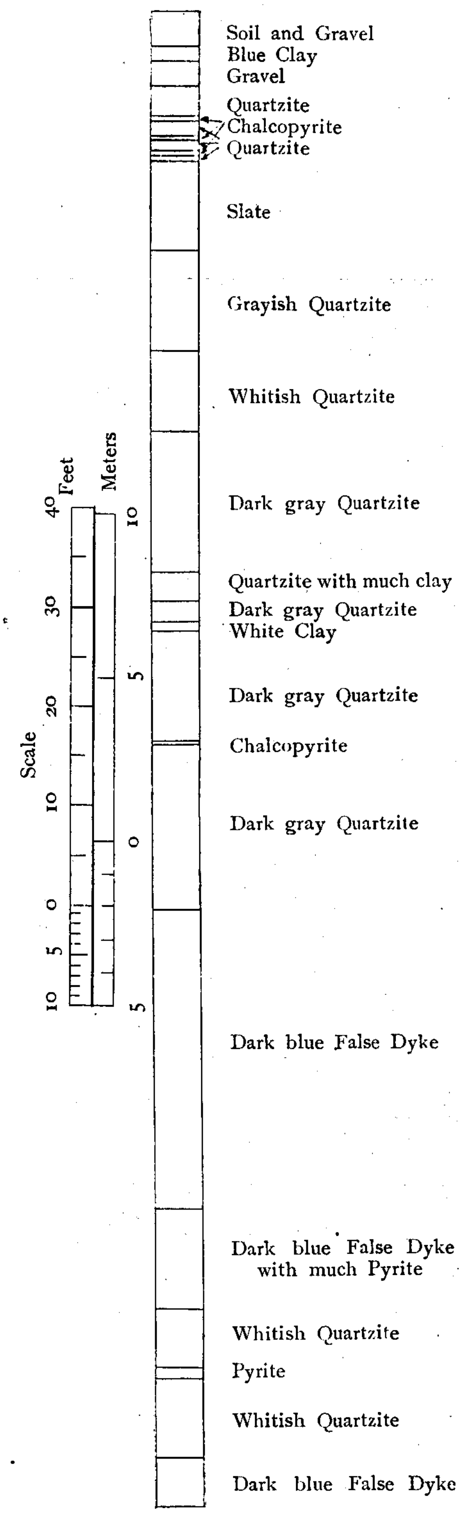
In the Renkeiji property, several very low equipotential curves were measured which are numerically related to those of the Sunokobashi area.

The following table shows the relation of the mutual equipotential curves which were investigated in both areas.

No. of equipotential curve	millivolts	No. of equipotential curve	millivolts
–L	0	XV	780
–XLIX	12	XXII	864
–XLVII	36	XXIII	876
–XLIII	84	XXVI	912
–XXVI	288	XXIX	948
–XVIII	384	XXXI	972
–XII	456	XXXVII	1044
–VIII	504	XXXIX	1068
–VI	528	XLIII	1116
–III	564	XLV	1140
–I	588	XLVIII	1176
I	612	LI	1212
III	636	LIV	1248
VI	672	LVI	1272
IX	708	LVII	1284
XII	744	LX	1320

After the investigation of the properties where the electrical pros-

Fig. 8. Boring Record near the Negative Center III N. C. in the Sunokobashi Area, Ashio Mine.



pecting was carried out, 1,320 millivolts of potential difference was measured.

Near the absolute negative center in this property, there were old shafts which were filled with débris, so we could not get any information. In the neighbourhood of this negative center, there are many outcrops of chalcopyrite. Although further prospecting was needed in this region by the fact that there are many old workings and the lowest potential was found, as shown in PL. VII, it was impossible to investigate the equipotential curves fully owing to the unfavorable conditions of the topography. Thus the following five negative center are located in this region which are situated in slate near the contact of slate and quartzite.

Negative center	Location	
	Latitude	Departure
–XLIX N. P.	9825	2119
–XLVII N. P.	9870	2104
–XLIII N. P.	9845	2173
–XVIII N. P.	9884	2162
–XII N. P.	9883	2204

(4) Electrical profiles.

It is very difficult to determine the nature and value of the deposits by electrical prospecting in this property where the conditions of the geology, deposits and their mutual relations are very complicated and obscure.

(4–a) The Sunokobashi Area.

From the profiles in Figs. 9 to 12, the writer is unable to discuss the geology and deposits of this area in detail unless more extended study of the potential curves is made in other parts of the property of the mine, and reasonable conclusions are drawn there from.

All profiles in Fig. 9 are plotted along the E. W. lines in the Sunokobashi property. One part of the E. W. line passing through the negative center I N. P. (Profile No. 1) is parallel to the contact line of liparite and quartzite generally. In profile No. 1, are two high and sharp peaks in the right half and one low and sharp peak in the left half. The former two peaks are situated in quartzite while the latter one is in liparite. The potential curve between the former two peaks in quartzite is nearly gentle and broad. Here we could not find any outcrop or other surface indications of the orebody.

In all profiles, potential curves rapidly rise where they cross the contact of the two different country rocks, as follows:

Fig.	Profile No.	Horizontal distance.
9	1	255
9	3	40
10	1	545

It will be noted that Sherwin F. Kelly[29] by investigations the Hollinger and the Kirkland mine, Ontario U. S. A., advanced the theory that the highly siliceous veins are not so active as those carrying less quartz, and quartz is a non-condudtor of electricity. If this view be correct, the potontial curves must rise in liparite and not in quartzite. Therefore the peaks of profile No. 1 depend on the electrical activity of the metallic deposits and not on that of the country rocks. Generally speaking, the experience from underground mining testifies that the Kajika deposits were much developed along a plane of folding in quartzite. In the N. E. part of PL. VI, there is a folding of quartzite and in this inner zone many negative center are located, which fact shows that there are orebodies in this area. This satisfactorily agrees with the results obtained by diamond boring as before described.

(29) Sherwin F. Kelly, Trans. Canadian Inst. Min. and Met. vol. 27, 178–179 (1924)

Potential curves in Fig. 10 are plotted along the N. S. lines. Potential curve in Profile No. 1 is very irregular, gentle and broad in the left hand side of the highest peak, but a very sharp inclined line in the right hand side. The former curve is due to the electrical activity of the metallic orebody, while the latter sharp inclined one crosses the intersecting line of liparite and quartzite as before mentioned.

(4-b) The Renkeiji Area.

Figs. 11 and 12 are plotted along E. W. and N. S. lines respectively in the Renkeiji property.

As already mentioned, meny more negative potentials are measured in this area than in the Sunokobashi area.

Between the two peaks of Profile No. 1 in Fig. 12, the potential curve is almost gentle and broad. Except the above one curve, in all profiles of Figs. 11 and 12, the potential curves which are plotted in this area have a tendency to be very much sharper and narrower than those of the Sunokobashi area.

In the Sunokobashi property, all profiles are plotted along E. W. and N. S. lines in quartzite, while in the Renkeiji area, all profiles are in slate. The writer is unable to discuss this matter in more detail unless further investigation is carried out.

SUMMARY.

The results of my experiments lead to the following summary:

(1) The record of 100 equipotential points per one shift was the maximum in my experiments.

(2) The potential differences recorded in these experiments are usually 300 to 600 millivolts, excepting in the Ashio mine, where some of them are over 1,000 millivolts. The following table shows the total maximum potential difference obtained in each area:

Prospected area	Potential difference in m. v.
Nagamune	117.0
Hisaki, Yanahara	243.0
Yokei, Besshi	340.0
Muneo	420.0
Sekizen, Besshi	510.0
Sunokobashi and Renkeiji	1,320.0

(3) The greater thickness of the overburden naturally diminishes the indication of the electrical activity of the orebody.

(4) The highly mineralized parts or parts of shallow depth may be detected with this method.

(5) In the presence of two or more outcrops in the measured property, one of them is the absolute negative center and the others are commonly the local negative and positive centers. The positive center for the whole area has not been found. The outcrops are closely encircled by the equipotential curves as shown in PLs. II, III, VI and VII.

(6) Parallel veins running close together can be distinguished with the help of potential profiles as shown in Figs. 6 and 7.

(7) The metallic surface débris and running water have to a certain extent of perturbations in the equipotential charts, perturbation due to the latter was recorded as less than 20 millivolts at the Nagamune Mine.

(8) The decrease of moisture in soil due to evaporation and migration has a marked disturbing effect in observing the slight deflection of the patentiometer needle. This difficulty experienced at the Ashio mine where the work was carried out in summer.

(9) The radius of interference by electrically operated mine appliances may be reckoned on as 600 meters in the Ashio

mine, where D. C. 500 volts is used underground.

CONCLUSION.

At the present stage of our knowledge, electrical prospecting has the possibility of measuring wide areas in question simply, economically and rapidly, giving a general view of the deposit, as an auxiliary to the usual methods of prospecting by geological survey, deep boring, shaft sinking and level driving, etc.

It is only by systematic studies and extended observations that this method of prospecting can be rendered more valuable and important, and much yet remains to be done in this respect. Some suggestions for further investigations would be as follows:

(1) More accurate information as to the nature of ore minerals.

(2) Influence of the thickness of the overburden on the electrical activity of the orebody.

(3) The disturbance of equipotential charts due to any form and inclination of the orebody.

(4) The disturbance of equipotential charts due to geological conditions, such as stratification and deformation of strata, etc.

(5) The causes as to the characteristic tendency of the potential distribution of the property under consideration, which would be of great value in locating orebodies.

ACKNOWLEDGMENT.

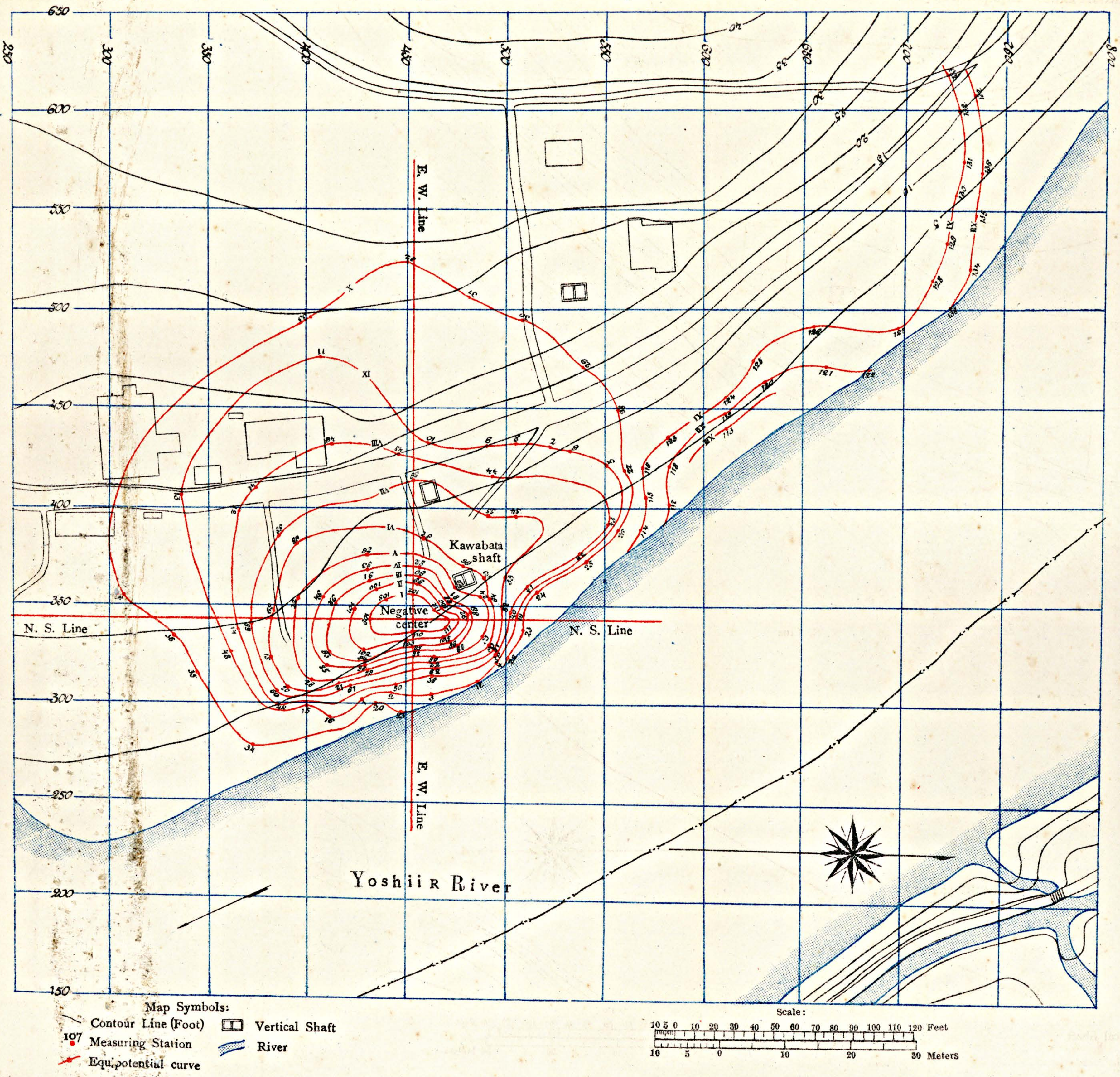
In conclusion the writer wishes to express his sincere thanks to Profs. K. Ide and T. Otagawa for their kind guidances.

The writer greatfully acknowledges the hearty cooperation of the owners and the operating officials of the mines in giving the assistance in carrying on the field studies and in permiting the publication of this paper.

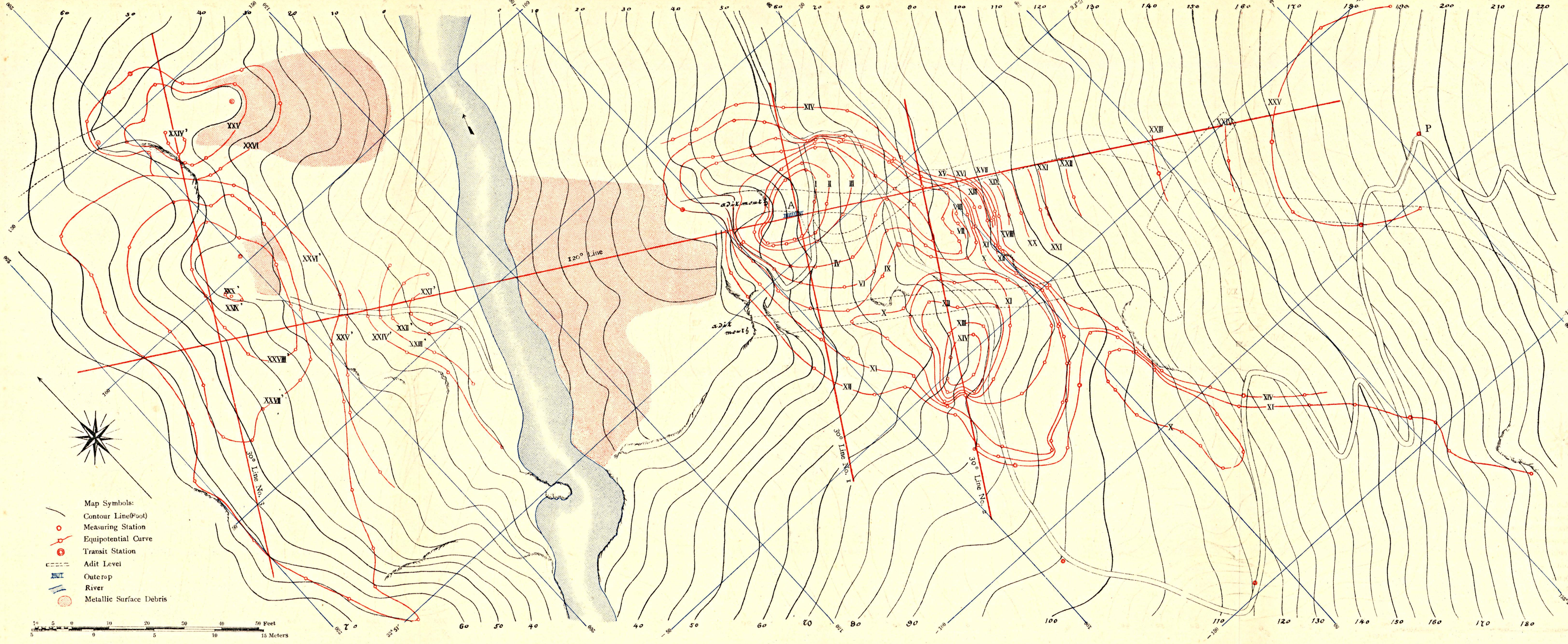
List of Maps.

List of Diagrams.

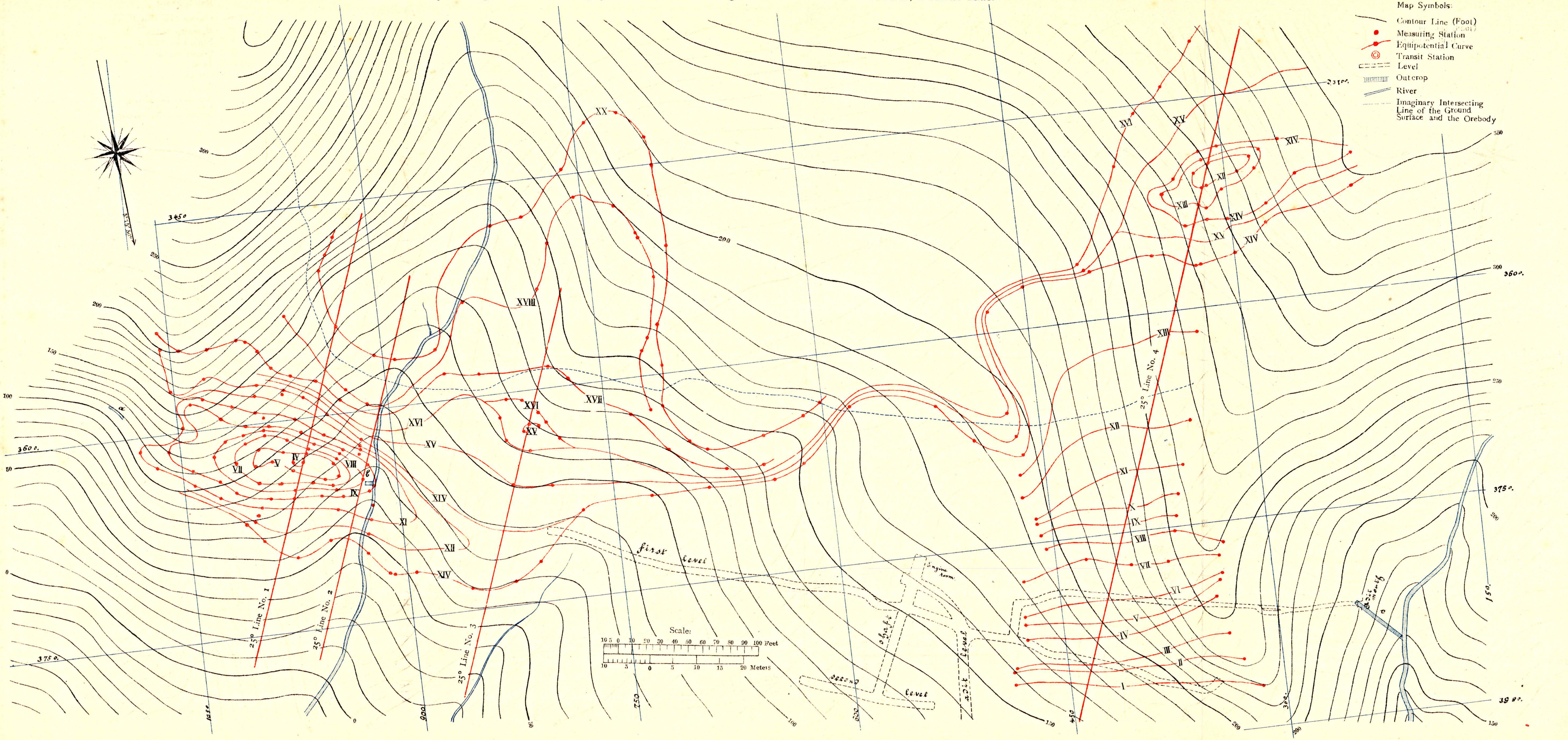
PL. I. Map showing Contour Lines, Equipotential Curves, and Negative Center in the Hisaki Area, Yanahara Mine.



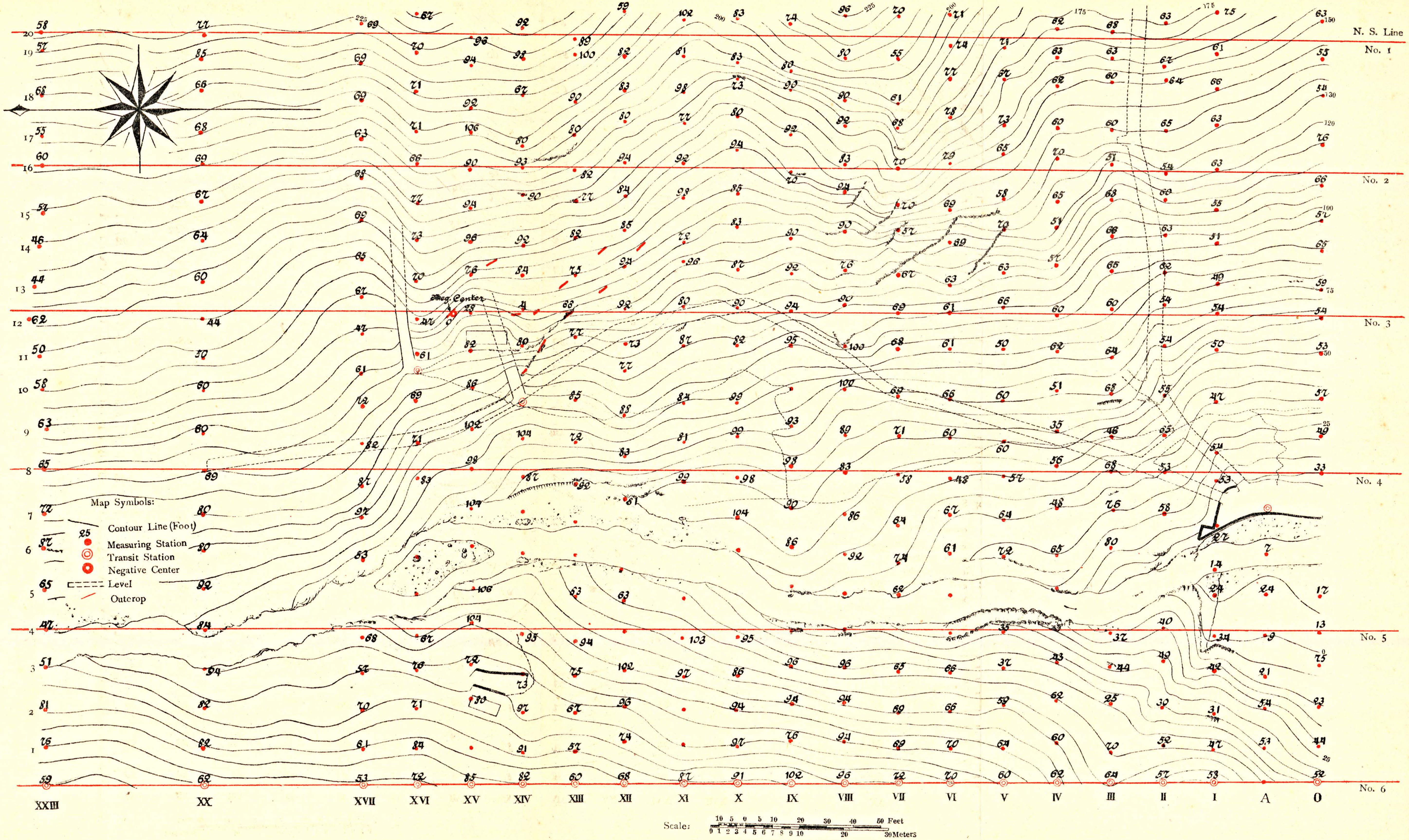
PL. II. Map showing Contour Lines, Equipotential Curves, and Negative or Local Positive Centers in the Sekizen Area, Besshi Mine

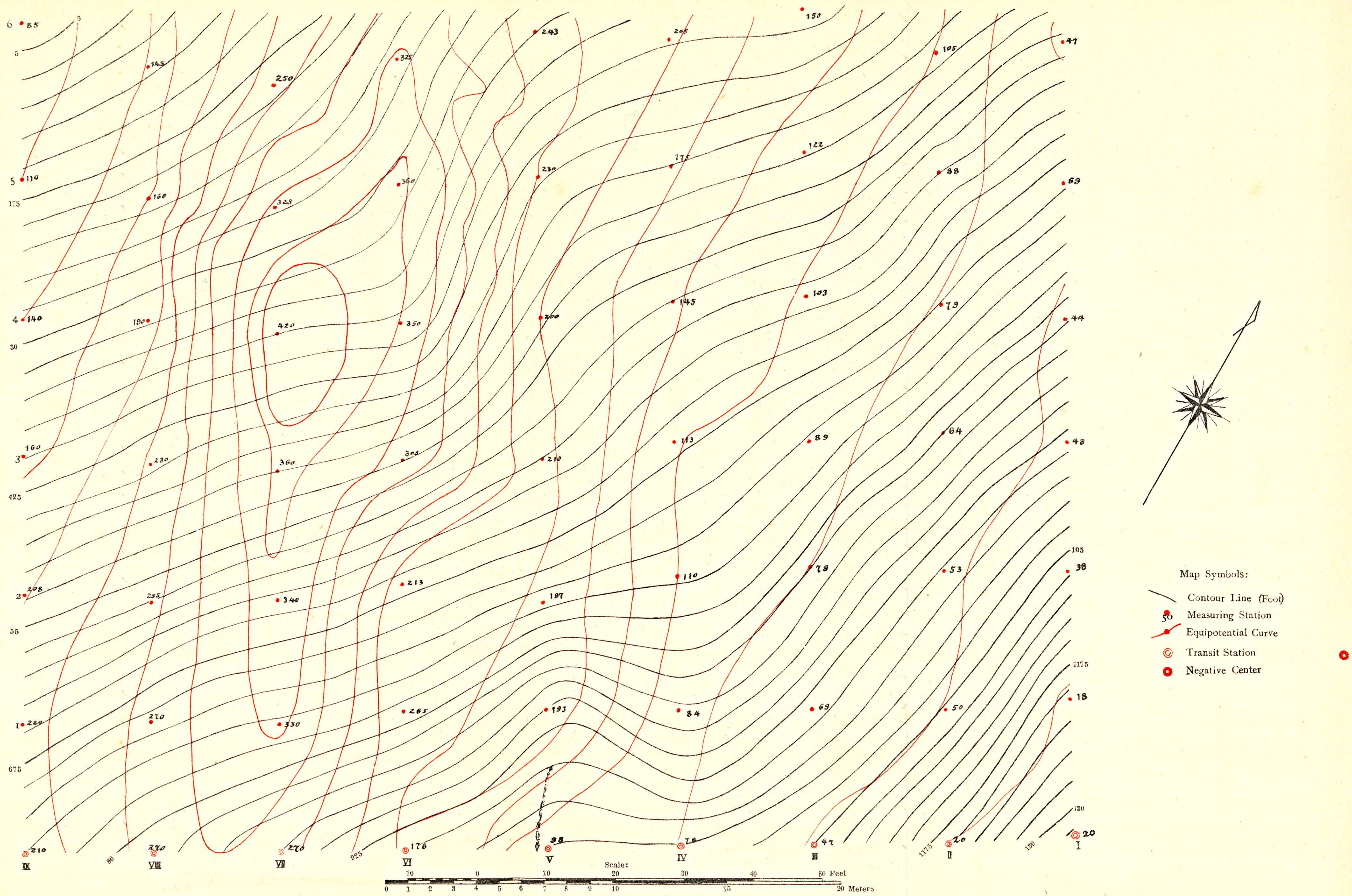


PL. III. Map showing Contour Lines, Equipotential Curves, and Negative Center in the Yokei Area, Besshi Mine.



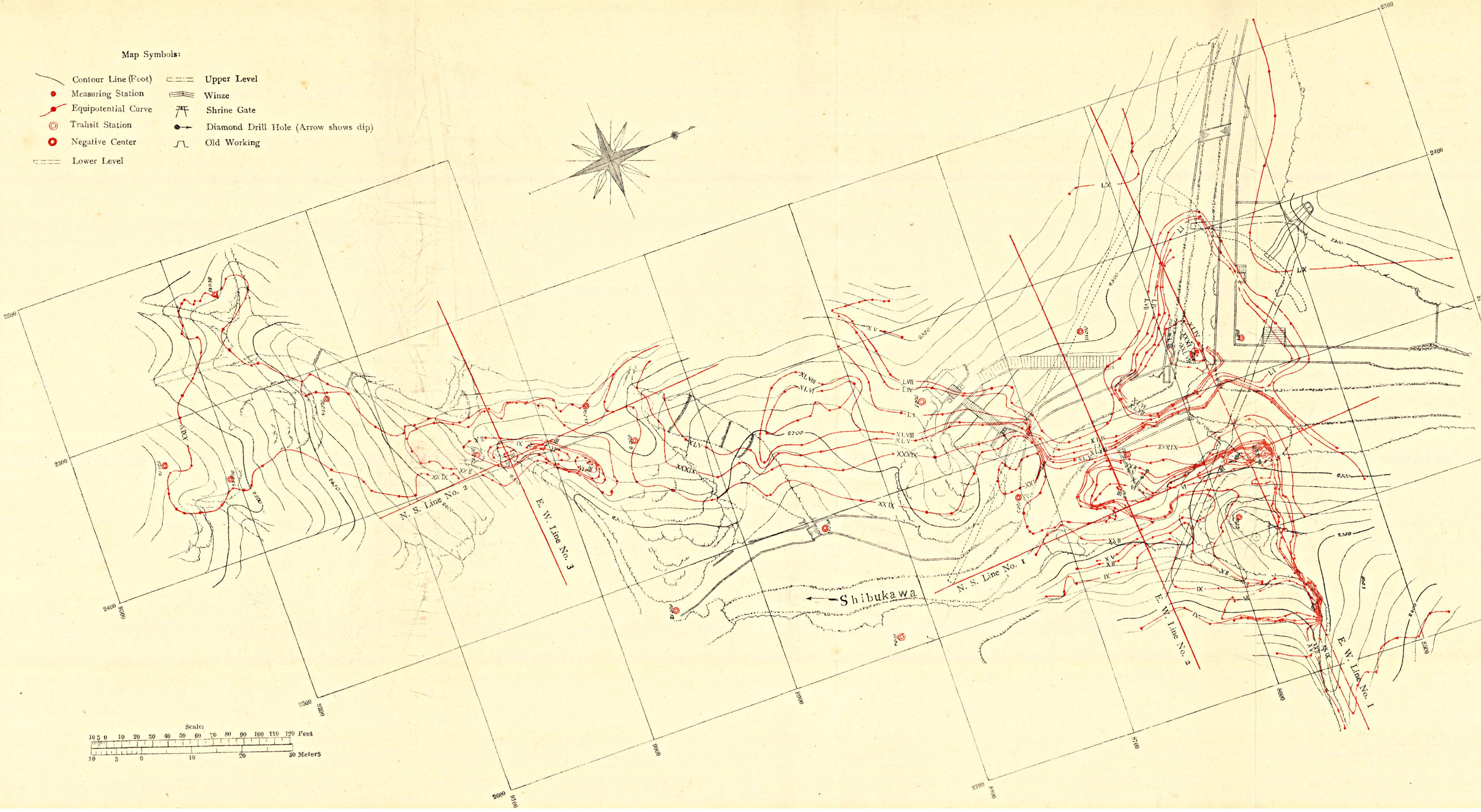
PL. IV. Map showing Contour Lines, Negative Center, and Potentials of Measuring Stations in the Nogamune Mine.





PL. V. Map showing Contour Lines, Negative Center, Equipotential Curves, and Potential of Measuring Stations in the Muneo Mine.

PL. VI. Map showing Contour Lines, Equipotential Curves, and Negative Centers in the Sunokobashi Area, Ashio Mine.



PL. VII. Map showing Contour Lines, Equipotential Curves, and Negative Centers in the Renkeiji Area, Ashio Mine.

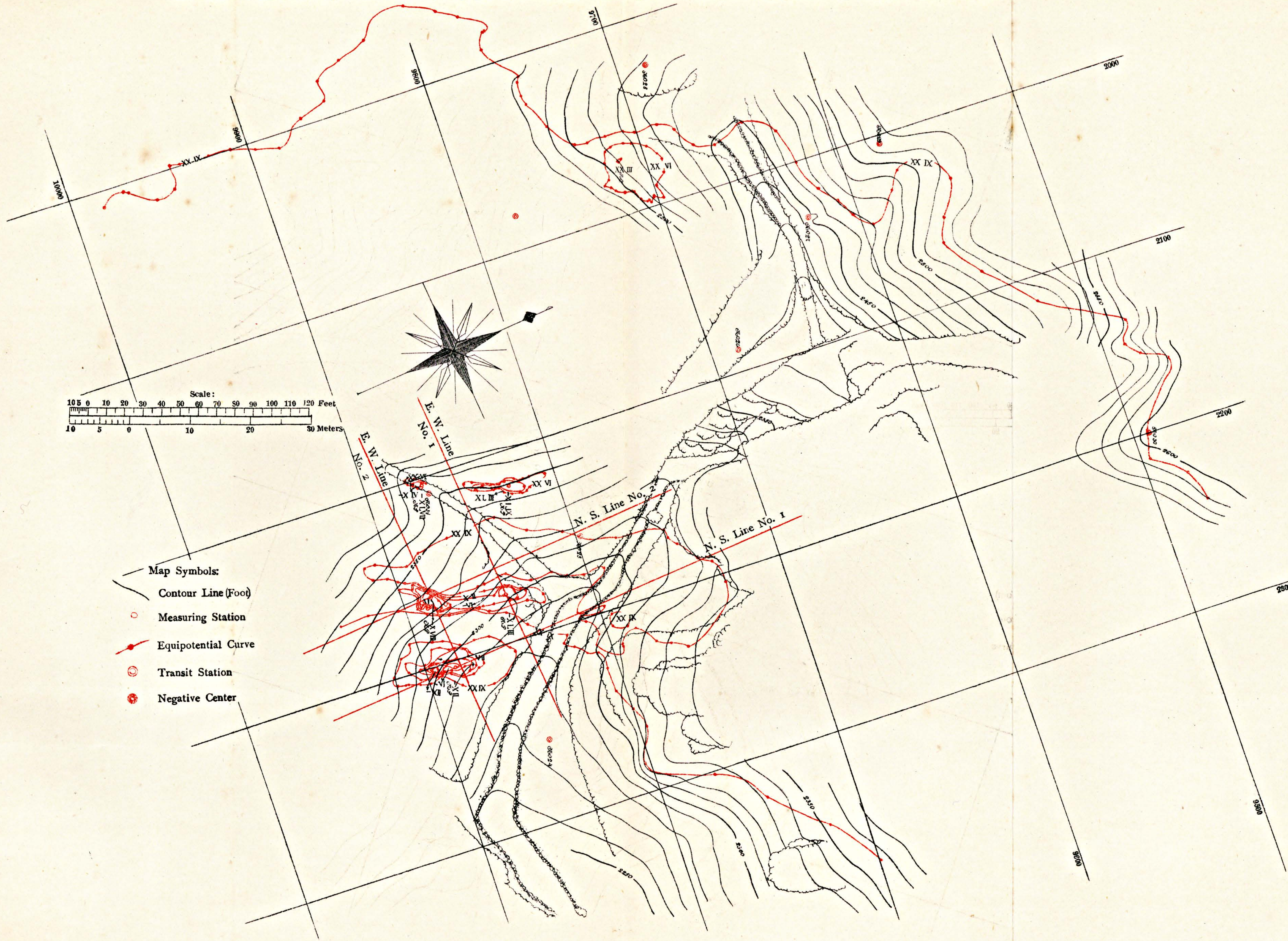


Fig. 1. Profiles along the E. W. Line in the Hisaki Area, Yanahara Mine.

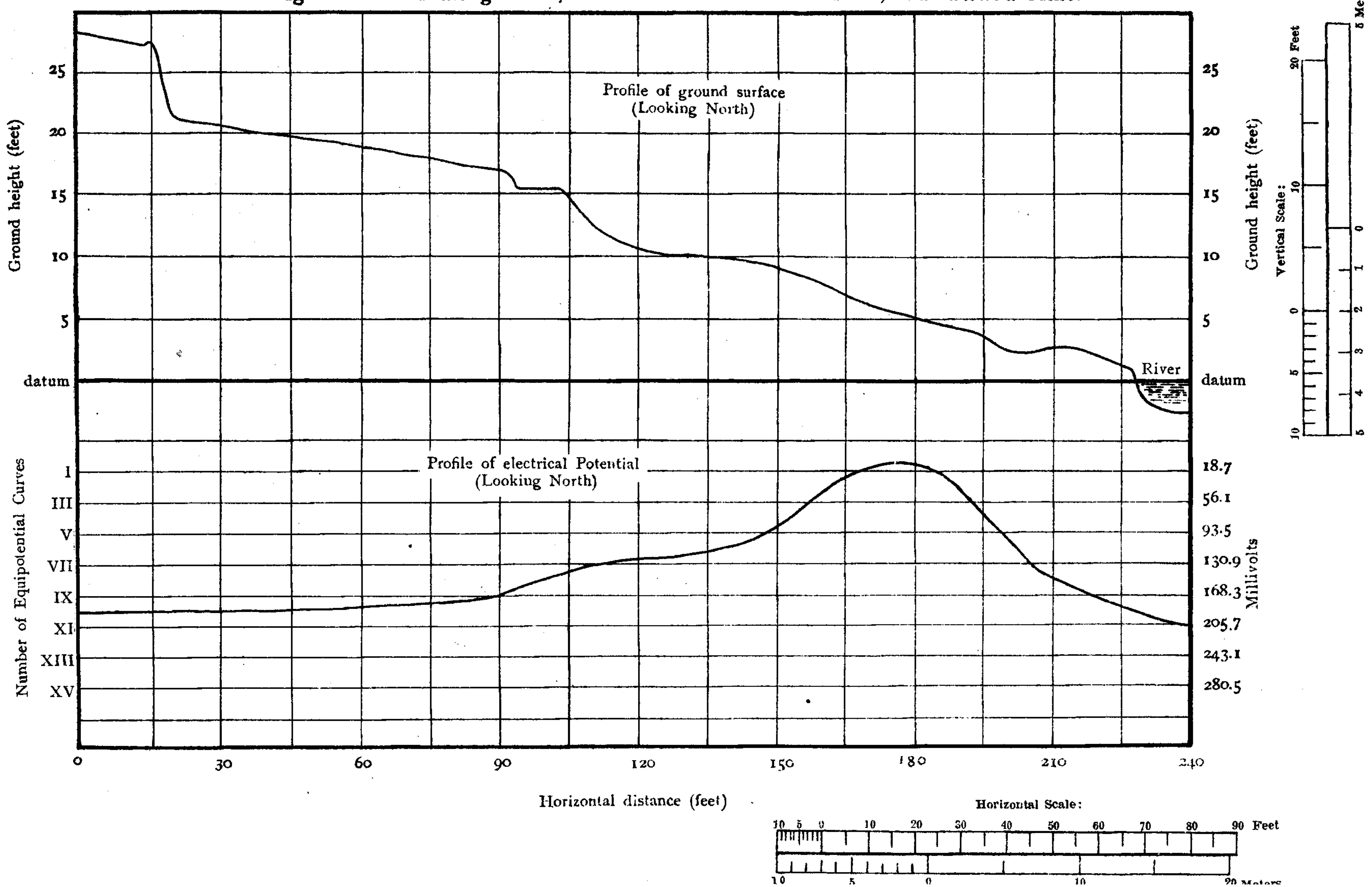


Fig. 2. Profiles along the N. S. Line in the Hisaki Area, Yanahara Mine.

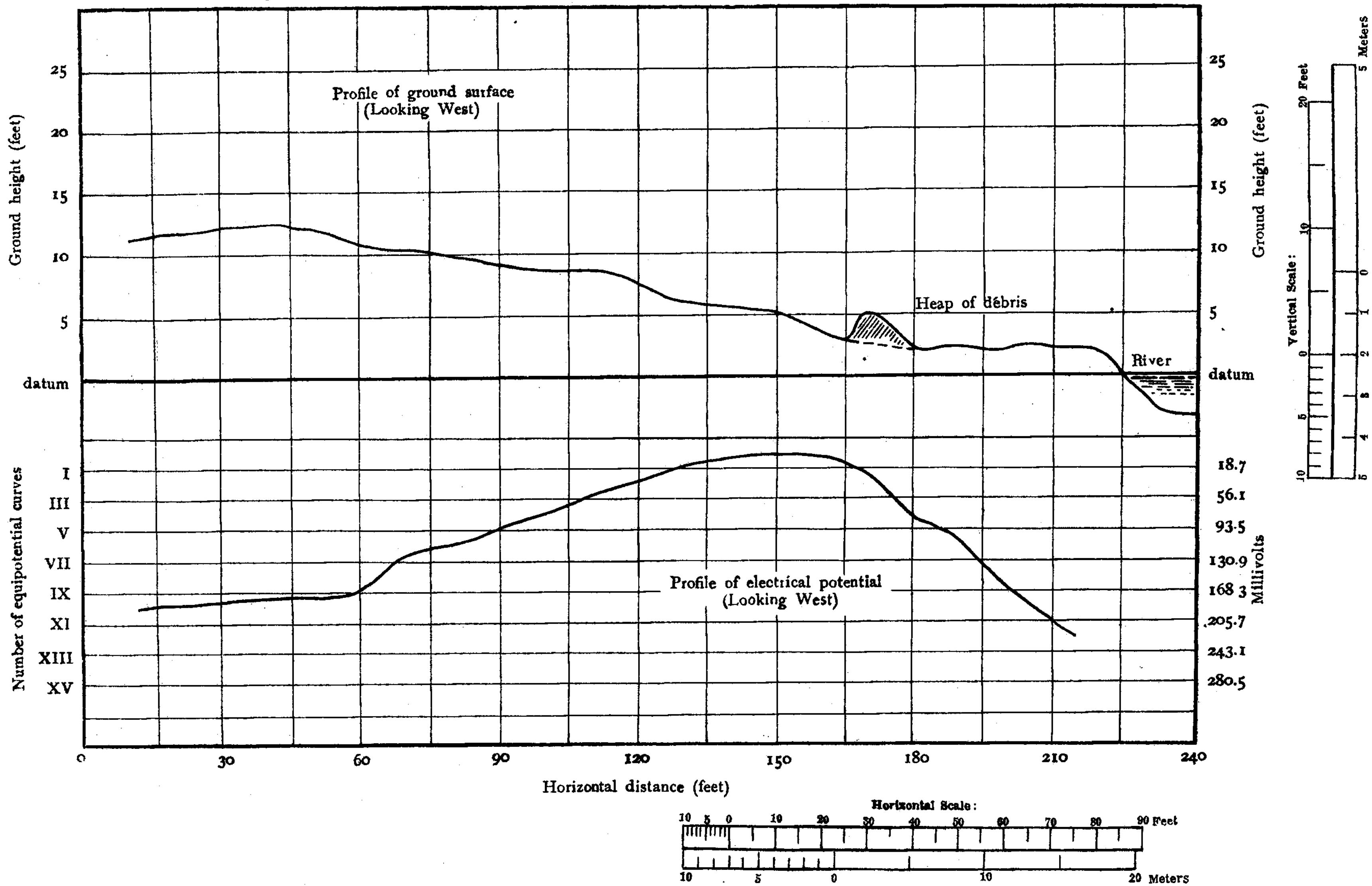


Fig. 3. Profiles along the 30° Lines Nos. 1, 2 and 3 in the Sekizen Area, Besshi Mine.

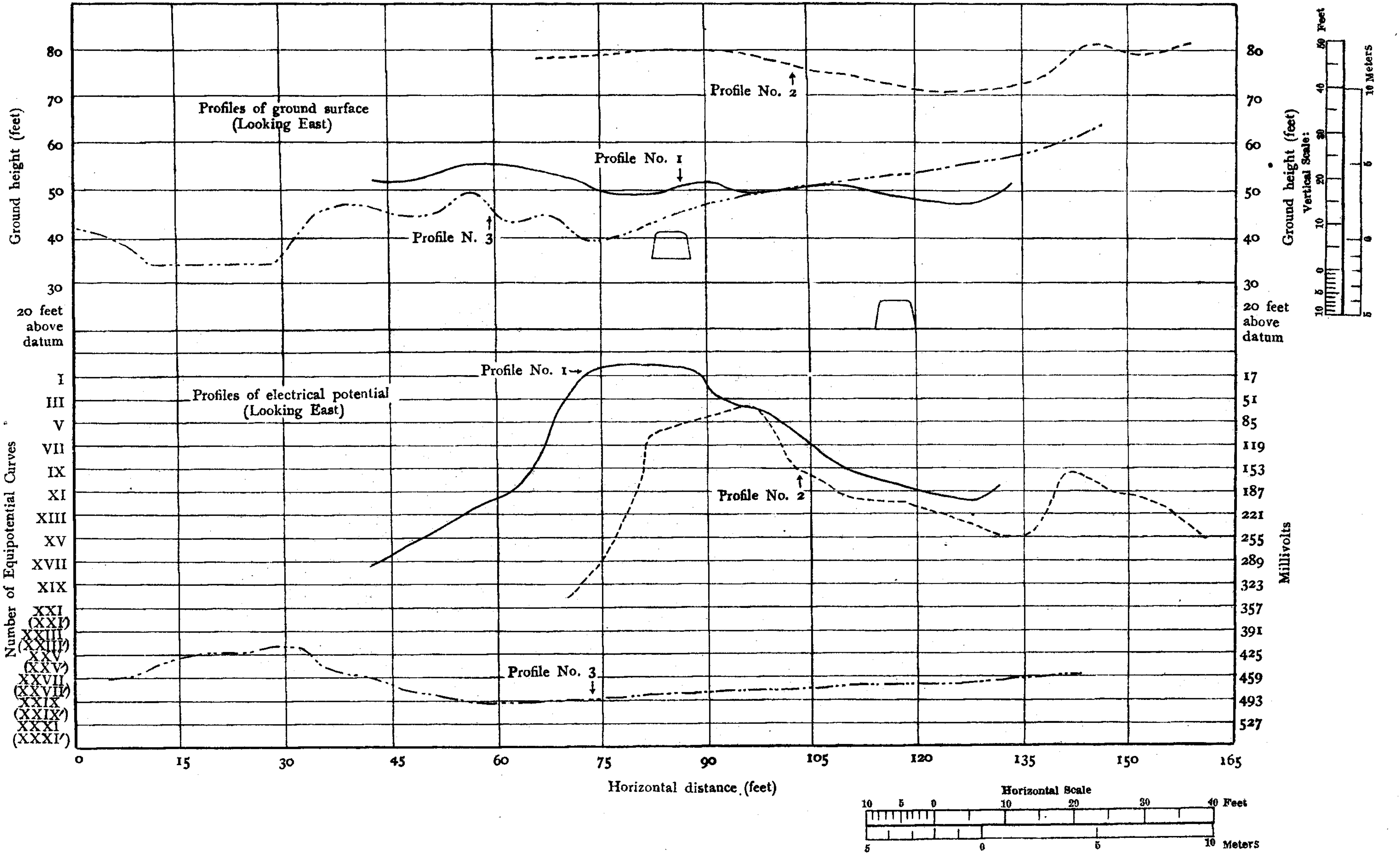


Fig. 4. Profiles along the 120° Line in the Sekizen Area, Besshi Mine.

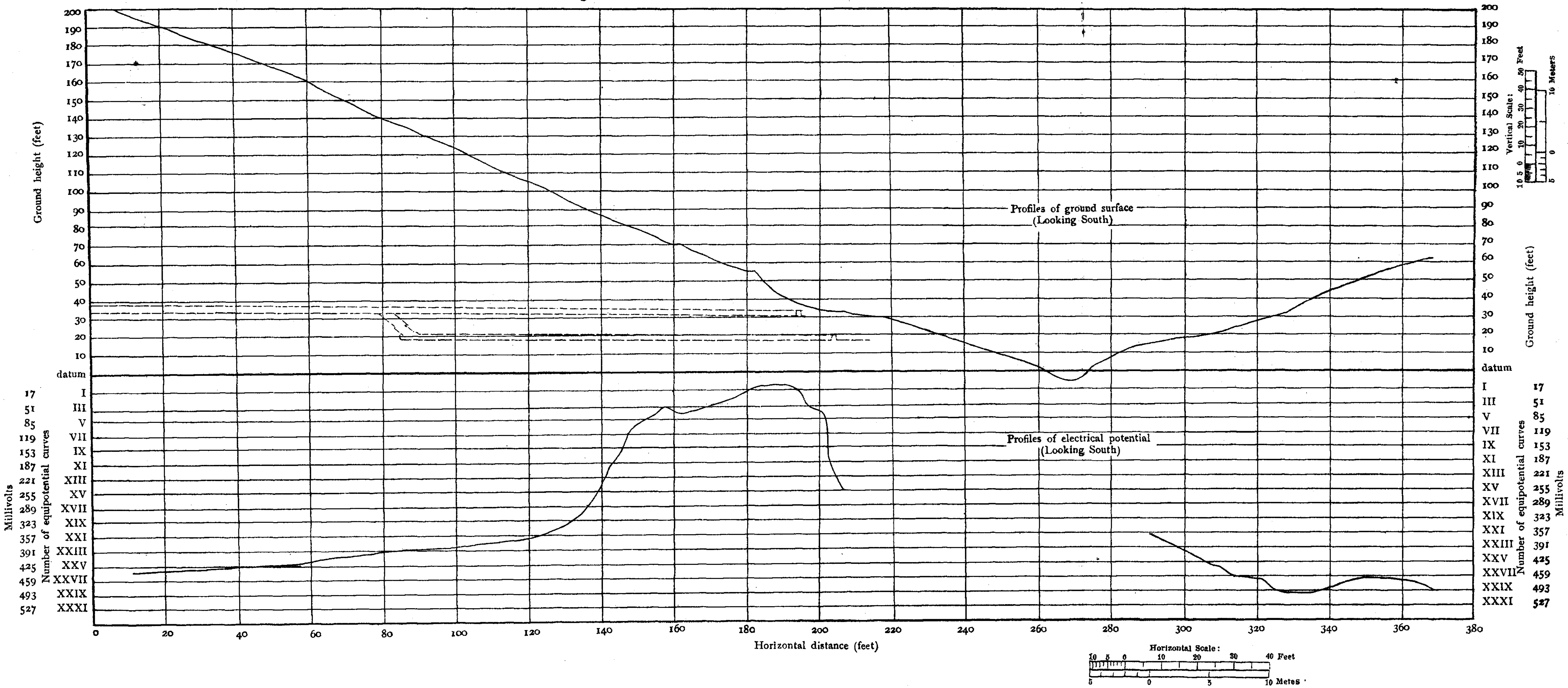


Fig. 5. Profiles along the 25° Lines Nos. 1, 2, 3 and 4 in the Yokei Area, Besshi Mine.

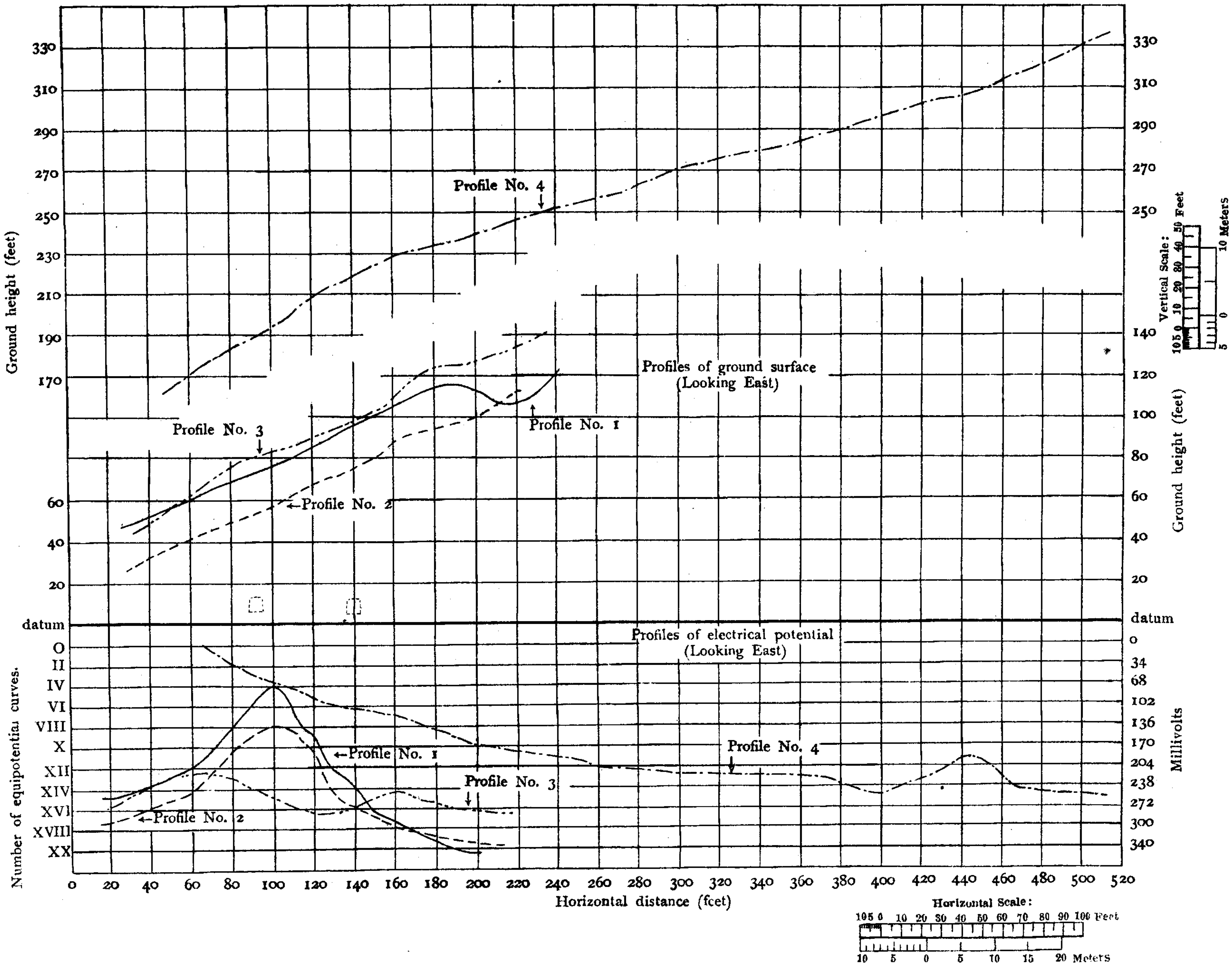


Fig. 6. Profiles along the N. S. Lines Nos. 1, 2 and 3 in the Nagamune Mine.

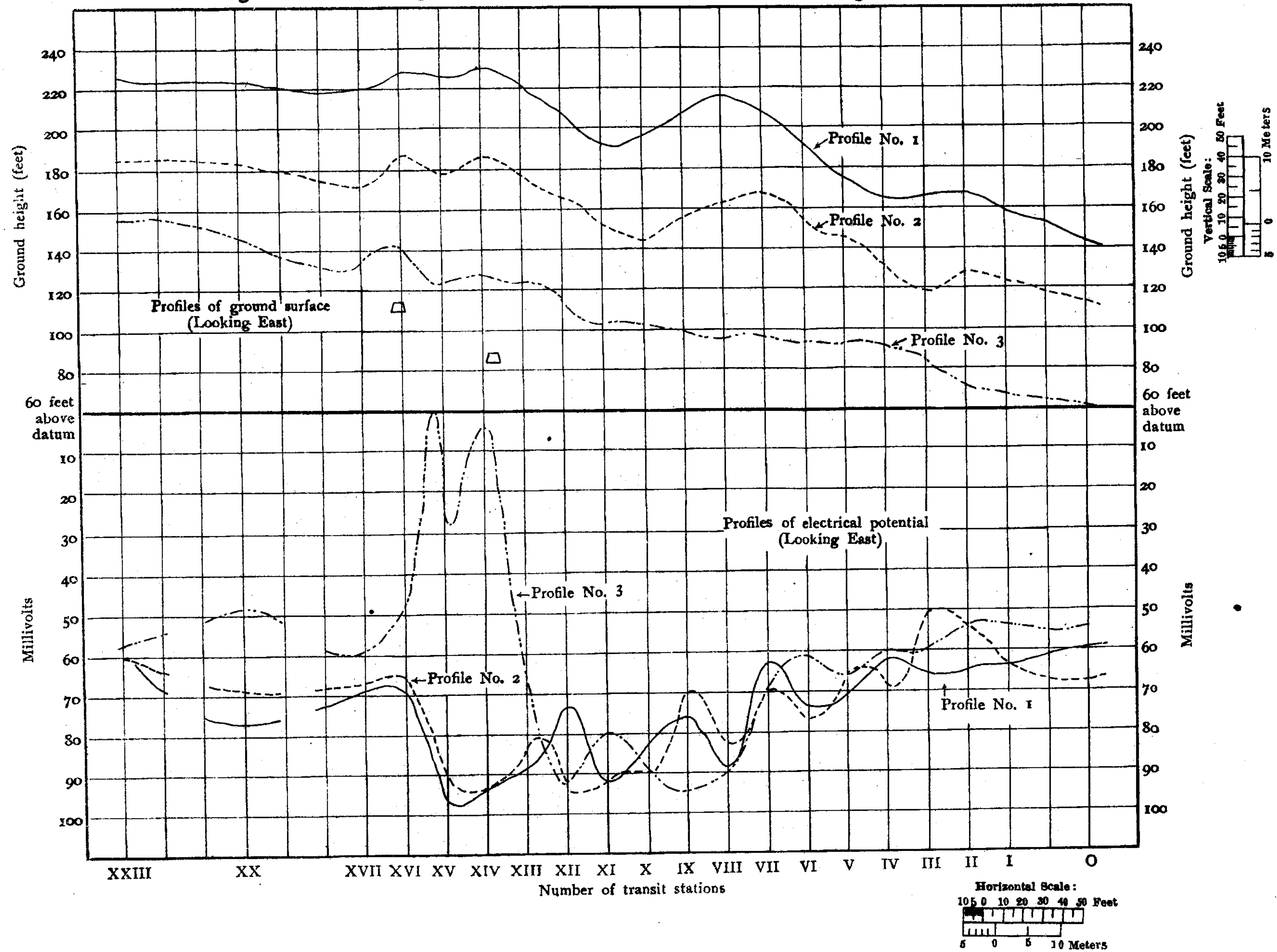


Fig. 7. Profiles along the N. S. Lines Nos. 4, 5 and 6 in the Nagamune Mine.

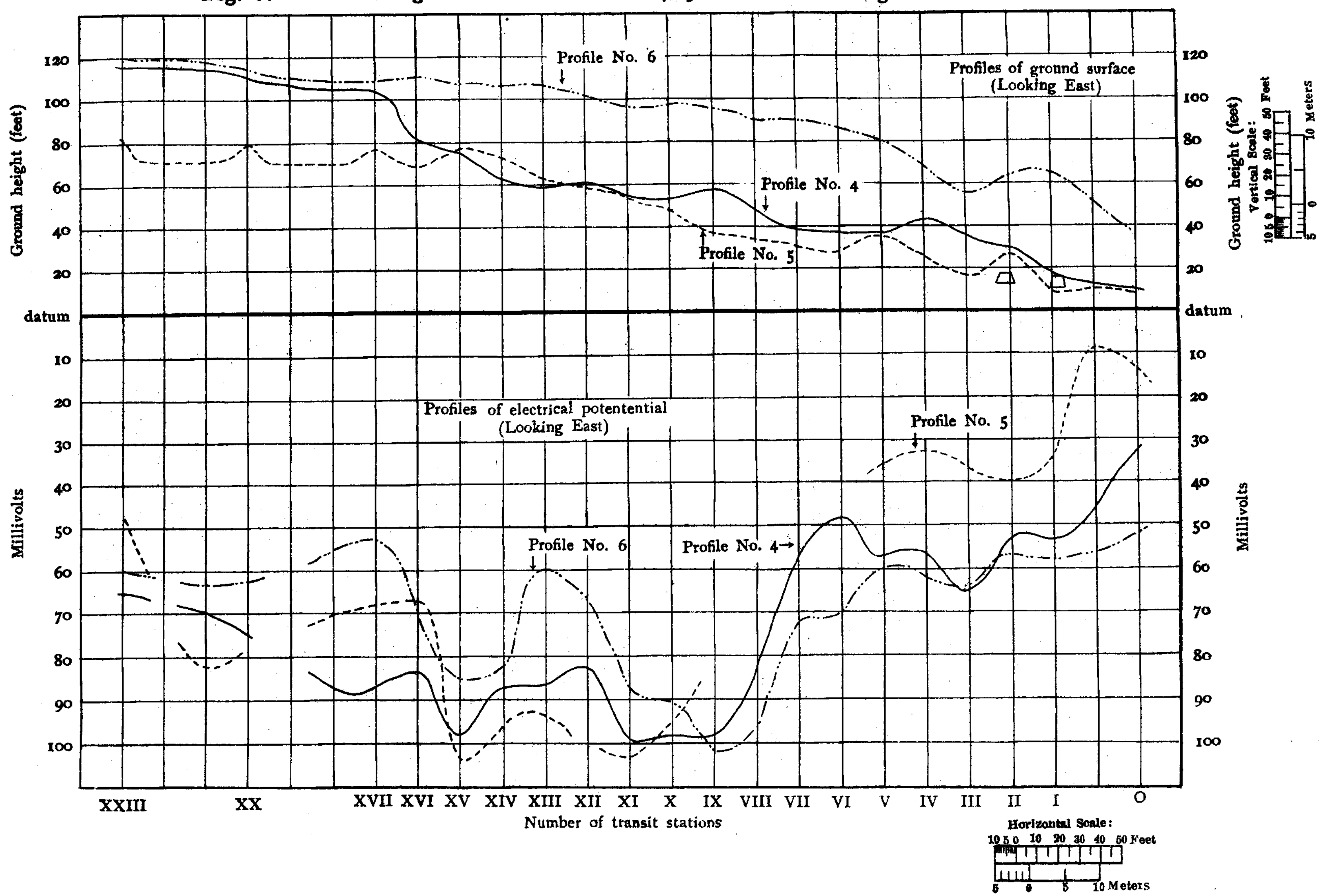


Fig. 9. Profiles along the E. W. Lines Nos. 1, 2 and 3 in the Sunokobashi Area. Ashio Mine.

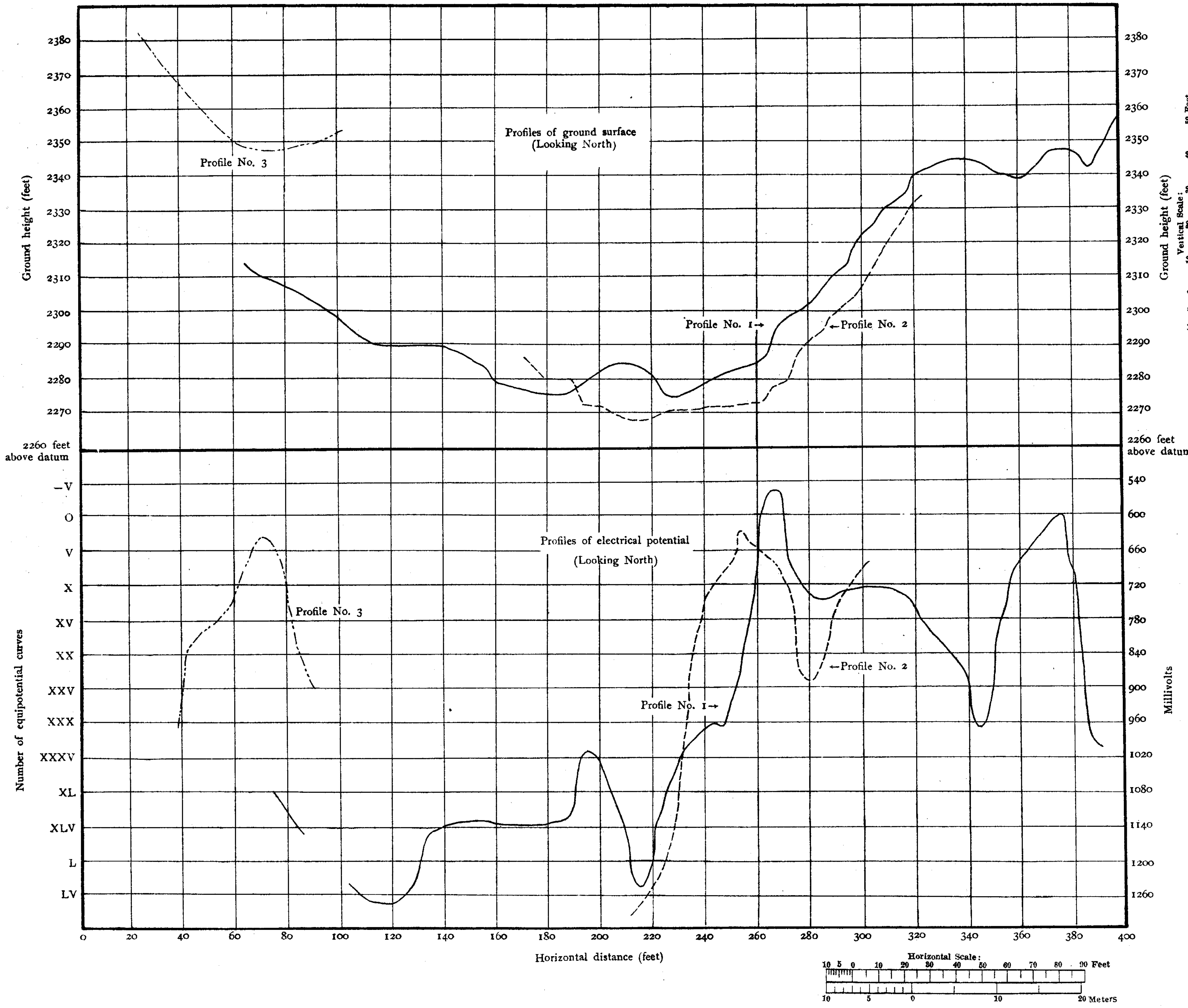


Fig. 10. Profiles along the N. S. Lines Nos. 1 and 2 in the Sunokobashi Area, Ashio Mine.

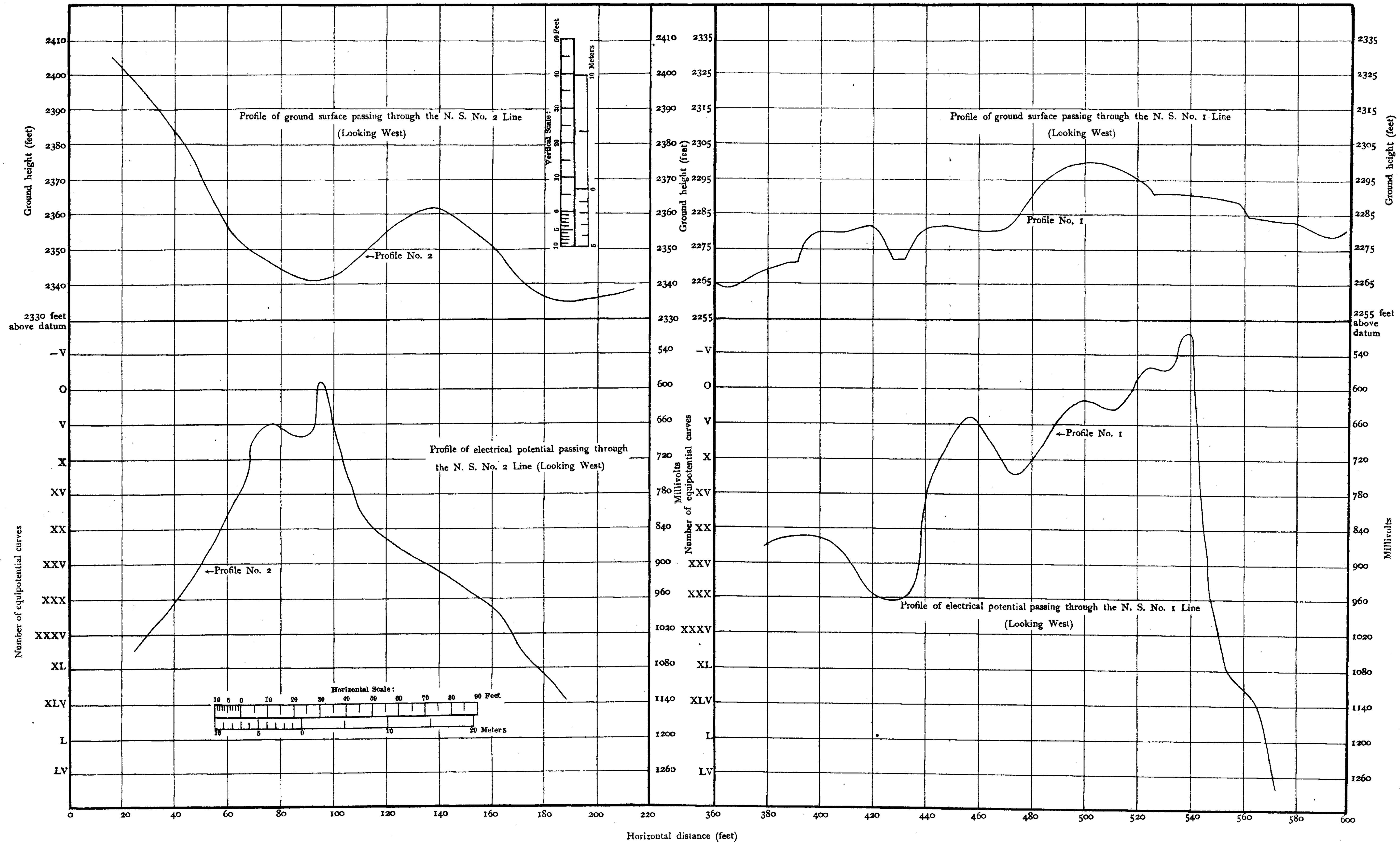


Fig. 11. Profiles along the E. W. Lines Nos. 1 and 2 in the Renkeiji Area, Ashio Mine.

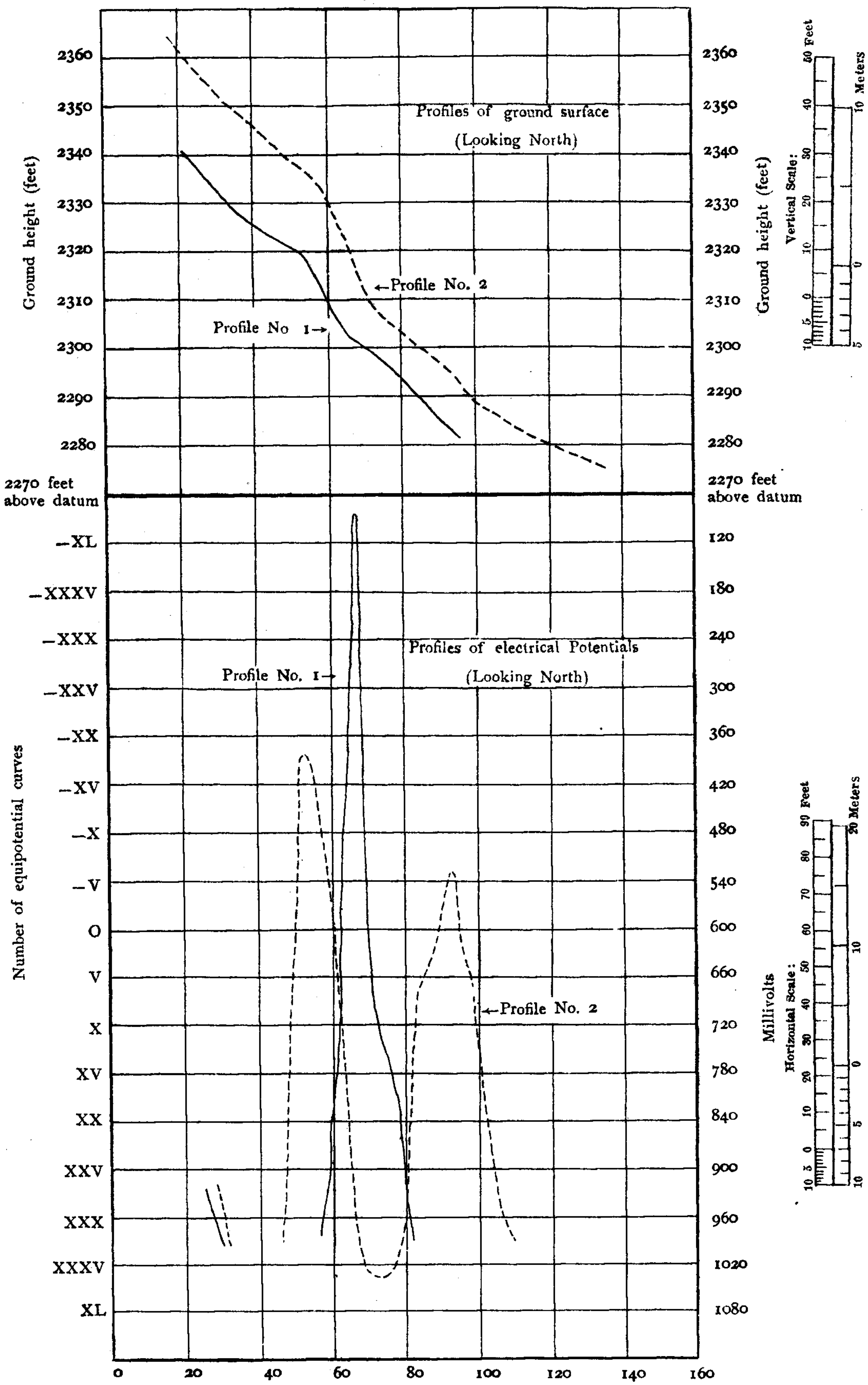


Fig. 12. Profiles along the N. S. Lines Nos. 1 and 2 in the Renkeiji Area, Ashio Mine.