Results Obtained by the Magnetic Prospecting at the Kamaishi Iron Mine.

By

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INTRODUCTION.

The Swedish compass and the dip needle, the former was invented by Daniel Tilas more than 155 years ago in Sweden, and the latter was already in use in the iron mines of New Jersey, U. S., in 1760, were, for a long time, accepted as the best available magnetic instruments in prospecting for magnetic ore bodies.

In 1879, the Swedish scientist Robert Thalén recommended for the measurements of the horizontal intensity either the tangent method by Gauss or the sine method by Lamont, and of the vertical intensity upon the magnetic ore fields, and invented the magnetometer for these purposes. As the magnetometer proposed by Robert Thalén for the measurement of the vertical intensity was not practical, the Swedish mining engineer Enoch Tiberg reconstructed it by the use of the compass as a Tiberg inclinator, which was invented in 1880. The Thalén-Tiberg magnetometer has proved of great value in discovering a great number of iron deposits in several countries, especially in Sweden and Canada.[1]

This magnetometer was improved by the Swedish engineer Th. Dahlblom, by attaching an extra arm which was screwed to the compass box. This modification gives good results and overcomes the defects of the sine method for the measurement of the horizontal intensity.

However, neither the Thomson-Thalén magnetometer constructed in 1899 nor the Th. Dahlblom convenient pocket magnetometer invented in 1903[5] was much used in actual practice.

Lately the magnetic portable theodolite, the Schering-Wild rotary inclinator[2] and the Adolf Schmidt magnetic variometer,[3] etc. are used for the purpose of the magnetic survey.

Since P. Uhlich,[4] Nordenström and Eugene Haanel[5] introduced

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(1) Department of mines (Canada), Iron Ore Occurrences in Canada, Vol. I, II. (1917).

(2) Richard Ambronn, Methoden der Angewandten Geophysik, (1926).

(3) C. Heiland, Zeitschrift fur Angewandte Geophycik, Bd. 1. Heft. 10, (1924).
Rudolf Krahmann, Zeitschrift für praktische Geology, Jan. (1926).

(4) P. Uhlich, Markscheidekunde, XI Abschnitt, P. 329. (1901).

(5) Eugene Haarnel, On the Location and Examination of Magnetic One Deposits by Magnetometric Measurement. (1904).

the Thalén-Tiberg magnetometer on the Continent, England and Canada respectively, all mining engineers took an interest in this prospecting method and recognized its practical value.

It is the purpose of my paper to record the results obtained from the magnetic prospecting which the writer carried out at the Kamaishi Magnetite Mine in Japan.

BRIEF DESCRIPTION OF THE MAGNETIC PROSPECTING APPARATUS USED.

The apparatus used by the writer for the survey was the Thalén-Tiberg magnetometer, which is intended to locate any magnetic deposits by the examination of the horizontal and vertical intensity of the disturbed magnetic field on the ground surface of the proposed regions.

The instrument cosists principally of a compass, on an arm of which is carried a deflecting magnet, a means for turning the compass into either a vertical or a horizontal position, a leveling device and a tripod. The compass has a needle 6 cm. long, which is the principal part of the instrument that is suspended by double pivot on an axis turning on agate bearings, so that it may be used to measure dip or deflecting angle in either the vertical or horizontal position of the compass box.

The instrument which is placed in a horizontal or vartical position, acts like an ordinary compass or inclinator.

TESTING AND ADJUSTING THE MAGNETOMETER.

The magnetometer was tested and adjusted by the writer in the normal terrestrial magnetic field near the proposed areas prior to its use.

(a) Testing the needle. Examination of error due to eccentric suspension of compass needle.

The following table shows the readings at both ends of the compass needle.

Table 1.

Number of measurements	Angle of rotation of the compass	Reading of graduation	
		North pole	South pole
1	—	90°.0 N	89°.2 S-W
2	30°	60°.0 N-O	61°.0 S-W
3	30°	30°.0 N-O	30°.8 S-W
4	30°	0° O	0°.2 S-W
5	30°	30°.0 O-S	29°.9 W-N
6	30°	60°.0 O-S	59°.5 W-N
7	30°	90°.0 S	89°.7 W-N
8	30°	60°.0 S-W	59°.5 N-O
9	30°	30°.0 S-W	29°.8 N-O
10	30°	0° W	0°.5 O-S
11	30°	30°.0 W-N	29°.8 O-S
12	30°	60°.0 W-N	60°.2 O-S
13	30°	90°.0 N	89°.2 S-W

As shown in the table, the maximum eccentricity error is 1°.0. It is very difficult to eliminate this eccentricity error except by the maker, so the writer took the readings of the north pole end of the needle only at all measuring stations.

(b) Neutralization of the vertical component of the normal terrestrial field.

The axis of rotation of the needle does not pass through the center of gravity of the needle, but the latter is below the pivot when the compass box is used in a vertical position. In a normal magnetic terrestrial field, the needle occupies a horizontal position, when the compass is in a vertical plane. This was adjusted by means of a sliding weight on the south end of the needle until the north pole of the needle gave a reading 0° in such a field.

(c) Determination of the definite postion of the deflecting magnet on the arm of the magnetometer.

Table 2.

Station No.		I	II	III	IV	Mean
Method	Deflecting angle α_0	Distance between the center of the compass needle and the north pole end of the deflecting magnet in cm.				
Sine method	10°	13.45	13.85	13.95	13.60	13.70
	20°	10.50	9.95	9.95	9.95	10.00
	30°	8.30	8.40	8.20	8.35	8.30
Tangent method	10°	13.10	13.50	13.40	13.70	13.40
	20°	9.85	10.00	9.81	10.10	9.90
	30°	8.33	8.50	8.52	8.56	8.50

As the writer adopted the tangent method for the determination of the horizontal intensity, the frame of the defecting magnet was fixed 8.50 cm. from the center of the compass.

(d) The other adjustments.

The compass box was set in a true horizontal or vertical position by means of a box level and scerws.

DESCRIPTION OF THE KAMAISHI IRON MINE.

The Kamaishi Mine is situated about 600 km. N. N. E. of Tokyo, and has been worked by the Kamaishi Mining Co..

The prospected area is one part of the concession of this mine.

The geologic formation of the mine consists of paleozoic sandstones, slates and limestones intruded by granites, diorites, grano-diorites and porphyrites by which the limestones are altered to garnetites. All the magnetite deposits, lenticular in shape, occur along the contact of the garnetite and the grano-diorite or porphyrite. There are two parallel principal series of deposits, striking N. 10° W., one of which including the Akaiwa, Sahinai Shimo-date, Sahinai Naka-Kami-date, Shinyama and other several deposits, was surveyed by the writer with the magnetic prospecting.

The following table shows the analysis of an average sample of the main deposits of this series which were studied by the magnetic survey and are considered fairly representative of these ores.

Table 3.

Element \ Deposit	Akaiwa	Sahinai Shimo-date	Sahinai Naka-Kami-date		Shinyama
			rich ore	medium grade ore	
	%	%	%	%	%
Iron	65.00	65.42	68.40	48.50	65.20
Alumina	1.18	1.50	0.34	4.56	0.80
Silica	4.25	4.00	3.10	14.60	4.10
Lime	2.37	2.83	1.10	11.82	2.18
Sulphur	0.44	0.05	0.03	0.01	1.35
Phosphorus	0.045	0.045	0.05	0.058	0.048
Copper	0.08	0.02	—	—	0.18

CHARACTERISTIC FEATURES OF THE PROSPECTED AREAS.

The writer laid out the base line of the proposed area along the contact line of the garnetite and porphyrite or grano-diorite as shown in PL. I.

Three base lines are selected in the prospected area.

Table 4.

Base line		Direction	Horizontal distance
from	to		
the Akaiwa deposit	the Sahinai deposit	N 39° W	300 meters
the Sahinai deposit	the Shinyama deposit	N 39° W	730 „
the Shinyama deposit	the Takinozawa deposit	N 14° W	1020 „

On the base line distances of 30.3 meters were laid off, and subsidiary lines run at right angles to the base line from these points to the limit of the disturbed field, where the vertical magnetic intensity of the ore body becomes zero or nearly zero.

The horizontal and vertical intensities of the field are observed at the corners of the squares, which are conveniently run 30.3 meter on a side, but if necessary, intermediates can be run in important or conplicated places.

As in the property under consideration, *bambusse veitchii* grow luxuriantly and the topography is marked by entangled masses of mountains, great difficulty and dınger were experienced in measuring the magnetic components, as well as in carrying out the stadia surveying. Before the commencement of the work, the *bambusse veitchii* were cut down in order to make several paths parallel or perpendicular to the base lines.

The number of laborers and the cost of this work were: 0.97 laborers of one shift (8 hours) and 0.54 dollars in setting up one measuring station which depends on the stadia surveying.

A preliminary investigation of the field was made with a Swedish and a dip compass.

The area examined was about 545,500 sq. meters, and contained seven known deposits, and one deposit which was discovered by this prospecting work.

The crew consisted of the writer, three assistants, four surveyors and eleven to fourteen laborers, The field work began in June and ended in September 1926.

RECORDS OBTAINED FROM THE EXPERIMENTS.

(a) The Akaiwa Area.

The ore deposit consists of magnetite, which occurs along the contact of the garnetite and grano-diorite. Two parts of the deposit cropped out on the ground surface.

PL. II shows the magnetic chart of the isoclinic lines which are drawn through the points of equal dip. The isoclinic lines are normal to the lines of force and are adapted to indicating the nature of a mild but extensive magnetic field.

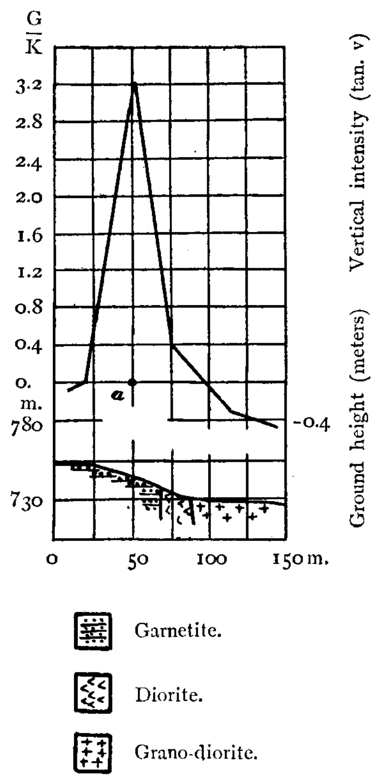
The north pole attraction of the compass needle, that is, the positive dip, is represented by a blue line, and the south pole attraction, the negative dip, by a red one.

Taking a cursory view of the whole, every isoclinic curve outline is elliptical in shape and similar to each other. The two groups of strong positive isoclinic lines, which were traced near the two outcrops of the deposit, are enclosed by the smaller intensity curves. In the positive area, the regular and parallel isoclinic lines are traced, but in the negative area, the large negative dip is not obtained, and the writer could not observe clearly the effect of the lower pole of the deposit.

Judging from the topography and the magnetic chart of the vertical intensity, which gave the most clear information, the attraction of the lower pole is very feeble, so the ore descends to a gerat depth or the dip of the deposit is nearly perpendicular to the ground surface.

Fig. 1.
Profiles along the No. 1 line in the Akaiwa Area. Looking North-West.

Scale : $\frac{1}{4,800}$



As the large positive dip curves will generally represent the approximate shape of the ore body, so the horizontal section of the deposit must be lenticular.

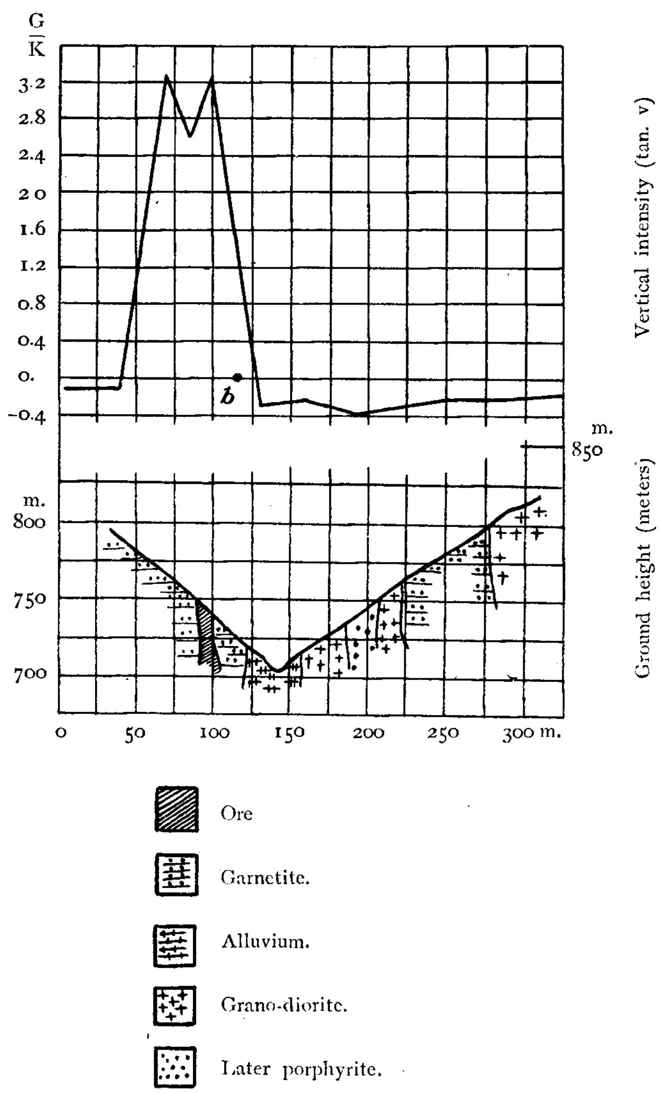
Figs. 1 and 2 are plotted through the line, which is normal to the base line or along the base line respectively, and pass through the maximum positive intensity.

As shown in the above profiles, the vertical intensity curve of Fig. 1 has a narrower peak than the one of Fig. 2, so that the deposit has a larger extension along the base line than along the line normal to the base line horizontally.

Fig. 2.

Profiles along the No. 2 line in the Akaiwa Area.
Looking North-East.

Scale : $\frac{1}{4,800}$



(b) The Sahinai Shimo-date Area.

The ore occurs as a lenticular mass along the contact of the garnetite and grano-diorite, and cosists of rich magnetite mixed with a tolerable amount of medium grade magnetite ore. Referring to the geological map PL. I, the ore body consists of two groups which are connected to each other with an ore stringer.

In the isoclinic chart which was traced on this area, two groups of positive curves are enclosed by the 40° isoclinic line, the northern group occupies a larger area than the southern one. As expected, the shape of the ore body which is assumed by the obtained magnetic chart agrees with the results obtained from the geological survey.

In the northern part of the northern positive dip group of the isoclinic lines, the large negative dip curves whose maximum intensity curve is 60°, were traced. If the ground surface is harizontal, the dip of the ore body is, as a rule, toward the area of the strongest negative attraction, and hence in the northern direction. But the ground slopes down toward the north, therefore from only the above reason, one can not decide that the dip of the ore body is to the north.

(c) The Sahinai Naka-Kami-date Area.

The deposit consists of several magnetite masses in the granetite near the contact of the granetite and grano-diorite or diorite. This deposit was worked as an open pit or underground cutting, and from this a very considerable tonnage was extracted. Since recents years the working has been stopped.

In this area, the condition for the magnetic prospecting were very unfavourable, as the natural ground was steeply sloped and the ground surface was made uneven by the open mining; moreover, obstacles, such as ore débris, rails, and other construtions were scattered about there, thus from the magnetic chart, one can not have an accurate interpretation upon this deposit.

As shown in PL. II, the positive or negative isoclinic lines were very irregular and intricate. Several groups of dip curves which encircled the maximum positive or negative dips, are traced. As a whole, the negative intensity shows a comparatively feeble attraction and the strong positive intensity field occupies a vast area, which indicate that the down pole of the ore body is at a considerable depth and the horizontal extension of the ore body is relatively broad.

Fig. 3 shows the relation between the ground surface, the geological condition and the magnetic vertical intensity along the *bd* line. The positions of the peak points of the magnetic profile curve are found directly over the ore bodies. On the stations (horizontal distance 470 and 515 meters in Fig. 3) where the ore bodies were mainly excavated, leaving large cavities, the intensity decreases rapidly and assumes a negative value.

(d) The New Deposit Area.

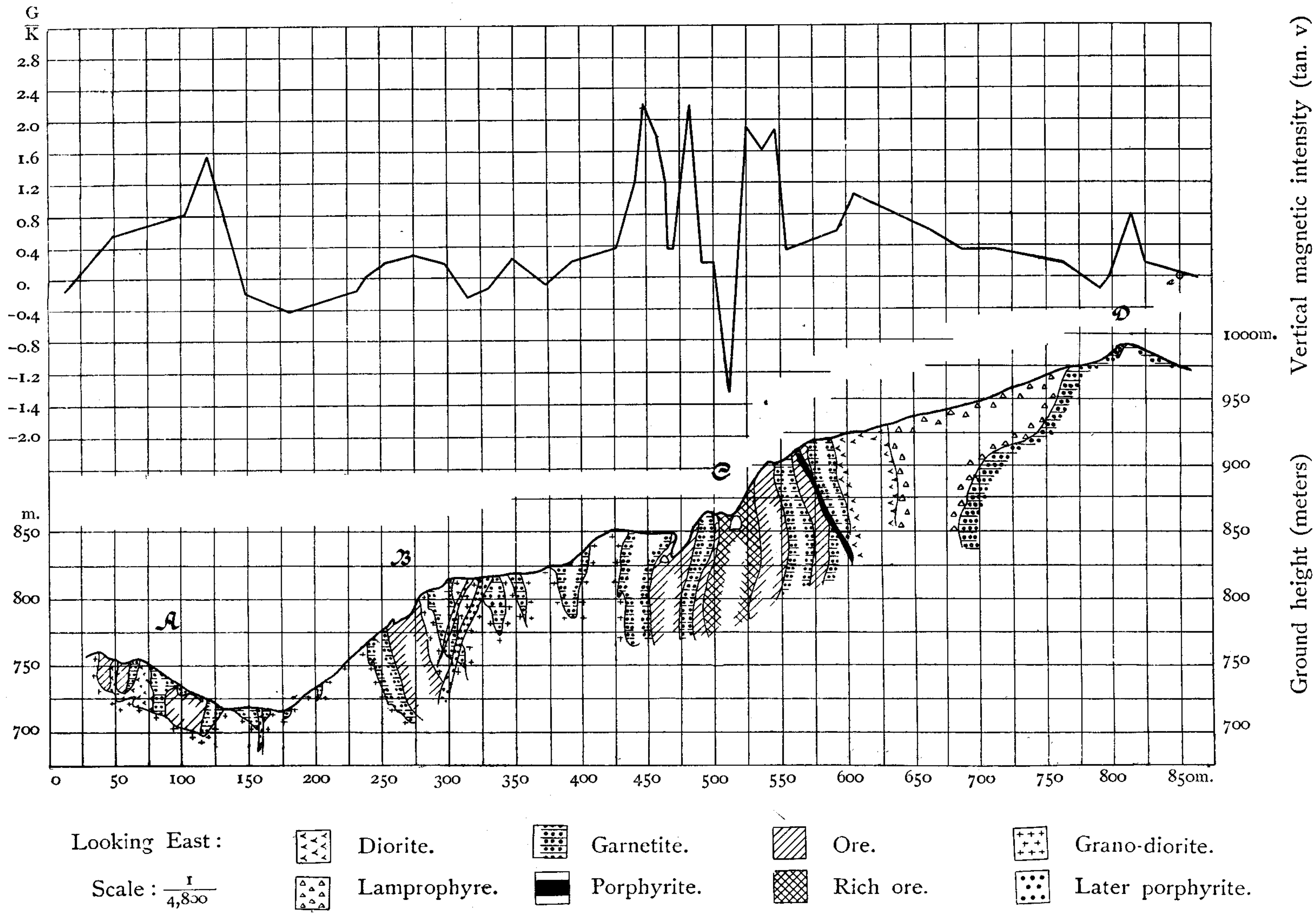
As no surface indication exist for this ore body, this deposit was overlooked when the geological survey was carried out several years ago. In consequence of the magnetic survey, the writer believes in the existence of an ore body which is covered by an overburden and has no visible indiacations.

Referring to PL. II, in the southern part of the Sahinai area, the lines of the strong positive dip were encircled in two places, and they are enclosed with a 20° dip curve. The two maximum dips in this area are 50° and 60°, the former was traced in the northern place near the Sahinai Naka-Kami-date area and the latter was far away to the south.

The maximum dips in this area occur where the intensity due to the Sahinai Naka-Kami-date ore bodies would be small or even negative and hence must result from some powerful influence.

The positive maximum intensity of this area is comparatively more feeble than the one that was measured in the other deposits which cutcropped on the ground surface. As shown in PL. II, the writer could not observe the negative dip in this area. The observation stations are further away from the lower pole of the ore body. From the above reasons, the writer concluded that the new ore body has a tolerable extension in both

Fig. 3. Profiles along the No. 3 line in the Akaiwa, Sahinai Shimo-date, Sahinai Naka-Kami-date and Aoban Areas.



A: Akaiwa Area, B: Sahinai Shimo-date Area, C: Sahinai Naka-Kami-date Area, D: Aoban Area.

geological section

after **S. Yamane.**

horizontal and vertical directions.

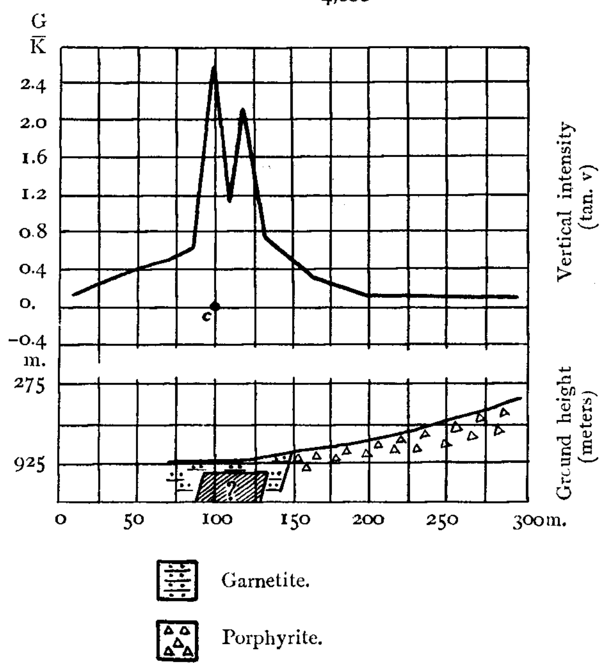
The general tendency of the profile curve, Fig. 4, which moves along the perpendicular line to the base line and passes through the southern maximum dip of the vertical intensity, is nearly the same as that calculated by Eugene Haarnel[(6)] on the ideal bar magnet.

Fig. 4.

Profiles along the No. 4 line in the New Deposit Area.

Looking North-West

Scale : $\frac{1}{4,800}$



(e) The Motoyama Area.

The ore occurs as small massive magnetite lenses along the contact of the garnetite and porphyrite.

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(6) Eugene Haarnel; On the Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements. Plate I. (1904).

Durham; Mine Surveying. P. 376 (1913).

This ore body was largely open mined and a comparatively large tonnage of ore was extracted. As the ore body lies in the middle part of the steep hill, and the unextracted ore body remains irregularly in situ, so the observations made beyond the outcrop may be taken below the upper pole of the deposit and the end of the inclinator needle be drawn upward, giving a negative reading.

In this region, the negataive dip area is very widely extended, and the positive dip shows a measurement more feeble than the other deposits in this mine.

(f) The Shinyama Area.

The ore body consists of magnetite which occurs along the contact line of the garnetite and porphyrite. The Shinyama deposit is the largest one in this mine, and the general strike of the ore body is nearly north to south, with a vertical dip.

This deposit was developed as an open-cut at first, and later as an underground workings, and a very considerable tonnage of ore was extracted. At present the ore is mined only from this deposit in this mine.

As shown in PL. II, the lines of the large dip encircles the outcrop of the ore body in a regular form, then the vertical intensity grows less toward every direction symmetrically. The writer could not observe the negative dip near this ore body.

The areas, which are enclosed by the isoclinic lines, are as follows.

Table 5.

Isoclinic line	Area (sq. meters)
$+40°$	27,500
$+50°$	17,750
$+60°$	9,000

Referring to the geological map, the mineralized area is about 7,380 sq. meters. The following table shows the areas which are excavated by the underground workings.

PL. IV. *Map showing the relation between the isoclinic curves and the underground workings in the Shinyama Deposit.*

Scale : $\frac{1}{3,600}$

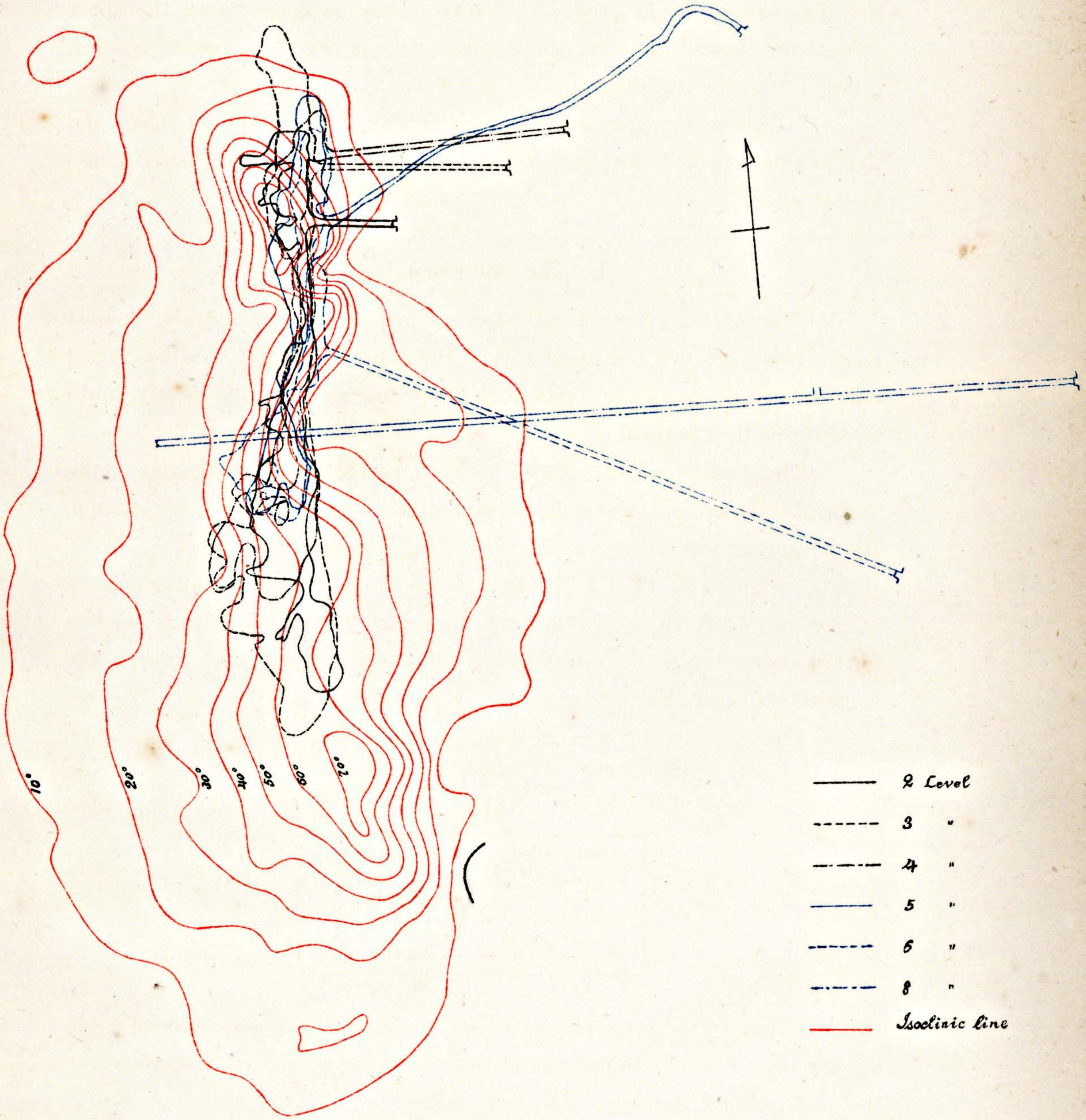


Table 6.

Level	Area (sq. Meters)			Remarks.
	rich ore	medium grade ore	total	
2	2,865	2,706	5,571	Boundary country rocks appear.
3	6,038	2,891	8,929	„
4	4,623	1,411	6,034	North and South sides are ore.
5	4,306	320	4,626	„
6	1,358	598	1,956	„

In the 2nd and 3rd levels, the ore has been perfectly extracted horizontally, exposing the boundary rocks. In the other levels, the development has not progressed as in the above levels, and a great quantity of ore remains to be extracted.

The following table shows the comparison of the horizontal areas between the exploited area in the 2nd or 3rd levels and the enclosed area by the isoclinic curves of 60° or 50° dips, which were obtained by the magnetic survey.

Table 7.

Isoclinic line	Level	Area (sq. meters)	Percentage
+60°		9,000	100
	2	5,571	62
	3	8,929	100
+50°		17,750	100
	2	5,571	31
	3	8,929	50

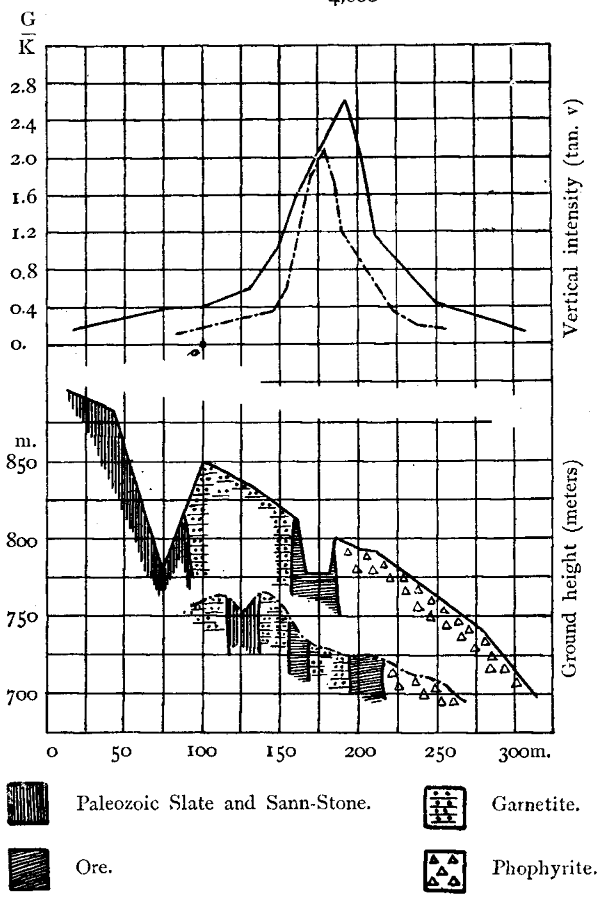
PL, IV shows the relation between the unnergraund workings and the magnetometric chart of the vertical intensity. All the underground exploited areas are commonly enveloped by a 50° dip curve. As the strong intensity curves are traced to the southward of the excavated area, and the southern boundary of the ore, the country rocks do not appear in the 4th, 5th and 6th levels, so the ore body possibly extends in the southern direction. In the south part of this area, the isoclinic line swells out widely as compared with its direction in the north part. From the above reasons, the mineralized area in the southern part of this deposit, has, beyond comparison, a superior extension to the other parts.

All profiles which are drawn along the perpendicular line to the general strike, in other words to the base line, have the same tendency to rise and fall. The value of the vertical intensity decreases from a maximum, directly over the open cut, to the east side of the ore body rapidly and to

Fig. 5.

Profiles along the Nos. 5 and 5′ line in the Shinyama Area.
Looking North-West.

Scale : $\frac{1}{4,800}$



the west side slowly. The east side of the ore body is the roots of the hill and from there the hill rises up with about a 30°—40° inclination to the westward. Notwithstanding the ore body has a vertical dip, the slope of the hill has an effect upon the declination of the profile curve.

(g) The other Areas.

Judging from the outcrops of the Aoban and Takinozawa deposits, these deposits did not warrant successful mining.

Referring to the magnetic chart, the maximum positive and negative intensities are located contiguously. As the positive dip areas in both deposits are very small, so the region influenced by the upper pole of the ore body is narrow. The effect of the down pole is very strong which indicates that this is a very shallow deposit.

MINERALIZED AREA.

The determination of the mineralized area must be based on the information from the magnetic survey, the geological survey and the underground cutting or diamond drill holes.

The followong table shows the ratio between the areas which are enclosed by the high positive dip curve.

Table 8.

Deposit	Ratio of the areas, enclosed by dip curves		
	+60°	+50°	+40°
Akaiwa	100	196	338
Sahinai Shimo-date	100	255	427
Sahinai Naka-Kami-date	100	205	291
Shinyama	100	197	306

Referring to the above table, the area which is enclosed by the 60°

dip curve is nearly egual to the area of the 60°—50° dip curves and also of the 50°—40° isoclinic lines.

The relation of the mineralized areas between the magnetic survey and the geological survey is a follows;

Table 9.

Mineralized Area / Deposit	Magnetic survey — Isoclinic line: positive dip angle	Magnetic survey — Isoclinic line: enclosed area in sq. meters	Geological survey (sq. meters)
Akaiwa	50°	680	813
Sahinai-Shimo-date	40°	3,406	4,805
Sahinai-Naka-Kami-date	50°	10,582	10,916
Motoyama	40°	399	396
Shinyama	60°	9,000	8,929*

* exploited area of the 3rd level.

Olin R. Kuhn[7] reported that "The Kamaishi mine contains about 35,000,000 tons of magnetite ore averaging 60 percent iron," and C. K. Leith[8] also estimated that the ore reserve of the Kamaishi mine is 35,000,000 tons.

From the points of view of the magnetic prospecting, the geological survey and the underground developments, the writer estimated that the ore reserve in the prospected area which is one part of this mine, is about 31,600,000 tons, and the mineralized area is about 30,700 sq. meters.

If further magnetic prospecting is carried out in the other series of ore deposits or unprospected regions in this mine, then the larger tonnage of iron ore and wide mineralized area may be determined.

CONCLUSION.

The general Conclusions drawn from the study of the magnetic

(7) Olin R. Kuhn: World's Iron Ore Resources Now Exceed 57,000,000,000 Tons. Eng. Min. Jour. Press Vol. 122 No. 3 July 17, P. 84 (1926).

(8) C. K. Leith: Mineral Resources of the Far East. Iron & Coal Trade Keview Aug. 20, P. 264 (1926).

prospecting are as follows ;

(1) The results obtained from the geological survey of this prospected regions agreed with the information obtained by the magnetic survey which was carried out more rapidly and economically than the former.

(2) The depth of the ore body, namely the lower magnetic pole of the ore body, could be determined neither by this prospecting nor by geological survery.

(3) The new deposit which has no surface indications and was overlooked when the geological survey was carried out, was easily found by this magnetic survey. If the normal terrestrial field is disturbed by the magnetism of an unknown buried ore body, then the deposit can easily be found by an observation of the anomaly due to the buried deposit.

(4) As near the rich ore part in the ore body of the Sahinai-Naka-Kami-date area, positive and negative strong magnetic vertical intensities were found, so a suitable site for a prospecting shaft or adit mouth and diamond drill hole can easily be determined.

(5) Magnetic charts show that the Shinyama deposit has a superior extension to the southern part of the exploited area. Generally a very good idea regarding the extension of the ore body in question is obtained by the chart of the vertical intensity.

(6) The magnetic survey is the best and most easily available prospecting method among the various geophysical methods for the attractive magnetic deposits.

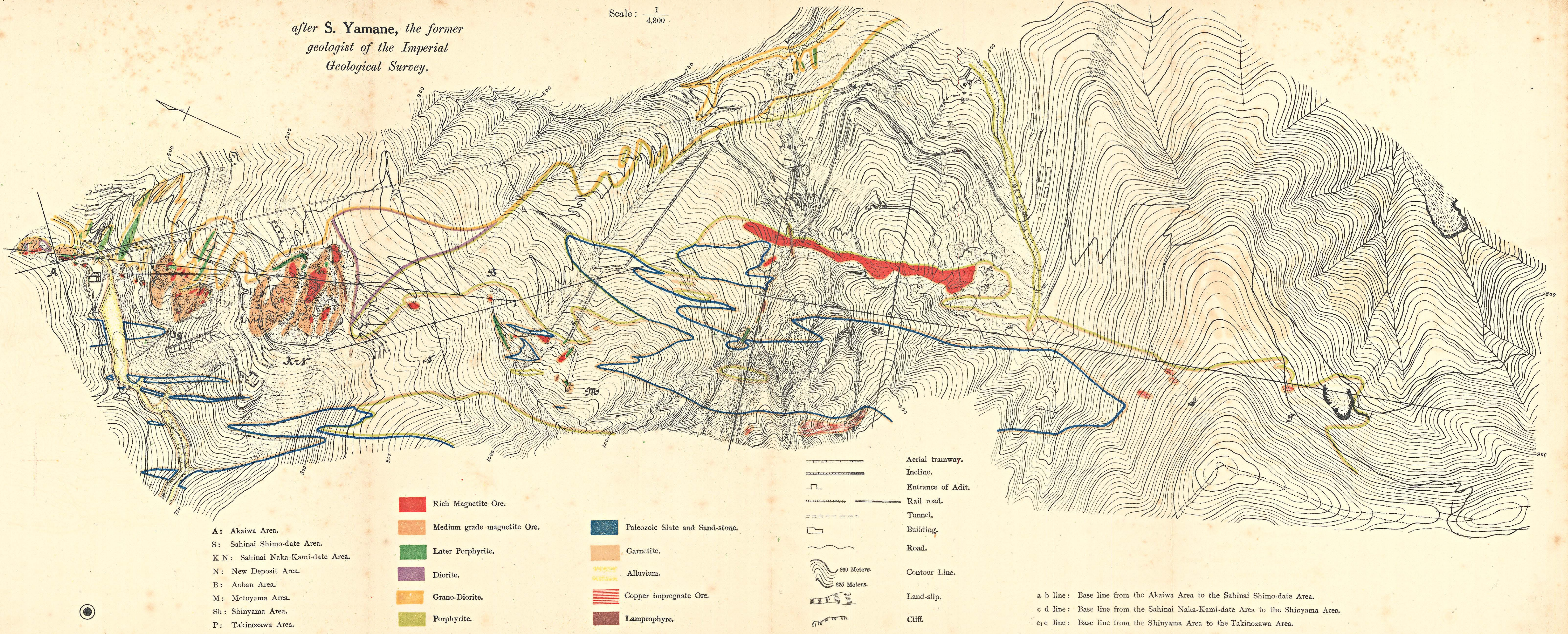
ACKNOWLEDGEMENT.

In conclusion, the writer wishes to express his sincere thanks to Professors G. Yamada and T. Otagawa for their kind advice and encouragement.

The writer gratefully acknowledges the hearty cooperation of the Kamaishi Mining Co. and the operating office of this mine in cheerfully giving all necessary assistance in carrying out the field studies and in permitting the publication of this paper.

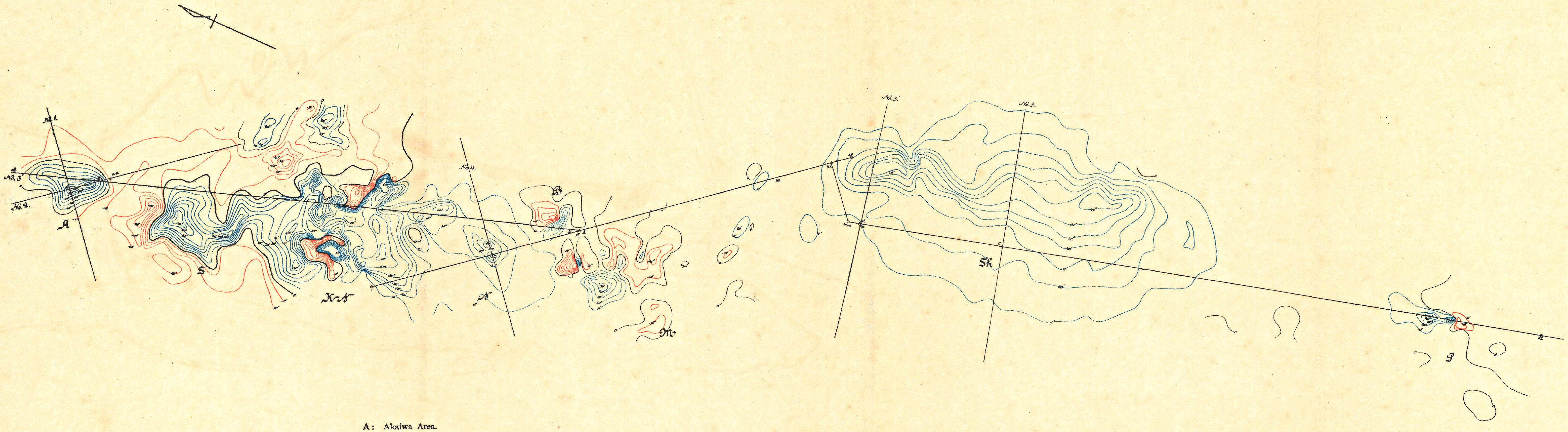
PL. I. *Topographical and geological map of the prospected areas of the Kamaishi Mine.*

Scale : $\frac{1}{4,800}$



PL. II. *Isoclinic chart of the prospected areas of the Kamaishi Mine.*

Scale : $\frac{1}{4,800}$

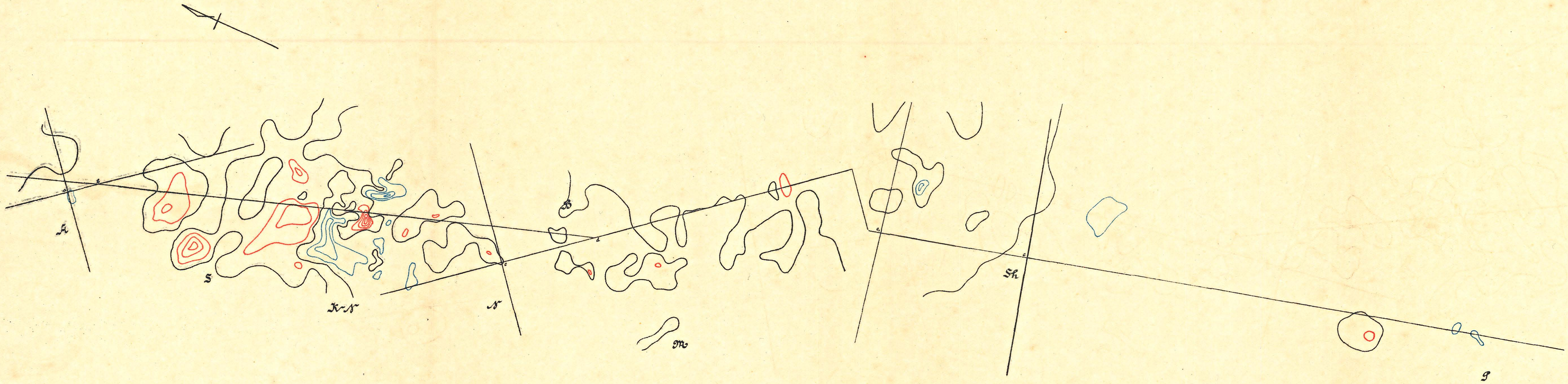


A : Akaiwa Area.
S : Sahinai Shimo-date Area.
K N : Sahinai Naka-Kami-date Area.
N : New Deposit Area.
B : Aoban Area.
M : Motoyama Area.
Sh : Shinyama Area.
P : Takinozawa Area.

a b line : Base line from the Akaiwa Area to the Sahinai Shimo-date Area.
c d line : Base line from the Sahinai Naka-Kami-date Area to the Shinyama Area.
e_1e line : Base line from the Shinyama Area to the Takinozawa Area.

PL. III. *Horizontal intensity chart of the prospected areas of the Kamaishi Mine.*

Scale : $\frac{1}{4,800}$



A : Akaiwa Area.
S : Sahinai Shimo-date Area.
K N : Sahinai Naka-Kami-date Area.
N : New Deposit Area.
B : Aoban Area.
M : Motoyama Area.
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P : Takinozawa Area.

a b line : Base line from the Akaiwa Area to the Sahinai Shimo-date Area.
c d line : Base line from the Sahinai Naka-Kami-date Area to the Shinyama Area.
e_1 e line : Base line from the Shinyama Area to the Takinozawa Area.