A Magnetic Survey of all Japan

carried out,

by Order of the President of the Imperial University,

by

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With Plates VI – XV.

Prefatory Note:—In the Summer of 1887, the Imperial University of Japan at last saw its way to carry into effect a proposal which had been made by me some years previously. Along with Mr. Tanakadate and Messrs. Nagaoka and Imagawa, I was accordingly instructed by the President of the University to make a Magnetic Survey of all Japan within, if possible, an interval of two and a half or three months.

I regret exceedingly that in the preparation of the account which follows I have not had the continued assistance of Mr. Tanakadate.

Before setting out for Scotland in January of this year, however, that gentleman left his own observations all but reduced, along with a full account of his instruments and modes of operation. This account is reproduced, very much in his own words, in Section III of the present paper. That Section, therefore, is peculiarly Mr. Tanakadate's contribution. For the rest—the combining of the observations by the method of Least Squares, the preparing of the Charts, etc.—

I am alone responsible. As a check upon my own calculations, Messrs Ashino, Hirayama, Kano, and Kimura, graduating students in Astronomy, Mathematics, and Physics, kindly went through the labour involved in combining the observations by the method of least squares. Messrs Nagaoka and Imagawa have, of course, always been at hand and have rendered most efficient aid throughout the whole process of reduction. To Mr. Nagaoka especially are my best personal thanks due for the many ways in which he has lightened my labours.—C. G. Knott.

Arrangement of Matter.

The Paper is divided into Five principal Sections, as follows:

Section I.—Historic Retrospect and General Description of the Aim and Methods of the Present Survey.

Section II.—Particular Account of the Equipment and Modes of Operation of the Northern Party.

Section III.—Particular Account of the Equipment and Modes of Operation of the Southern Party.

Section IV.—Final Reduction of the Observations and General Conclusions.

Section V.—Comparison of Results with those of previous Observers.

Section I.

The earliest determination of any of the magnetic elements in Japan was probably made by Inō* about the beginning of the present century. In all the charts which were at that time made by

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* This Inō was certainly a remarkable man. As an Appendix to the present Memoir I give a short biography.

him, he represents the magnetic north as being identical with the true geographical north. Dr. Naumann, in a paper on secular changes of magnetic declination published in the Transactions of the Seismological Society of Japan (Vol V, 1883), has given an interesting discussion of some of Inō's bearings, which seem to differ from the true bearings by amounts that can be explained only on the supposition of considerable local magnetic deviations. That the average value of the Declination over Japan in Inō's days was zero is no doubt true ; but, by assuming his magnet to point always true north and south, Inō appears to have fallen into appreciable error in laying down the positions of certain of the mountains in north Japan. Inō began his geographical survey of Japan in 1800 A. D. and finished it in 1818.

In 1860 Mr. Arai, the present superintendent of the Meteorological Office, measured the magnetic declination at a locality in Yedo (now Tōkyō) and found it to be 3° 11′ West. In 1882 a second determination by the same gentleman gave the value 4° 24′ W. From these two determinations we find by a simple calculation that the mean secular variation of magnetic declination during the interval was 3′. 3 per annum. If we assume this rate to hold throughout the century we find, on reckoning either from 1882 or 1860, that the year of zero declination was 1802. This year falls within the period during which Inō made his survey ; and the concordance between the various observations is, to say the least, striking.

In 1880, Mr. Otto Schütt of the Geological Survey Department made a series of observations of all the elements at certain stations in the south easterly part of Japan.* His furthest north-west point

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* "*Ein Beitrag zur Kenntniss der Magnetischen Erd Kraft*" published in the *Mittheilungen der Deutschen Gesellschaft für Natur und Völkerkunde Ostasiens* (22tes Hest. 1880).

was Oiwake at the base of Asama Yama ; while fully half his stations lay on a route encompassing Fuji Yama. At these latter, however, only the Declination seems to have been measured. The observations bring out very markedly the disturbing effect of volcanoes upon the magnetic characteristics of any district. The horizontal forces measured by Mr. Schütt appear to be on an average about 2 per cent. greater than the values indicated by the observations of the present survey,—a difference which, surely, must be due to instrumental error.

From March 16th to August 20th, 1883, Mr. Wada of the Meteorological Observatory, Tōkyō, took complete hourly observations of the Declination. It may be well to give here the mean hourly values during the whole interval of 5 $^1/_6$ months.

Diurnal Variation.

Hour.	Declination.	Hour.	Declination.	Hour.	Declination.
0 a.m.	4° 16'.71	8 a.m.	4° 13'.46	4 p.m.	4° 18'.72
1 ,,	16.54	9 ,,	13.89	5 ,,	17.57
2 ,,	16.24	10 ,,	15.21	6 ,,	16.68
3 ,,	15.97	11 ,,	17.25	7 ,,	16.79
4 ,,	15.82	12 ,,	18.99	8 ,,	16.93
5 ,,	15.69	1 p.m.	20.16	9 ,,	16.85
6 ,,	14.84	2 ,,	20.39	10 ,,	16.76
7 ,,	13.76	3 ,,	19.96	11 ,,	16.70

The mean value is 4° 16'.75 and the mean diurnal range is 6'.93, These hourly observations of Mr. Wada are the most complete and valuable of the kind that have been made in Japan. It may be remarked that within the last few months the same gentleman has got into fair working order a complete set of Mascart's self-registering magnetographs. Unfortunately they were not ready for use during the months of our survey, so that we have no means of applying even approximate corrections so as to reduce our results to one epoch.

We had hoped before starting to have had the cooperation of the observers at the Naval Observatory, where for some years fairly systematic measurements of the magnetic elements have been made. Since 1883, the declination has been taken regularly every day at 7 a. m.— not a very good hour if probability of steady values or of good means is aimed at. The Horizontal Force and Dip have been taken each twice a month, the former always in the afternoon between 2 p. m. and 5 p. m., and the latter usually immediately thereafter, excepting on a few occasions when it was observed in the morning. The Horizontal Force was measured with the Deflecting Magnet at one distance only. The mean values for the years 1885–6–7 are given here, being calculated from the tables published in the Annual Reports of the Naval Observatory. The Horizontal Force was measured in foot-grain-second units; but the values are here reduced for convenience to the centimetre-gramme-second units.

Mean Annual Values of the Magnetic Elements at the Naval Observatory, Tōkyō.

Year.	Dip.	Horizontal Force.	Declination W.
1885	49° 36′.2	.29098	4° 4′.2
1886	49° 36′.7	.29151	4° 6′.2
1887	49° 39′.4	.29180	4° 7′.1

All show evidence of an annual rate of increase. It will be noticed more especially that the annual rate of change of Declination is much smaller (about 1′.5) than the value deduced from Inō's and Arai's observations.

Another fact deducible from the Naval Observatory Reports is that, so far as can be judged from the limited number of observations made, the magnetic conditions during the summer months of 1887 seem to have kept fairly constant. The several measurements of the Horizontal Force do not differ amongst themselves by so much as 1 in 1000; the Dips agree to within 7′; and the mean monthly declinations to within 3′.

To regard all the observations of the present survey as made at the same epoch is, therefore, in the circumstances, the safest course. Indeed it would be impossible with the data at our command to apply monthly corrections having any claim to probability.

During the years 1882–3 a magnetic survey of Japan was carried out by Messrs. Sekino and Kodari, members of the staff of the Geological Survey Department. Their chart was presented at the International Geological Congress at Berlin in 1885, and is reproduced, along with the observations, in a pamphlet of Dr. Naumann's, entitled "Die Erscheinungen der Erdmagnetismus in ihrer Abhängigkeit vom Bau der Erdrinde" (Stuttgart, 1887). In this pamphlet, which contains a full account of previous magnetic work in Japan, Dr. Naumann calls special attention to the apparent trend of the lines of equal magnetic declination, and suggests a possible relation between their form and the geological structure of the country.

Some three or four year ago, however, an inspection of the results of this first survey and a consideration of the routes chosen convinced me that it would be unsafe to deduce from them any definite conclusions as to the general magnetic characteristics of Japan. For example, with the exception of a few in the neighbourhood of Niigata and Sado Island and a few between longitudes 136° and 138° E., there were no stations along the western coast of Japan. North of latitude 38° N. there was but a single line of stations, confined to the Ōshiū-kai-dō (the Ōshiū High-way). Then the observations were made in two sets, the one in 1882 between August 18th and December 7th, and the other in 1883 between September 10th and

December 24th. The observations were made usually about 9 a.m. or 3 p.m., but not with absolute regularity. Thus to make the results comparable amongst themselves, corrections due to the diurnal, annual, and secular variations ought to be applied. Of these the diurnal variation is the one which will tell most in the circumstances; but I am not aware if any attempt has been made to reduce all the observations (especially of the declination) to one hour.*

Considering then the manner in which Sekino's survey was carried out, we are I think justified in regarding the observations as an insufficient basis for any safe generalization.

It thus appeared that the thing to be desired was a new survey—what might be called a preliminary survey of all Japan, special attention to be paid to the distribution of stations, and the whole to be completed within as short a time as possible. The scheme finally decided upon was briefly as follows:—To form two parties, the one or Northern Party to survey the northern and eastern parts of Japan, including some stations in the Island of Yezo, the other or Southern Party to survey the south-western parts including one or more stations in Korea. This required two sets of instruments. Already the University possessed the ordinary Kew Portable Magnetometer; and with this the Northern Party conducted their survey. The Dipping Needle used by the Northern Party was loaned by the Royal Society Committee; and I take this opportunity of cordially thanking them for their kindness to me personally as well as to the Imperial University of Japan. In the work of the northern party I was ably assisted by Mr. H. Nagaoka, one of the graduates of the year.

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* There seems to be a slight inaccuracy in Dr. Naumann's remarks (See page 8 of the pamphlet) on the reduction of these observations to one hour. I understand from Mr. Sekino that no diurnal correction was applied to the observations made at the northern stations (Aomori and Iwanuma being excepted). At the southern stations corrections were applied in accordance with the three-hourly observations that were being made in Tokyo at the time, the observations being reduced to the mean of the 9 a.m. and 3 p.m. observations.

The southern Party was under the charge of Mr. Tanakadate, who was assisted by Mr. K. Imagawa, an elective student of Physics. This party used a Dipping Needle of the usual Kew pattern (Dover, Charlton Kent, Circle No. 24); but measured the declination and horizontal force by means of an instrument constructed by Mr. Tanakadate himself. This will be fully described further on.

Each Party was completed by the addition of a University servant.

In selecting the stations we aimed at two things; 1st, a fairly good distribution, 2nd, a shunning of local disturbances due to volcanic rocks. As the observations will show, the second condition was extremely difficult to fulfil—indeed practically impossible except by leaving out large tracts of country. This was especially true in the northern part of Japan, where magnetic rocks abound. We always tried however to give volcanoes a wide berth, as these had been shown by previous observers to be great sources of disturbance, especially as regards the declination.

As the tabulated values of the various elements sufficiently indicate by the dates attached the chronological order of the stations, it is enough to give a very general indication of the routes.

The northern Party left Tōkyō on June 20th, 1887, and proceeded by rail and jinrikisha northwards to Shiogama. From here they took boat to Ishinomaki, thence up the river (the Kita-kami-gawa) to Ichinoseki, and on by road to Morioka. Here they turned due east and made over the hills to Miyako, a coast town of considerable importance. A Japanese junk then took them northwards to Kuji, whence by packhorse and jinrikisha they proceeded by Hachinohe to Aomori. From Aomori they crossed to Hakodate, from which as a centre they made expeditions by sea to Sapporo and Nemuro. The return journey was made on the western side of the great central ridge, coast towns such as Akita, Sakata, Niigata, etc., being included as well as the more easily accessible inland stations. The west coast was left at Takata in latitude 37°, and the route continued over the high central mountains to Kōfu down the river (Fuji-kawa) to Hara, and then round the south-eastern coast to Chōshi and so back to Tōkyō.

The southern Party left Tōkyō on June 22nd and proceeded, partly by steamer partly by land, westwards along the South Coast to Osaka. From here an excursion was made to Shikoku; and, after their return to Osaka, they pursued their westerly course by steamer along the northern shores of the Inland Sea. By August 1st they reached Nagasaki, whence they made a trip to Korea and back again, which occupied nearly three weeks. The subsequent route lay round Kyūshū and finally, chiefly by steamer and boat, along the North Coast of the western portion of the main Island. Their last station was Nanao lying on the east side of the peninsula of Noto which projects northward into the Sea of Japan.

The Northern Party completed the prescribed survey by September 3rd. Two other stations, however, at which observations were made on September 25th and 26th, were subsequently included. The distances travelled by road, railway, and water were roughly as follows:

By road	1350 miles.
,, railway	400 ,,
,, water	1700 ,,

The Southern Party completed their work on October 14th. The distances travelled by road, railway, and water were as follows:

By road	1100 miles.
,, railway	300 ,,
,, water	2450 ,,

Almost all the travelling by water accomplished by the Northern Party occurred during six days of their stay in Yezo— otherwise, with a few unimportant exceptions, their route lay wholly overland. On the contrary, the Southern Party accomplished over all nearly a month's travelling by water.

Section II.

The Northern Party, as already mentioned, were provided with the Portable Magnetometer (Elliott Brothers, No. 64) and Dipping Needle of the well-known Kew Pattern (Barrow & Co. London, No. 24). In addition to these was the indispensable Chronometer (Negus Sidereal, No. 1669).

The chronometer was systematically checked by Sextant Observations, usually of the sun, sometimes of a planet or star. When circumstances were favourable, equal altitude observations were taken. Generally, however, this method was impracticable, since the plan of survey decided upon prevented the Party sojourning more than 16 or 17 hours at most of the stations. The chief source of error in determining the time by single altitude observations lay in the somewhat uncertain values of the latitudes and longitudes of many of the stations. Frequently the only choice was to estimate these coordinates from the authoritative maps prepared by the Meteorological and Military departments. For a few important stations (Hakodate, Niigata, etc.) recent determinations of latitude and longitude were available; in other cases Inō's observations were utilised. The clock-error was necessary for the determination of the declination, and the rate for the determination of the horizontal intensity. Any possible error in the latter can affect the value of the horizontal intensity by, at the most, *one* in the 5th significant figure. As the declination was, in the great majority of cases, determined by observation of the azimuth of Polaris, a few seconds' error in the determination of the clock-error was insignificant. Occasionally, however, cloudy weather prevented the observation of Polaris, and in that case the Sun's azimuth was taken instead. It was customary indeed, if the station were reached early enough in the afternoon, to take a Sun's azimuth, in case the night should not prove propitious: and in not a few cases the declination was obtained by both methods. Once or twice, on broken nights, Jupiter, Arcturus, or Spica was utilised for obtaining the true astronomical meridian.

The azimuth was taken in the usual way by means of the small mirror fitted to the Kew instrument. If Polaris or other star were being observed, four transits were taken,—first, two with the star in front of the observer, the mirror being reversed on its Y's between the observations, and then two similarly with the star behind. If the sun were being observed, two transits were taken, one fore and one back, the mirror being in each case reversed between the contacts. In this way the small errors of adjustment were taken proper account of.

Immediately before or immediately after the transit observations, the magnetic declination was taken, the magnet being always viewed in the inverted as well as in the proper position. During the whole survey, the point on the scale corresponding to the magnetic axis never varied by as much as the tenth of a small division.

On two occasions only did continued wet weather prevent the azimuth observation being made—namely at Ichinoseki (No. 7) and at Ueda (No. 37)

In the final working up of the results only those stations are chosen at which the azimuth was obtained by means of Polaris observations. In all except one case, these Polaris observations were made between the hours of 8 p.m. and 12 p.m. local time: in that one case (at Sekiyama No 36) they were made at 3 a.m. Now it is just at these hours that the magnetic declination is subject to the slowest change and has besides a value which can hardly differ more than 1′ of arc from the mean value for the day. Where a complete series of hourly abservations throughout a whole day is out of the question, observations of declination made a little before midnight will give a fairly good approximation to the true mean value. When the sun was used for finding the azimuth, it was usually before 8 a.m. or after 4 p.m. On one occasion, however, (at Ebisu, No. 33) circumstances compelled a transit of the sun to be taken at about noon.

The dip and horizontal force observations were usually made at early morning before eight o'clock or in the afternoon after four. As there was but one tripod, it was necessary to remove the one instrument so as to make way for the other. It was found more convenient generally to observe the dip first, and then make the deflection and vibration experiments. If necessary a declination was taken and the azimuth obtained as usual from two transits of the sun. If it was a morning observation and if the declination had been obtained by means of Polaris the night before, this final declination was dispensed with. If it was an afternoon observation, however, and the sun visible, a solar azimuth and magnetic declination were always taken, to guard against the mischance of a cloudy night. The dip and magnetometer observations were make by both observers alternating. Thus the one who observed the dip during this set of observations would operate with the magnetometer during the next set, and *vice versâ*. The one who was not observing recorded and kept time.

The sextant observations were all undertaken by Mr. Nagaoka, who had carefully trained himself to the work before the Expedition started. The sextant used was one of Browning's (London), No. 6295.

The travelling was usually effected by means of jinrikisha; and there cannot be the least doubt that the rattling and jolting did not increase the steadiness of the chronometer. Frequent sextant observations were therefore absolutely necessary, so that a fairly accurate value of the mean daily rate could be obtained. There always must be, however, a certain doubt as to whether the mean rate so obtained is really the true rate when the chronometer is resting. It is highly probable, in fact, that irregularities must result from such a jolting as *jinrikisha* give; we can only hope that these irregularities balance each other in the long run.

The results obtained will be discussed along with the observations of the Southern Party. Their mode of operating was in many details quite different from the mode adopted by the Northern Party, and calls for a full account both of instruments and methods.

The following account is drawn up, almost in his very words, from Mr. Tanakadate's own descriptive notes.

Section III.

With the Exception of the theodolite, which was fitted up both for transit and for magnetometric observations, the South Party resembled the North Party in its equipment. A chronometer, (Negus Sidereal, 1629), a dip circle, a box of tools and necessary books, and a tent, completed the out-fit.

The dip and vibration Experiments were always carried out by Mr. Imagawa; while Mr. Tanakadate undertook the chronometer rating, and the declination and deflection experiments. Usually the one acted clerk to the other, noting down what the latter read off. In the vibration experiments, the observer signalled the vibrations, and the instants of signal were timed by Mr. Tanakadate from the chronometer and noted down. In the transit-observations, however, Mr. Tanakadate worked alone by the usual eye and ear method.

The object aimed at being to obtain a general magnetic survey of Japan, it was advisable as far as possible to eliminate local and diurnal disturbances. The stations had all originally been chosen after a careful study of the distribution of volcanoes throughout the country. If further we assume that all mountains are a possible source of disturbance—of underground sources of disturbance it is impossible of course to take any preliminary account—the following rough rule, which guided us in most cases, will probably be found useful:—A station should be so placed that no mountain as seen from it shall subtend a vertical visual angle greater than 5°. Thus, let there be a mass of magnetic substances of volume v and susceptibility k at a distance r from the station; and suppose that this mass is a cube* of height h. Then, if I be the intensity of the magnetic field in which the mass is placed, the disturbance at the station will be $k\,I\,v/r \doteq k\,I\,(h/r)^3 = k\,I\tan^3\theta$, where θ is the visual angle. Take $I = \cdot 4$, $k = 10$ (bad iron), $\theta = 5°$, and the value of the disturbance comes out ·0027. In the most favoured circumstances, however, it is highly improbable that more than 1 or 2 p. c. of iron is present in the substance of the mountain. Hence we may safely assume that a mountain at such a distance will only affect the 5th decimal place. In a few cases, such as Wakwan (No. 62) Hagi (No. 72) Hamada (No. 73), we were compelled by circumstances to break the above rule; but in no case did the visual angle amount to 10°.

The station was usually chosen in an open field within 1 or 2 kilometres of some village or town. Occasionally a cotton field was cleared sufficiently to permit the tent to be pitched.

On a few occasions dip observations were made at two or three spots in the vicinity of the chosen site; and if the values came out

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* Such an assumption gives of course a higher value than is likely to be. [C. G. K.]

within the limits of errors of observation, the place was assumed to be free from local disturbance. At two stations, Hamada (No. 73) and Maizuru (No. 78), this dip test was made after the regular series of magnetometer observations had been completed. At the former station, the values differed by as much as 20′, at the latter by 3′. From the nature of the environment such discrepancies were just what might have been expected.

At Minabe (No. 59) we first made a series of hourly observations of the declination; and this proved such an easy matter with the form of declinometer used that at all subsequent stations declination observations were made in sufficient number to obtain a diurnal curve. Excepting when the number of distinct observations was less than five, these diurnal variations are shown in diagram (Plates XII to XV). The general smoothness of the curves is a sufficient proof of the efficiency of the electromagnetic declinometer, to be described below.

The diurnal variation of the Horizontal Intensity was observed twice, namely, at Hiroshima (No 61) on July 29th, and at Miyazaki (No. 69) in September 1st. The values are all given in the tables at the end of the memoir. A comparison of the two sets of observations shows how very dissimilar are the measured variations of the horizontal force in the two cases, although the relation between the temperature and magnetic moment of the bar magnet comes out very similar in the two cases. From these results it is possible to obtain in the usual form an expression for the Moment of the magnet in terms of the temperature.

On two occasions, at Minabe (No. 59) on July 22nd, and at Shioya (No 80) on October 5th, a series of observations of the dip was made throughout the day. These gave nothing definite (see complete list in Table) although the variation of declination on these days was as usual.

At each place, three observations at least of all the elements were made, one in the morning, one near noon, and one in the evening. In the final tabulation, the arithmetic means of the dips and horizontal intensities are given. The mean declination is however obtained by a different method. From the complete observations made at Hagi (No. 72) and Hamada (No. 73), means were taken by summing the 24 ordinates corresponding to each hour of the civil time. In both cases this mean came out lower than half the sum of the principal maximum and principal minimum by one-tenth their difference. Thus if d, d' be the maximum and minimum respectively, the true mean was found to be

$$\frac{d+d'}{2}-\frac{d-d'}{10}$$

This rule is applied to all the observations. In several cases the maximum and minimum are only inferred from the neighbouring points.*

The magnetometer used by the South Party presents many points of novelty, both in construction and in mode of using. It combines the ordinary apparatus for the measurement of the horizontal force with a special form of declinometer invented by Mr. Tanakadate and described in a paper published in the *Proceedings of the Royal Society of Edinburgh* (1884–6).† The whole apparatus is built up upon a theodolite, which in its ordinary form as an alt-azimuth instrument serves for all the astronomical observations necessary for finding the latitude, longitude, and meridian of the station, and the true sidereal time. The instrument is shown in Plate VI, mounted for its

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* A glance at the curves will show that this method gives a mean in neither case differing by as much as half a minute from the value of the declination as observed between the hours of 9 and 12 p. m., so that (if we disregard the possibility of the existence of a magnetic storm at these hours) the methods adopted by the North and South Parties to obtain a good mean declination give quite concordant results. [C. G. K]

† Also in the *Rigakukyōkwa Zasshi* (Vol. II).

several purposes. It consists essentially of a theodolite, a mirror magnetometer, a declination coil, a small galvanic cell, a resistance box, a vibration case, a deflection bar, and a bar magnet. At any given station, the base of the theodolite is fixed and adjusted once for all, and, if possible, never changed throughout the whole series of experiments. Only in this way can a really satisfactory series of diurnal observations of the declination be made. That this might be done, a second tripod was necessary for mounting the dipping circle and vibration apparatus.*

The instruments will be described (1) as a Declinometer, (2) as an apparatus for measuring the horizontal force, (3) as an alt-azimuth or transit instrument for determining the astronomical meridian, the clock error, and latitude.

The theodolite, which formed the basis of the whole, was one of Negretti and Zambra's construction. To fit this up as a magnetometer, the compass needle had first to be removed, and into the hollow space left in the centre of the theodolite base, was fitted what may be called a magnetometer stage. In figures 1 and 5, Plate VI., this stage may be seen, and its form is specially will shown in figure 5. In the subjoined cut, it is shown in clearer detail. The chief points aimed at in its construction were ease of adjustment and facilities for clamping it either to the base of the theodolite or to the Y's. The disk-shaped base of the stage with its circumferential ring-clamp (*c*) nearly fitted the circular cavity left after removal of the theodolite compass needle. This ring-clamp, when tightened, abutted against the sides of the receptacle, and fixed the whole stage to the Y's of the theodolite. When loosened, its two halves collapsed upon the disk-shaped base of the stage, which then simply rested, unclamped, upon the plat-

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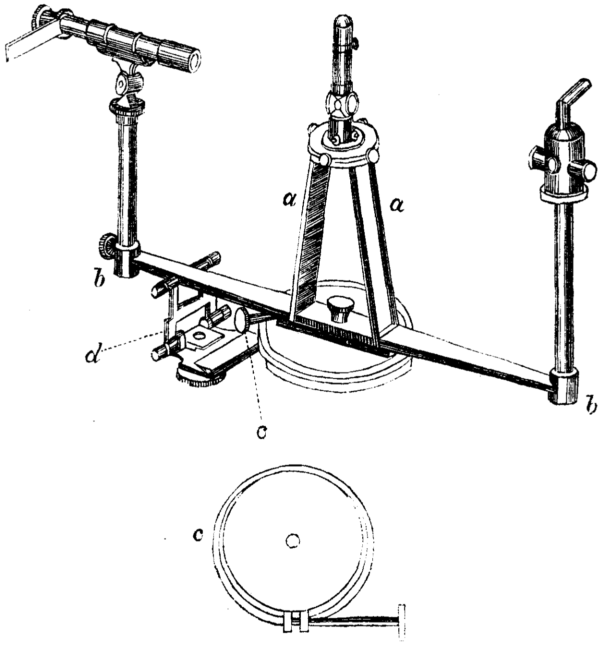
* A second tripod might will be added to the Kew set of instruments, and a distinct saving of time be effected in making a series of observations throughout the day. [C. G. K.]

form of the theodolite. The central part of the stage (*a a*) rose up to a height which fell somewhat short of the level of the Y's, and ended in a socket intended for the insertion of the base of the magnetometer proper. The last essential part of the stage was a stout brass bar (*b b*) running through between the Y pillars. From its ends rose uprights, to one of which was fixed the telescope and scale used in the readings, and to the other a lamp for night work, which also played the rôle of counterpoise. The fixing of the stage to the base of the theodolite instead of to the Y's was effected by means of a clamp (*d*) attached to the brass bar and attachable to the rim of the theodolite. In this way the stage could be clamped to either base or Y's, singly or together, as occasion might require.

Fig. 1.

(⅛ natural size).



(⅛ natural size).

The magnetometer case (Plate VI, fig. 2, and Plate VII, fig. 3), when set in position on the central ring socket of the stage was centred by means of four adjusting screws. The magnetometer is shown dissected on Plate VII. Figures 1 and 2 show the magnet and mirror suspension. The magnet (Fig. 2. *m*) is a small hollow cylinder piercing the mirror centrally perpendicular to its plane. Mirror and magnet are fastened to an aluminium stem (*a a'*), whose lower end is broadened, so that it may when necessary be securely gripped by the vice *s s'* shown (magnified) in figures 5 and 6 (Plate VII).

The suspension was by means of a spider line. Several experiments were made to test the torsional effect of such a suspension. A full account of these was given in the Rigaku Kyō Kwai Zasshi (Vol. II, p. 108); but it will suffice to say here that the torsion due to a twist of 180° on a spider line of the length indicated cannot cause an error of 1″ of arc in the orientation of a suspended magnet. The spider-line was drawn out directly from the living animal, and a suitable length attached to the mirror and the disk *d* (Figs. 1 and 2), from which the magnet and mirror were to be suspended.* The disk *d* is a fan-shaped horn damper, whose weight is nearly the same as that of the mirror and magnet, and whose purpose, as such, is to remove all torsion out of the spider line, after the suspension has been carefully mounted in the case. The case consists of four parts, as follows (See Plate VII, fig. 3). (1) The top cover—a glass tube capped by a bell glass, below which is a shelf (*b*) with a triangular hole and a slit wide enough to let the horn damper pass through easily. (2) The glass tube, on which the top cover is slipped, and to which it is fixed by a clamp (*c*) at any height within certain limits,

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* There cannot be the least doubt that the spider-line is *the* perfect mode of suspension of a small light mirror, such as is used in delicate galvanometers and magnetometers. The zero point *never* changes, so far at least as the suspension is concerned. [C. G. K.]

the height being adjusted to suit exactly the length of the suspension. (3) The magnet chamber—a brass tube with two circular glass windows, a little larger than the magnet-mirror, and facing usually north and south. Two small windows are also made facing east and west, so that, in the process of centering, the middle of the magnet can be seen from these directions. (4) The vice, which grips the stem (*a'*) when the magnetometer is being carried about. This vice occupies the lowest part of the magnetometer casing, lying inside the part *n n* shown in Figure 3. The details of its construction are indicated in Figures 4, 5, 6 (Plate VII). Two brass springs *ss' ss'* are fixed below at *s's'*. A tube *tt*, with two side openings through which the springs bulge out when the vice is to be released, can be made to slide up and down inside the magnetometer case. When this perforated tube is down (Fig. 6) the vice closes ; when it is up (Fig. 5) the vice opens. The vice-springs grip the stem *a'* of the suspended magnet. When they are opening so as to leave the magnet free, there is considerable risk that the stem may stick to one of them ; and to free it by a jerk or tap would be liable to break the delicate suspension. To obviate this, two thin strips of brass (*pp' pp'*) are fixed to the sliding tube at *p'p'*, and are so adjusted that their upper sharpened edges press always against the inside surface of the vice-springs. Thus, as the tube *tt* slips up, the ends *pp* glide along the inner faces of the springs and gently detach the stem, should it chance to be sticking to either arm of the vice. The up and down motion of the sliding tube is effected by means of a special combination of rack and screw. Into a rectangular socket cut in the sliding tube, a small piece of brass (*r*, Fig. 4) fits. This piece of brass, which must be inserted after the sliding tube has been slipped into position, is toothed on its outward facing surface so as to fit into a screw cut internally on the ring *nn* (Figs. 3 and 4.). A vertical slit, cut in the tube of the magnetometer case, serves as a guiding slot in which the small toothed piece moves. The ring *nn* is milled on the outer surface. When it is turned by the finger, the toothed piece in gearing with it rises or falls according to the direction of turning; and with it the sliding tube also moves, and opens or closes the vice.

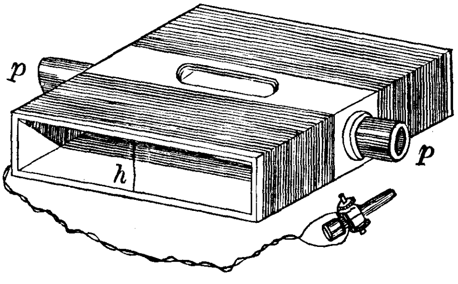
The magnetometer case expands below into a disk (*ll*), with a hemispherical knob on its lower surface. This knob rests in a tetrahedral hole cut in the base-plate. By screws passing through the disk and bearing on the base plate, the magnetometer case can easily be adjusted to a true verticality. (See Fig. 3, Plate VII, also Fig. 2, Plate VI).

To mount the magnet and damper in the case, after they have been connected by the spider-line, the top-cover must first be unclamped and removed. The small screw, *b*, is uncrewed a little so as to leave the triangular space or notch in the shelf quite open. The top is then held inverted in the one hand; and with the other the stem *a'* is carefully lifted until the damper hangs free. The damper is then dropped through the slit, the magnet and mirror carefully deposited on the table near by, and the screw *b* tightened so as to jam the "handle" of the fan-shaped damper up against the sides of the notch. The top piece is now held up in its proper position, so that the magnet and mirror hang freely from it. These are next gently lowered into the tube-case of the magnetometer, and the top is clamped in the position which makes the mirror hang level with the circular windows. The stem *a'* will now hang in its proper position between the arms of the vice, which should be opened before these operations are begun. If the hanging is done carefully by an experienced hand there should be little or no twist on the spider line. Any twist can however be easily removed by gripping the stem below the magnet with the vice, inverting the magnetometer case, unscrewing the small screw *b*, and so leaving the damper to hang freely. It is for this reason indeed that the fan-shaped body, *d*, is called by that name. For, in virtue of its shape, it very speedily comes to approximate rest as it swings in the small space between the bell-glass and the shelf, and of course comes to final rest only when all twist has been taken out of the spider line. If the suspension is left for a few hours in this position, say overnight, we are safe in assuming that the twist has been practically eliminated. A slight tip will now bring the handle of the damper into the notch, where it is securely clamped by screwing the screw *b* home. The magnetometer, when placed erect, is now ready for use. This magnetometer is an essential part of the apparatus required both for the declination and deflection experiments. The Declinometer will now be described.

The peculiar feature of the electromagnetic declinometer is coil of wire of a convenient form, whose axis can by a simple experimental method be accurately made to coincide with the magnetic meridian. The coil is shown in Plate VI, Fig. 1, and also in the annexed cut. It is wound on a flat rectangular frame of brass in two separate parts, a certain portion in the middle being left vacant. Looked at from above, it is square. Two pivots *p p* project from the middle of the sides in a direction perpendicular to the axis of the coil. These pivots are hollow, and are made of the same external diameter as those of the telescope belonging to the theodolite. The upper and lower surfaces are pierced so as to allow the magnetometer to project above the coil. The middle part of the frame where no wire is coiled is equal to the height of the frame and

Fig. 2.

(¼ natural size).



one-fifth its breadth. These dimensions were carefully calculated * so as to make the error due to an excentric position of the magnetometer a minimum.

To bring the coil into adjustment, it is necessary to operate as follows. Place the stage and magnetometer on the theodolite, and mount the coil with its pivots resting on the Y's (Plate VI, fig. 1). Adjust the Y's into an approximate east and west direction by sighting the freely hanging mirror edge-on through the pivot cores. Lay the coil horizontal, so that the ends of the coil now face north and south. On one of these ends, which is partly closed, a small pin-hole is made accurately at the centre. On the other end, exactly opposite it, a wire (*h* in the cut) is stretched. When this wire is sighted through the pin-hole and *through the small hollow magnet*, then we know that the magnet is truly centred with regard to the coil. If the wire cannot so be seen, the magnetometer must be adjusted in position by means of the screws provided in the ring socket in which the base of the magnetometer rests. If every thing is in accurate adjustment, a reversal of the coil, so that what was at first the east pivot becomes west and *vice versâ*, will still leave the pin-hole, magnet, and wire in one and the same line. If it is not so, then the pin-hole and wire are at fault. It is evident, however, that once the adjustment is made, it is made once for all as far as the coil is concerned—that is until the wire should give way. The magnetometer being thus centred east and west, it must next be centred north and south. This is done with sufficient accuracy by sighting the magnet through the hollow pivot of the coil, and working the north-and-south adjusting screws until the magnet hangs central.

If the small telescope with attached scale and lamp-counterpoise

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* The details of the calculation are given in the Paper in the *Proceedings of the Royal Society of Edinburgh* (1884-6) already referred to.

are now mounted in position (see Plate VI, Fig. 1), everything is ready for making a determination of the magnetic meridian. The stage and all its belongings are clamped to the base of the theodolite and rendered quite free of the Y's; and, consequently, the coil can be turned round independent of everything else. The magnetometer stage is adjusted until some convenient division on the scale, as reflected from the magnet mirror, is brought to coincidence with the cross-wire of the observing telescope.

The coil is now put in circuit with a small cell, which is shown in Plate VI, Fig. 1, hanging from the centre of the theodolite. This is done by putting the terminal double-plug (see small cut on page 184) into one of the holes of the resistance box, whose terminals (see Plate VI figure 1) are joined to the poles of the battery. At the first trial the direction of the current should be such as to make the magnetic field due to the current in the coil have the same (general) direction as that of the earth. This is readily judged of by the quickened movement of the magnet. The reflected image of the scale will in general be seen to move. With the current always on, let the azimuth of the coil be shifted until the originally observed reading of the scale is brought back again to the cross-wires. Since the magnetometer and telescope have been absolutely fixed in position during the whole operation, this gives to the first approximation the direction of the declination. The current in now reversed by simply turning the double-plug half-way round in its hole. In general, the result of this will be that the image of the zero scale reading will slowly move to one or other side of the cross-wire. The resistance in circuit is then adjusted until the current is such as to cause the time of oscillation of the magnet to be some three or four times as long as that under the earth's force alone. The original division of the scale is again brought back to the cross wire by careful adjustment of the azimuth of the coil. If the current is now broken and the scale image does not shift, it is certain that the magnetic axis of the coil lies in the magnetic meridian. The reading on the theodolite gives its azimuth.

During the series of operations, however, the magnetic meridian might have changed—during the forenoon, indeed, the change is quite perceptible in five minutes. Or, the magnetometer stage might itself have got shifted somewhat in the process of adjustment. In either of these cases there will be a shifting in the scale image at the instant of making the final break in the circuit. By adjusting, however, until at the final break the scale image remains absolutely unaffected, we know that at that instant, which should be noted on the chronometer, the magnetic meridian is determined. An exactly similar observation must be made with the coil reversed as regards east and west; and then the mean of the two readings so obtained may be assumed to give the declination at that instant corresponding to the mean of the two instants of adjustment, quite independent of any error resulting from any (slight) deviation from perpendicularity between the axis of the pivots and the line of magnetic force at the centre of the coil due to the current in it. An experienced hand can make the interval between the two final adjustments as small as 2½ minutes.

For the determination of the horizontal force, the declinometer coil must be removed and in its place a deflection bar substituted as show in figure 5, Plate VI. This bar is made of brass and has a V-groove on its upper surface—or rather two V-grooves extending the one to the east and the other to the west, when the instrument is mounted ready for use. Where the bar rests on the Y's, it is made in the form of a semi-cylinder—the upper surface being flat, the lower having the same curvature as the pivots of the theodolite telescope and the declinometer coil. Between the Y's, the bar swells out into an oblate ring, through which the magnetometer projects. A semi-circular groove is cut in front of the ring, so that the magnet-mirror can be sighted by the small telescope. Over the brass ring and surrounding the magnetometer a ring of wood is placed, with three semi-circular grooves cut in it at suitable places. It facilitates observation by cutting away all extraneous light, while at the same time the central groove in combination with the groove on the brass ring gives a clear front to the mirror. The side grooves are needed during night observations to allow the lamp-light to illuminate the scale. On the V-groove of the bar there are four stops, two on each side of the centre. The deflection magnet rests in the groove, and the stops are so placed that the two distances of the magnet from the centre are obtained simply by slipping the magnet along the groove from one stop to the other, without having to lift it out. The stops are placed so as to make the ratio of the two distances the best possible, according to the usual rule.

The instrument is obviously available for use either according to the method of sines or the method of tangents. The former method is the preferable one; and, in using it, it is necessary to clamp the stage to the Y's, and free it from the base of the theodolite. The operations are then conducted exactly as with the Kew Instrument. The temperature of the bar is measured by means of a thermometer placed on the V-groove outside the further stop. It is advisable to dust with a small brush the surfaces of the magnet and stop just before they are brought together. The chronometer time is taken as the final deflection is adjusted. The beginning of the experiment is given by the first time record in the vibration experiment, which it was found most convenient to make first. The mean of these times is taken as the time corresponding to the value of the horizontal force as finally deduced.

The vibration experiment is made in a vibration box somewhat similar in construction to the one used in the Kew Instrument (See Plate VI, Fig. 3). It is mounted on a second tripod, so that the magnetometer stage need never be removed until the theodolite has to be used for the astronomical observations. The magnet employed during the survey was a solid steel bar of square section and polished on all sides. Its length was 7·0024 cms. and its breadth ·803 cms. at 0° C. Its mass was 35·061 grammes, and its moment of inertia 145·15 (cm^2. gr.) at 0° C. It was suspended by two loops of silk from the end of a silk fibre freed from twist in the usual way by means of a brass weight as heavy as the magnet. To get the magnet horizontal, the base of the vibration case was first levelled by means of a spirit level. The magnet was then lowered down till it just rested on the floor. Then, by raising it gently, the observer could readily tell whether or not it was horizontal by the way in which it left the floor. A few slight taps with the brush on the dipping end, if dipping end there was, and a repetition of the same operation until the magnet left the floor as a whole simultaneously, were sufficient to make it practically horizontal. It was then raised to the height of the side window in the box and steadied by means of a fine brush. The telescope was adjusted and focussed till a clear image of the scale was seen reflected from the polished side of the magnet. A horizontal swing of about half a degree was given to the magnet by the approach and removal of a screw-driver; and the experiment conducted in the usual way. The observer signalled the instants of transit of the middle point of the swing, and these were noted down by the recorder, who was posted at the other extremity of the tent with the chronometer. The eye and ear method is no doubt more accurate, the observer himself recording the transits; but to this there is the objection that the chronometer must be brought close up to where the observer is, thereby producing a possible magnetic disturbance. A specimen sheet is here reproduced of a single complete experiment for determining the horizontal force. The torsion and arc corrections are applied in the usual way; and the time correction is applied so as to reduce the time-unit at once to the mean solar second.

As already mentioned, it was found most convenient to take the vibration experiment before the deflection experiment, thereby saving the time necessary for the adjustment of the swinging magnet. From the first recorded swing to the last deflection adjustment the whole experiment took 23 minutes. *

The observations of Dip were made in the usual way. The magnetization of the needle was reversed by means of the large magnets that form an essential part of the apparatus. It might be remarked, however, that, if the electromagnetic declinometer is used, it would be much more convenient for the observer to provide himself with a suitable coil for reversing the magnetization of the dipping needle. The large magnets would not then be required, and the necessity done away with of constantly removing them 15 or 20 yards from the tent whenever a declination experiment was to be made. For, closed though these magnets are, they cause an appreciable disturbance within a distance of a few yards from the magnetometer.

On the occasions on which a series of observations of the dip

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* It is impossible, I believe, to go through these operations with the Kew Instrument so rapidly as this. The gain of time with Mr. Tanakadate's instrument seems to be in the deflection experiment, in which the small deflected magnet is much more quickly damped than is possible with the comparatively large magnet used in the Kew Instrument. In my opinion there is quite an unnecessary amount of manipulation required in using the Kew Magnetometer as at present constructed. A small magnet mounted in a manner similar to Mr. Tanakadate's hardly ever requires a renewal of the suspension line, delicate though that is. It requires but to be placed in position, and the deflection experiments begun. A slight modification in this direction would enable us to dispense with the deflection box altogether, and considerably shorten the time required to make a deflection experiment. [C. G. K.]

was taken, the azimuth was adjusted every third observation. This is certainly sufficient; since, as is well known, a small error in the azimuth causes an error in the dip of a higher order of small quantity. *

To make the observations that are necessary for finding the astronomical meridian, all the magnetometric pieces of apparatus must be dismantled and the theodolite telescope mounted in position. (See Plate VI, Fig 4.) The observations were made as much as possible on stars, since it is always objectionable to expose such an instrument to direct solar light and heat. Then, again, there is more chance of instrumental error when the theodolite is turned into the prime vertical, inasmuch as all the declination observations in this country happen to be made near the meridian.

In general the perfection of observation aimed at was to obtain transits of eight conveniently destributed stars across an approximate meridian, and, by combining these observations, deduce the values of the four unknown quantities,—the clock error, the two azimuth errors, and the collimation error.

The approximate meridian was found by taking two transits of Polaris, the telescope being reversed by turning the Y's through 180° between the two transits. The mean of the two azimuths read was taken as corresponding to the instant midway between the noted

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* The following proof, from its simplicity, may be of interest. Let V be the vertical, H the horizontal component, and θ the dip; then $\tan\theta = V/H$. If the plane of the needle makes a small angle a with the magnetic meridian, the apparent dip θ' is given by the equation

$$\tan\theta' = \frac{V}{H\cos a} = \frac{V}{H}\left(1 + \frac{a^2}{2} + \ldots\ldots\right) = \tan\theta + \tan\theta.\frac{a^2}{2}$$

$$\text{or, } d(\tan\theta) = -\tan\theta.\frac{a^2}{2}$$

$$\text{which gives } d\theta = -\sin 2\theta.\frac{a^2}{4}$$

If we put $a = 10'$, which is roughly the range of the diurnal variation, we find for the greatest possible value of $d\theta$, the utterly insignificant quantity 0″·4.

times of transit. By applying a clock error reckoned from the preceding set of observations, we obtained an approximate hour angle; and from this with assumed latitude it was easy calculating the astronomical azimuth of Polaris. The finding of this azimuth was much facilitated by the use of a table of Polaris azimuths, previously prepared, and tabulated with latitudes and hour angles as arguments. On applying the level correction, we have the azimuth to a first approximation. This value was used to set the instrument in the approximate meridian.

From the list of stars given in the Berlin *Yahrbuch*, four stars were now selected—if possible, two near the zenith and two near the horizon, and lying in pairs on each side of the zenith. Each star's transit was observed across three of the micrometer wires. Immediately after the last transit was taken the star was bisected by the horizontal wire and the zenith distance read off on the vertical circle. The striding level was read twice, once with the telescope pointing north, and once with it pointing south. The level in connection with the vertical circle was also observed, the telescope being then set to zero reading.

The azimuth was now read, and the Y's turned through 180°. Another set of four stars was chosen and their transits observed in the same way.

On a fine night, from 1½ to 2 hours' observations sufficed for carrying out the complete transits of the eight stars; and from these the collimation, azimuth, and clock errors could be calculated. A similar set at the same spot the next night furnished the means of calculating the clock rate.

On one occasion, at Miyazaki (No. 69) the clock rate was obtained by making two sets of observations not quite 8 hours apart—the one set in the evening, the other set in the morning.

From the Zenith distances of the observed stars, the latitude of the place could be calculated by applying the usual corrections—reduction to the meridian and refraction.

When a sufficient number of stars could not be observed, the first observation of Polaris was utilized for the purpose of obtaining the azimuth to a closer approximation, the newly evaluated clock error and latitude being employed, and the calculation made without the use of the Polaris azimuth table.

At four stations (Nos. 52, 56, 67, 71) observations of the sun alone were possible. In these cases, the local time was determined from altitude observations, and the azimuth from prime vertical transits.

On two occasions, at stations (62) and (80), Polaris was observed through clouds and the clock error was assumed.

Section IV.

General Results of the Survey.

I now pass to the consideration of the principal results obtained.

There were 81 stations in all, of which 50 belonged to the Northern Party, and 32 to the Southern, the recreation ground of the Imperial University being a common station to both Parties. The Parties might with equal accuracy be termed the Eastern and Western Parties, inasmuch as all the stations of the former lie to the east of the longitude line 138° E., and (with the exception of three, including Tokyo) the stations of the latter lie to the west of that line. Roughly speaking, this line separates the main island of Japan into two regions markedly different as to their geological characters. Compared to the Western portion, the Eastern and Northern portion is highly volcanic. Here, consequently, considerable magnetic disturbances are to be looked for. It is the more important, then, to have as many different stations as possible, so that in the final combining of the results a good selection may be made. This conviction grew upon us more and more as the work progressed, as may be inferred from the less scattered distribution of the later stations as compared with that of the earlier ones. Indeed, only by a much closer distribution of stations can we hope to make out anything very definite regarding the magnetic characteristics of the north-east parts of Japan. In the subjoined table are given the stations with their latitudes and longitudes. The dates on which the observations were made will be found in the detailed tables forming Appendix B to the paper. The stations are numbered from 1 up to 81; Nos. 1 to 50 being the Northern Party's stations arranged chronologically, and Nos. 50 to 81 the Southern Party's similarly arranged. In the other tables to be given here, the stations will usually be represented by their numbers.

After the individual observations were finally reduced, rough charts were prepared showing the broad features of the various isomagnetic lines. From these it was easy to tell where the principal centres of disturbance lay. Guided by this and other considerations, a selection of 50 points was made. These are indicated in the four succeeding tables by being represented in thicker type. The coordinates of the Mean Station of these fifty chosen stations are:—

Latitude...........	36° 30′ N.
Longitude.........	137° 9′ E.

Referred to this Mean Station as origin, the four sets of fifty observations—representing respectively the Dip, the Horizontal Force, the Total Force, and the Declination—were combined by the method of Least Squares. The results will be discussed in the order just named. For the sake of showing how far the formula deduced from the 50 chosen stations is applicable to the remaining 31, the various tables

Table I.

The Co-ordinates of the Stations.

	Station.	Latitude.	Longitude.		Station.	Latitude.	Longitude.
		° ′ ″	° ′ ″			° ′ ″	° ′ ″
1.	Ishibashi	36 25 54	139 52 15	42.	Ōtsu	35 15 48	139 42 30
2.	Yabuki	37 10 48	140 18 15	43.	Hōjō	35 0 22	139 53 0
3.	Matsukawa	37 47 42	140 23 45	44.	Katsuura	35 8 0	140 19 15
4.	Shiraishi	37 59 18	140 33 15	45.	Tōgane	35 33 30	140 21 45
5.	Shiogama	38 19 38	141 2 15	46.	Chōshi	35 43 0	140 50 30
6.	Ishinomaki	38 26 8	141 19 30	47.	Kioroshi	35 50 48	140 9 30
7.	Ichinoseki	38 55 30	141 2 24	48.	Shimmachi	36 17 12	139 7 0
8.	Hanamaki	39 25 0	141 1 45	49.	Ōmiya	35 54 18	139 36 30
9.	Morioka	39 43 0	141 8 0	50.	Tōkyō	35 42 35	139 46 0
10.	Miyako	39 38 48	141 59 15	51.	Shimoda	34 40 16	138 57 15
11.	Kuji	40 11 17	141 48 0	52.	Shimizu	35 0 10	138 30 15
12.	Hachinohe	40 30 12	141 29 30	53.	Nagoya	35 10 40	136 55 0
13.	Gonohe	40 33 0	121 15 15	54.	Kamiyashiro	34 30 25	136 45 15
14.	Nobechi	40 52 19	141 8 15	55.	Nagahama	35 23 48	136 46 0
15.	Aomori	40 51 5	140 44 45	56.	Hyōgo	34 39 20	136 10 30
16.	Hakodate	41 46 30	140 44 30	57.	Tokushima	34 4 0	134 35 0
17.	Sapporo	43 4 0	141 22 45	58.	Kōchi	33 32 50	133 33 15
18.	Kiitup	43 4 33	145 7 15	59.	Minabe	33 46 0	135 20 0
19.	Nemuro	43 20 5	145 35 15	60.	Okayama	34 38 0	133 55 30
20.	Hirosaki	40 35 30	140 24 0	61.	Hiroshima	34 23 10	132 27 0
21.	Ōdate	40 16 36	140 28 15	62.	Wakwan	35 5 0	129 1 30
22.	Nōshiro	40 12 30	140 0 0	63.	Meiho	35 4 6	128 53 45
23.	Akita	39 42 12	140 4 15	64.	Pusan	35 7 36	129 3 0
24.	Kariwano	39 33 48	140 18 0	65.	Fukuoka	33 36 8	130 21 45
25.	Yokote	39 18 12	140 25 15	66.	Nakatsu	33 36 8	131 11 30
26.	Shimo-innai	39 3 0	140 21 15	67.	Saganoseki	33 14 30	131 53 15
27.	Shinjō	38 45 30	140 14 45	68.	Hichiyamura	32 25 15	131 39 30
28.	Sakata	38 57 31	139 51 15	69.	Miyazaki	31 55 11	131 26 30
29.	Yamagata	38 15 0	140 16 45	70.	Yatsushiro	32 30 43	130 37 0
30.	Yonezawa	37 54 30	140 7 45	71.	Nagasaki	32 45 0	129 52 30
31.	Oguni	38 4 12	139 42 15	72.	Hagi	34 25 3	131 22 30
32.	Nakajō	38 1 12	139 20 30	73.	Hamada	34 53 41	132 5 45
33.	Ebisu	38 5 0	138 26 15	74.	Matsue	35 28 24	133 4 0
34.	Niigata	37 51 1	139 2 30	75.	Imaichi	35 21 35	132 50 0
35.	Kashiwazaki	37 23 36	138 32 0	76.	Kanōmura	35 28 33	134 12 30
36.	Sekiyama	36 56 0	138 11 30	77.	Koyamamura	35 31 6	134 10 30
37.	Ueda	36 24 0	138 14 15	78.	Maizuru	35 26 52	135 20 45
38.	Takanomachi	36 8 54	138 26 30	79.	Obama	35 30 20	135 44 45
39.	Kōfu	35 39 0	138 35 45	80.	Shioya	36 18 2	136 14 0
40.	Hara	35 7 44	138 48 30	81.	Nanao	37 3 19	137 0 15
41.	Hakone	35 12 30	139 1 30				

comparing the observed and calculated values of the elements contain also these 31.

Each of the charts representing the various systems of lines (see Plates VIII—XI) shows two sets of lines. The full lines are the graphic representation of the Mean Formula for the whole country worked out in the usual way by the method of Least Squares. The dotted lines give a better idea of things *as they are*, being drawn by free-hand interpolation amongst the neighbouring stations. The eye can thus tell almost at a glance, not only to what degree of approximation the full lines agree with the true state of things, but also in what parts of the country magnetic disturbances are most pronounced.

In combining the combinations, I assumed linear expressions in longitude and latitude for the Dip, the Horizontal Force, and the Total Force. It is quite clear, however, that any attempt to represent the Declination by a simple linear function would end in utter confusion. On the Declination Chart (Plate XI) it will be seen that, roughly speaking, the dotted lines run parallel to the general trend of the country itself and have a somewhat parabolic or hyperbolic form. To add other two terms involving the squares of both the longitude and latitude would have increased the labours of calculation enormously. I therefore contented myself with adding a term involving the square of the longitude, assuming, so to speak, a parabolic curve with its axis parallel to a meridian line. The result was much more satisfactory than I had expected it to be.

In the working out of the calculations, the stations were all of course referred to the mean station (36° 30′ N. Lat., 137° 9′ E. Long.), and the co-ordinates were expressed in angular units. From the Formulæ so obtained, the lines shown on the charts were constructed. The kilometre was then taken as the unit in which the co-ordinates were to be expressed, the particular change-ratios being those which held for the Mean Station. The lengths in kilometres of one minute in arc of latitude and longitude at that station are :—

1 minute of Latitude.........1.85 kilometres.
1 „ „ Longitude......1.49 „

This transformation of units being effected, it was then easy to find the angle at which any given iso-magnetic line at the Mean Station cuts the meridian line, and the greatest rate of change per kilometre of the particular element at that Station.

I.—The Dip.

The fifty selected observations, when combined by the method of least squares, gave the following formula expressing the Dip (θ) in terms of the co-ordinates :—

$$\theta = 50^\circ\, 28'.6 + (1.141\, \varphi - .1556\, \lambda)'$$

φ and λ are the latitude and longitude co-ordinates referred to the mean station (36° 30′ N. Lat., 137° 9′ E. Long.) and measured in minutes of arc.

In the annexed table, Table II., the values of the Dip as observed at all the stations are given, and along side of them the values as calculated from the Formula.

The selected stations, on which the calculation depended, are indicated by having their numbers printed in heavier type. Including the other stations serves to indicate to what degree of approximation the formula applies to them also. This will be best shown by giving the probable error of a single observation in the different cases.

If we take all the 81 stations, the probable error comes out ± 11′.33.

If we neglect Nos. 39, 41, and 73, whose differences are very large indeed, the probable error becomes ± 8′.54. Nos. 39 and 41 are respectively Kōfu and Hakone, stations which lie in what is one of the most disturbed regions in Japan. Hakone indeed is quite peculiar magnetically, and is included amongst the 81 stations more as a curiosity than otherwise. It is situated in a hilly and highly volcanic region on the shores of a deep tarn-like lake. A small piece of stone picked up from the ground and brought near the declination magnet had a large effect upon it. Neither Kōfu nor Hakone belong to the selected stations. No. 73, Hamada, near the extreme westerly end of the country, does however belong to the selected stations. It will be noticed that the contiguous station, No. 72, Hagi by name, shows also a large difference between the observed and calculated values of the Dip, but that the difference is positive whereas the difference in the case of No. 73 is negative. The same approximate balancing of differences exists also in the case of Kōfu and Hakone. We shall consider this point more in detail subsequently.

If we take into account only the Fifty selected stations, the probable error is ± 9′.56.

Four of the selected stations stand out prominently by virtue of their large differences. These are Kashiwazaki (No. 35), Hichiyamura (No. 68), Hagi (No. 72) and Hamada (No. 73). If we neglect these, the probable error becomes ± 6′.96. Hichiyamura is one of the Kyūshū group of stations (Nos. 65-71), all of which lie in a very volcanic region and all of which have their observed Dips less than the corresponding calculated Dips.

It is worthy of note that the extreme Yezo stations, Kiitup and Nemuro (Nos. 18 and 19), fit in remarkably well with the general formula—better indeed than do the less extreme stations Hakodate and Sapporo (Nos. 16 and 17). At Hakodate (which is one of the Fifty) the proximity of Hakodate Peak, a hill of volcanic rock 1,100 feet high, might well be a source of disturbance. At Sapporo again,

Table II.

The Mean Dips for all the Stations.

	Dip.							Dip.					
Station.	Observed.		Calculated.		Difference.		Station.	Observed.		Calculated.		Difference.	
	°	′	°	′	°	′		°	′	°	′	°	′
1	50	7·3	49	57·6	+	9·7	**42**	48	33·8	48	40.2	−	6·4
2	50	57·3	50	45·6	+	11·7	**43**	48	32·6	48	20·4	+	12·2
3	51	13·8	51	15·0	−	1·2	44	48	30·6	48	26·4	+	4·2
4	51	20·9	51	38·4	−	17·5	**45**	49	2·5	48	54·6	+	7·9
5	51	48·7	51	57·0	−	8·3	**46**	48	43·1	49	0·6	−	17·5
6	51	56·2	52	1·8	−	5·6	**47**	49	32·5	49	15·6	+	16·9
7	52	32·0	52	37·8	−	5·8	48	49	56·0	49	56·4	−	0·4
8	53	17·7	53	11·4	+	6·3	49	49	39·0	49	25·2	+	13·8
9	53	10·9	53	31·8	−	20·9	**50**	49	12·0	49	10.2	+	1·8
10	53	36·0	53	18·6	+	17·4	**51**	47	59·4	48	9·6	−	10·2
11	54	7·4	53	57·6	+	9·8	**52**	48	41·3	48	36·6	+	4·7
12	54	23·3	54	21·6	+	1·7	**53**	48	58·2	49	3·0	−	4·8
13	54	39·4	54	27·6	+	11·8	**54**	48	16·8	48	25·2	−	8·4
14	54	44·1	54	52·2	−	8·1	**55**	49	17·6	49	24·6	−	7·0
15	54	47·1	54	54·0	−	6·9	**56**	48	42·3	48	44·4	−	2.1
16	55	35·5	55	55·2	−	19·7	**57**	48	0·4	48	4·2	−	3·8
17	56	41·5	57	18·6	−	37·1	58	47	32·0	47	42·6	−	10·6
18	56	48·4	56	44·4	+	4·0	59	47	46·3	47	40·8	+	5·5
19	57	7·1	56	58·2	+	8.9	**60**	48	47·9	48	54·0	−	6·1
20	54	24·6	54	37·8	−	13·2	**61**	48	39·6	48	50·4	−	10·8
21	54	12·5	54	16·2	−	3·6	62	50	9·3	50	10·2	−	0·9
22	54	17·8	54	16·2	+	1.6	**63**	50	27·0	50	10·8	+	16·2
23	53	37·6	53	19·8	+	17·8	64	50	1·2	50	13·8	−	12·6
24	53	30·5	53	28·8	+	1·7	**65**	48	6·5	48	15·0	−	8·5
25	53	5·0	53	11·4	−	6.4	**66**	48	2·0	48	7·8	−	5·8
26	52	51·1	52	52·8	−	1.7	**67**	47	20·9	47	31·8	−	13·9
27	52	37·2	52	33·6	+	3.6	**68**	46	27·7	46	55·2	−	27·5
28	52	51·9	52	51·6	+	·3	**69**	45	51·3	46	10·2	−	18·9
29	52	1·6	51	58·8	+	2·8	**70**	46	40·0	46	58·2	−	18·2
30	51	31·6	51	37·2	−	5·6	71	46	57·1	47	21·6	−	24·5
31	51	47·2	51	52·8	−	5·6	**72**	48	44·1	49	16·8	−	32·7
32	51	49·2	51	52·2	−	3·0	**73**	50	12·2	49	28·8	+	43·4
33	52	3·7	52	4·8	−	1·1	**74**	50	1·8	49	58·8	+	3·0
34	51	56·9	51	47.4	+	9·5	**75**	50	13·1	49	54·0	+	19·1
35	51	55·4	51	16·2	+	39·2	76	49	43·4	49	49·8	−	6·4
36	50	55·7	50	48·0	+	7.7	77	49	53·8	49	52·8	+	1·0
37	50	3·3	50	11·4	−	8·1	**73**	49	24·8	49	37·2	−	12·4
38	49	40·6	49	52·8	−	12·2	**79**	49	30·4	49	37·8	−	7·4
39	50	5·7	49	16·2	+	49·5	**80**	50	30·8	50	27·6	+	3·2
40	48	33·3	48	39·0	−	5·7	**81**	51	15·1	51	12·6	+	2.5
41	47	25·7	48	42·6	−	76·9							

we were compelled by very wet weather to make our observations on the stone pillars in the meteorological observatory,* and this may have been a source of disturbance.

If we now express the co-ordinates in kilometres, the Formula for the Dip becomes

$$\theta = 50^\circ\ 28'.6 + (.6168\ \varphi - .1044\ \lambda)'$$

Let u be the angle between the Line of Equal Dip drawn eastward and the longitude line drawn northward; and let r be the rate of change of Dip per kilometre of distance measured in a direction perpendicular to the Line of Equal Dip; then we find in the usual way for the mean station

$$u = 80^\circ\ 23'.6$$
$$r = 0'.626$$

II.—The Horizontal Force.

The fifty selected observations, when combined by the method of least squares, gave the following formula expressing the Horizontal Force (H) in terms of the co-ordinates :—

$$H = .29482 - .0000617\ \varphi - .0000117\ \lambda$$

H is measured in absolute C. G. S. electro-magnetic units; and φ and λ, the latitude and longitude co-ordinates referred to the mean station (36° 30′ N. Lat., 137° 9′ E. Long.), are measured in minutes of arc.

In the annexed table, Table III., the values of the Horizontal Force as observed at all the stations are given, and alongside of them the values as calculated from the Formula. As before the selected stations are indicated by having their numbers printed in heavier type.

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* The observatory is built wholly of wood; but the tile-roof or the stone pillars themselves may have been appreciably magnetic.

Table III.

The Mean Horizontal Forces for all the Stations

	Horizontal Force				Horizontal Force		
Station.	Observed.	Calculated.	Difference.	Station.	Observed.	Calculated.	Difference.
1	.29143	.29317	— .00174	42	.29655	.29762	— .00107
2	.28952	.29009	— 57	43	.29630	.29854	— 224
3	.28785	.28836	— 51	44	.29607	.29760	— 153
4	.28830	.28692	+ 138	45	.29533	.29604	— 71
5	.28755	.28531	+ 224	46	.29696	.29511	+ 185
6	.28753	.28470	+ 283	47	.29377	.29516	— 139
7	.28426	.28309	+ 117	48	.29367	.29420	— 53
8	.28032	.28132	— 100	49	.29428	.29528	— 100
9	.28180	.28010	+ 170	50	.29642	.29590	+ 52
10	.27876	.27975	— 99	51	.29991	.30033	— 42
11	.27983	.27789	+ 194	52	.30046	.29942	+ 104
12	.27687	.27695	— 8	53	.29904	.29986	— 82
13	.27615	.27695	— 80	54	.30199	.30247	— 48
14	.27576	.27576	± 0	55	.30026	.29950	+ 76
15	.27727	.27615	+ 112	56	.30295	.30301	— 6
16	.27318	.27274	+ 44	57	.30603	.30562	+ 41
17	.26766	.26762	+ 4	58	.31006	.30826	+ 180
18	.26667	.26485	+ 182	59	.30494	.30621	— 127
19	.26025	.26356	— 331	60	.30455	.30400	+ 55
20	.27819	.27739	+ 80	61	.30714	.30592	+ 122
21	.27743	.27848	— 105	62	.30469	.30576	— 107
22	.27854	.27908	— 54	63	.30663	.30589	+ 74
23	.28275	.28091	+ 184	64	.30908	.30556	+ 352
24	.28224	.28127	+ 97	65	.31019	.31031	— 12
25	28309	.28203	+ 106	66	.31000	.30972	+ 27
26	.28226	.28313	— 87	67	.31137	.31057	+ 80
27	.28524	.28428	+ 96	68	.31367	.31378	— 11
28	.28465	.28381	+ 84	69	.31562	.31577	— 15
29	.28651	.28614	+ 37	70	.31490	.31416	+ 74
30	.28836	.28750	+ 86	71	.31392	.31380	+ 12
31	.28748	.28721	+ 27	72	.30886	.30657	+ 229
32	.28762	.28765	— 03	73	.30045	.30391	— 346
33	.28950	.28807	+ 143	74	.30006	.30148	— 142
34	.28699	.28823	— 124	75	.30022	.30207	— 185
35	.28878	.29055	— 177	76	.30144	.30066	+ 78
36	.29152	.29245	— 93	77	.29984	.30053	— 69
37	.29629	.29442	+ 187	78	.30097	.29996	+ 101
38	.29502	.29528	— 26	79	.30018	.29946	+ 72
39	.29261	.29694	— 433	80	.29555	.29621	— 66
40	.30150	.29873	+ 277	81	.29399	.29284	+ 115
41	.30490	.39827	+ 663				

If we take all the 81 stations, the mean probable error of a single observation comes out ± .00108.

If we throw out Nos. 39, 41 and 73, which are again conspicuous by the magnitude of their Differences, No. 41 (Hakone) being especially so, the probable error becomes ± .00091. It will be noticed that No. 64, one of the Korean stations, is more conspicuous even than No. 73 in respect to the magnitude of the Difference; and that No. 19 (Nemuro) does not fall far short of it. If these also be neglected, the probable error comes out ± .00084.

If we take into account only the fifty selected stations, the probable error is ± .00080.

Here four Stations stand out prominently by virtue of their high differences. These are Shiogama (No. 5), Hōjō (No. 43) Hagi (No. 72) and Hamada (No. 73). If we neglect these the probable error becomes ± .00064.

Two of these four neglected Stations, namely Hagi and Hamada (Nos. 72 and 73), were also amongst the Stations that were similarly treated in the discussion of the Dip. Kashiwazaki (No. 35), which was one of the four neglected in the discussion of the Dip, is fairly prominent also by reason of the magnitude of the difference between the observed and calculated Horizontal Forces. Hichiyamura (No. 68), however, the remaining one of the four neglected Dip observations, is characterised by an exceptionally small difference between the observed and calculated values of the Horizontal Force. A similar remark applies to Shiogama (No. 5) and Hōjō (No. 43), whose Horizontal Force differences are large, but whose Dip differences are comparatively small.

And now, expressing the co-ordinates in kilometres, we find

$$H = .29482 - .00003335\,\varphi - .00000785\,\lambda$$

From this we obtain the following values for the inclination of the Line of Equal Horizontal Force to the direction of geographical north, and for the greatest rate of change of Horizontal Force per kilometre :

$$u = 103^\circ \, 14'.9$$

$$r = .000034$$

III.—The Total Force.

The Total Forces were calculated from the Horizontal Forces and Dips ; and the values at the fifty selected stations, when combined by the method of least squares, gave the following expression for the Total Force (F) in terms of the co-ordinates :—

$$F = .46407 + .000094\ \varphi - .000045\ \lambda$$

F is measured in absolute C. G. S. electromagnetic units : and φ and λ, the usual geographical co-ordinates referred to the Mean Station (36° 30′ N. Lat., 137° 9′ E. Long.), are measured in minutes of arc.

Table IV. is constructed after the same fashion as Tables II. and III.

If we take all the 81 Stations, the mean probable error of a single observation comes out ± .00128. If we neglect Nos. 11, 18, and 38, which are conspicuous by the hugeness of their differences the mean probable error is at once reduced to ± .00099.

If we take into account only the fifty selected Stations, the mean probable error is ± .00089.

It will be noticed that, out of the six Stations (Nos. 5, 35, 43, 68, 72, 73) which were conspicuous in Tables II. and III. by the magnitudes of the Differences, only one is so distinguished in Table IV. With the exception of Kashiwazaki (No. 35), these Stations just enumerated are rather to be distinguished by the smallness of the differences between the observed and calculated values of the Total Force.

Running our eye down the difference columns in the Dip and Horizontal Force Tables, we are struck by a general tendency for the differences at any one locality to have opposite signs. That is to say, where the observed value of the dip is greater than the calculated value, the observed value of the horizontal force is, in the majority of cases, less than the calculated value. More particularly, of the 81 Stations only 26 are characterised by having their dip and horizontal force differences of the same sign; or, if the selected stations are alone considered, of these 50 only 17 are similarly characterised.

It would thus appear that the magnetic disturbances in Japan are of a nature to affect the *direction* rather than the *amount* of the total force—a result quite in accordance with the usual laws of magnetic action. In this connection there are two very interesting cases that seem to call for special remark. To bring out their peculiarities the more distinctly, it is advisable to draw up in tabular form the differences only for the stations that are to be discussed. They are as follows:—

Station		Differences		
No.	Name	Dip	Hor. Force	Total Force
39	Kōfu.........	+ 49′.5	− ·00433	+ ·00075
41	Hakone......	− 76′.9	+ ·00663	− ·00104
72	Hagi.........	− 32′.7	+ ·00229	+ ·00035
73	Hamada.....	+ 43′.4	− ·00346	+ ·00071

These form pairs of contiguous points. In all four the Dip and Horizontal Force differences are exceptionally large; whereas the Total Force Differences are all distinctly smaller than the mean probable error for the whole. Here we have evidence in both cases of a

Table IV.

The Mean Total Forces for all the Stations

Station.	Total Force Observed.	Total Force Calculated.	Difference.
1	.45454	.45632	— .00178
2	.45961	.45940	+ 21
3	.45967	.46263	— 296
4	.46163	.46329	— 166
5	.46479	.46390	+ 89
6	.46635	.46374	+ 261
7	.46729	.46727	+ 2
8	.46901	.47001	— 100
9	.47023	.47149	— 126
10	.46975	.46879	+ 96
11	.47746	.47233	+ 513
12	.47548	.47491	+ 57
13	.47737	.47583	+ 154
14	.47763	.47807	— 44
15	.48083	.47895	+ 188
16	.48343	.48414	— 71
17	.48743	.48971	— 228
18	.48710	.47967	+ 743
19	.47937	.47986	— 49
20	.47800	.47837	— 37
21	.47438	.47642	— 204
22	.47728	.47730	— 2
23	.47677	.47423	+ 254
24	.47458	.47283	+ 175
25	.47130	.47120	+ 10
26	.46741	.46980	— 239
27	.46984	.46845	+ 139
28	.47151	.47064	+ 87
29	.46564	.46550	+ 14
30	.46350	.46398	— 48
31	.46473	.46603	— 130
32	.46530	.46673	— 143
33	.47088	.46952	+ 136
34	.46564	.46698	— 154
35	.46825	.46536	+ 289
36	.46252	.46368	— 116
37	.46147	.46057	+ 90
38	.45591	.46250	— 659
39	.45612	.45537	+ 75
40	.45550	.45187	+ 363
41	.45069	.45173	— 104
42	.44809	.45017	—.000208
43	.44754	.44823	— 69
44	.44690	.44790	— 100
45	.45053	.45002	+ 51
46	.45009	.44971	+ 38
47	.45272	.45222	+ 50
48	.45624	.45757	— 133
49	.45452	.45401	+ 41
50	.45365	.45255	+ 110
51	.44813	.44887	— 74
52	.45515	.45196	+ 319
53	.45554	.45725	— 171
54	.45379	.45391	— 12
55	.46039	.46025	+ 14
56	.45905	.45903	+ 2
57	.45741	.45730	+ 11
58	.45924	.45714	+ 210
59	.45371	.45358	+ 13
60	.46234	.46223	+ 11
61	.46499	.46485	+ 14
62	.47555	.47800	— 245
63	.48155	.47829	+ 326
64	.48104	.47821	+ 283
65	.46455	.46604	— 149
66	.46359	.46380	— 21
67	.45956	.45990	— 34
68	.45536	.45588	— 52
69	.45316	.45365	— 51
70	.45887	.45920	— 33
71	.45988	.46256	— 268
72	.46828	.46793	+ 35
73	.46941	.46870	+ 71
74	.46710	.46929	— 219
75	.46920	.46930	— 10
76	.46628	.46621	+ 7
77	.46546	.46658	— 92
78	.46260	.46302	— 42
79	.46227	.46228	— 1
80	.46478	.46542	— 64
81	.46971	.47039	— 68

very obvious kind of disturbance. Take, for example, the first pair. Kōfu, the more northerly station, has an increased dip and a diminished horizontal force ; whereas Hakone, the more southerly station has a diminished dip and an increased horizontal force. Now this is exactly what would happen if between the two stations there existed material of magnetic permeability greater than the average for the earth's crust. But we know that these stations are separated by rocks, which presumably belong to the volcanic system of Fuji-yama, and are almost certainly highly magnetic. It is not at all surprising to find such huge disturbances ; but it is peculiarly interesting to find that the disturbance in the Dip largely accounts for the disturbance in the horizontal force, the total force being comparatively slightly affected. This Kōfu-Hakone disturbance falls in remarkably well with our preconceived ideas as to the perturbing effect of volcanoes upon magnetic distribution.

The other pair of stations, Hagi and Hamada, present exactly the same magnetic features. Thus it is Hamada, the more northerly station, which has the increased dip and the diminished horizontal force. It corresponds therefore to Kōfu. Magnetically considered, Hamada and Hagi are just a repetition of Kōfu and Hakone. But here the likeness apparently ends ; for between Hamada and Hagi no important mass of volcanic rocks is known to exist. Of course there are magnetic rocks other than volcanic ; and the apparent absence of the latter does not necessarily imply the absence of the former. All we can say is that between Hagi and Hamada a more than usually magnetic mass lies.

A careful scrutiny of the various tables of differences does not reveal any distinct tendency for the stations to occur in groups, excepting in one case only. That exceptional group embraces the Kyūshū stations. For them both the dips and total forces are smaller than the mean formula requires. This may have some significance. From the pretty scattered distribution of the stations we should hardly expect to find them adjusting themselves into groups characterised by similar errors. The disturbances are generally of such a local character that they must almost certainly affect in different ways the magnetic elements at stations which are never very close together.

And now expressing the co-ordinates in kilometres we find, for the Total Force,

$$F = .46407 + .0000508\ \varphi - .0000302\ \lambda$$

from which we obtain, as in the other cases,

$$u = 59^\circ\ 16'.5$$
$$r = .000059$$

IV.—The Declination.

As already stated, it is impossible to regard the Declination as at all expressible by means of an equation involving only first powers of the co-ordinates. Fortunately for the labours of calculation, the general form of the isogonic lines for Japan may be taken as fairly parabolic. On this assumption, then, the fifty selected observations were combined by the method of least squares, and the result is embodied in the following formula expressing the Declination (δ) in terms of the co-ordinates:—

$$\delta = 4^\circ\ 53'.3 + (.241\ \varphi - .109\ \lambda - .000231\ \lambda^2)'$$

The latitude and longitude co-ordinates (φ, λ) are referred to the Mean Station (36° 30′ N, Lat., 137° 9′ E. Long.) and measured in minutes of arc.

Table V. is constructed in the same fashion as Table II., III. and IV.

If we take into account all the 79 observations—at two of the Stations (Nos. 7 and 37) the Declination could not be observed—the mean probable error comes out ± 13′ .4. There are three Stations, however, which have such large differences that, when they are neglected, the mean probable error is reduced to ± 8′. These Stations are Miyako (No. 10), Hakone (No. 41) and Pusan in Korea (No. (64). The manner in which the declinations at these Stations diverge from the values given by the formula suggests local disturbances of quite a limited area of action. This is peculiarly true of Hakone (No. 41). That the disturbance at Pusan (No. 64) is of quite a local character is proved by the fact that at the contiguous stations (Nos. 62 and 63) the differences are comparatively small. Miyako (No. 10) is another striking instance, for which, however, no certain conclusions can be drawn as, unfortunately, observations at neighbouring points were not taken.

This whole region indeed, lying between the thirty-eighth and forty-first parallels of latitude—and more especially the central and eastern portions of it—seems to be one of marked magnetic disturbance. It is highly volcanic and contains nearly a score of distinct volcanoes, of which four are especially prominent. These are* Iwaki-san (5,260 ft.) in the northwest near Hirosaki (No. 20), Ganju-san (7,000 ft.) in the centre near Morioka (No. 9), Moriyoshi-san (5,800 ft.) to the south of Ōdate (No. 21), and Chōkai-san (7,100 ft.) to the north of Sakata (No. 28). This great spread of volcanic rock, however, is confined entirely to the Central and Western portions. The Kita-kami River, which flows from its sources a little to the north of the fortieth parallel due south to Ishinomaki (No. 6), is virtually the dividing line between the volcanic and non-volcanic deposits. In the hilly country to the east of this river the rocks are largely schists and granites. Nevertheless in this part also the dis-

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* See Professor Milne's "The Volcanoes of Japan," Transactions of the Seismological Society of Japan Vol. XI. (1886).

Table V.

The Mean Declinations for all the Stations.

	Declination West.							Declination West.					
Station.	Observed.		Calculated.		Difference.		Station.	Observed.		Calculated.		Difference.	
	°	′	°	′		′		°	′	°	′		′
1	4	1·6	4	28·3	—	26·7	**42**	4	19·2	4	13·3	+	5·9
2	4	31·5	4	34·6	—	3·1	**43**	4	23·4	4	7·6	+	15·8
3	4	29·6	4	39·6	—	10·0	44	4	1·5	4	5·0	—	3·5
4	4	33·7	4	43·4	—	9·7	**45**	4	13·6	4	10·0	+	3·6
5	5	5·5	4	41·7	+	23·8	**46**	4	19·2	4	6·5	+	12·9
6	5	4·1	4	39·9	+	24·2	**47**	4	25·9	4	16·7	+	9·2
7	—		4	56·6	—		48	4	45·7	4	34·2	+	11·7
8	5	25·2	4	57·9	+	27·3	49	4	35·9	4	24·0	+	11·9
9	5	2·5	5	1·1	+	1·4	**50**	4	21·0	4	19·1	+	1·9
10	5	47·0	4	47·9	+	59·1	**51**	4	13·0	4	12·4	+	·6
11	4	37·7	4	58·6	—	20·9	**52**	4	2·1	4	20·7	—	18·6
12	4	32·6	5	11·4	—	38·8	**53**	4	31·9	4	35·7	—	3·8
13	4	57·7	5	10·9	—	13·2	**54**	4	21·8	4	27·0	—	5·2
14	5	31·7	5	17·4	+	14·3	**55**	4	45·1	4	42·5	+	2·6
15	5	22·2	5	22·0	+	·2	**56**	4	34·1	4	36·4	—	2·3
16	5	31·3	5	35·3	—	4·0	**57**	4	26·0	4	29·5	—	3·5
17	6	0·0	5	46·2	+	13·8	58	4	20·8	4	23·8	—	3·0
18	4	46·0	4	43·3	+	2·2	59	4	30·1	4	23·4	+	6·7
19	4	21·3	4	37·8	—	16·5	**60**	4	38·1	4	38·8	—	·7
20	5	23·3	5	22·4	+	·9	**61**	4	27·1	4	35·5	—	8·4
21	5	15·7	5	16·9	—	1·2	62	4	25·0	4	31·4	—	6·4
22	5	32·3	5	21·6	+	10·7	**63**	4	42·7	4	30·1	+	12·6
23	5	9·3	5	13·4	—	4·1	64	3	36·6	4	32·7	—	56·1
24	5	9·2	5	9·0	+	·2	**65**	4	17·8	4	17·6	+	·2
25	5	23·1	5	4·0	+	19·1	**66**	4	22·6	4	20·9	+	1·7
26	5	11·7	5	1·1	+	10·6	**67**	4	12·0	4	17.6	—	5·6
27	4	58·9	4	51·6	+	7·3	**68**	3	59·4	4	5·2	—	5·8
28	5	11·0	5	5·2	+	5·8	**69**	3	58·4	3	58·7	—	·3
29	4	32·6	4	50·1	—	17·5	**70**	3	59·2	4	2·9	—	3·7
30	4	32·6	4	46·5	—	13·9	71	3	33·7	4	3·0	—	29·3
31	4	51.4	4	54·0	—	2·6	**72**	4	30·1	4	33·4	—	3·3
32	5	0·3	4	56·9	+	3·1	**73**	4	38·8	4	42·1	—	3·3
33	5	0·0	5	6·5	—	6·5	**74**	4	51·6	4	51·3	+	·3
34	5	9·4	4	58·4	+	11·0	**75**	4	48·9	4	49·6	—	·7
35	5	3·4	4	55·6	+	7·8	76	5	9·0	4	50·9	+	18·1
36	4	36·2	4	51·7	—	15·5	77	5	5·0	4	51·5	+	13·5
37	—		4	43·9	—		**78**	4	59·4	4	47·3	+	2·1
38	4	2.8	4	38·6	—	35·8	**79**	4	54·1	4	46·5	+	7·6
39	4	32·4	4	30·1	+	2·3	**80**	4	59·2	4	55·2	+	4·0
40	4	29·4	4	20·7	+	8·7	**81**	5	5·7	5	2·4	+	3·3
41	2	24·0	4	19·8	—	115·8							

turbances in the Declination are very marked. There is no evidence whatever of a Declination less than 5° W. until we reach the stations on the North East Coast. That is to say, the isogonic line of 5°, which general considerations would lead us to expect to run right across the region from S. W. to N. E., seems to form an extra distinct contour round the schistose granitic portion on the East. The declinations at Hanamaki (No. 7) and Miyako (No. 10) are especially large. So great in fact was the value of the declination at Miyako—just about a whole degree greater than was expected—that at first sight it looked like a misreading of a whole degree on the azimuth circle. Three distinct observations, however, were taken at this station—two by means of the sun and one (three transits in all) by means of Polaris. All the values agree to within 7′, so that the large value of the declination is undoubted. This peculiarity may be purely local, or it may be of wider extent. Our stations are not sufficiently numerous to enable us to come to any sure conclusion on this point. It should be mentioned that a little to the south of Miyako considerable quantities of iron ore are known to exist.

If we take account only of the 50 selected Stations, the mean probable error of a single observation is ± 7′. Three of the Stations are conspicuous by reason of the largeness of the differences between the observed and calculated values. These are Ishibashi (No. 1), Shiogama (No. 5) and Hachinohe (No. 12). It will be noticed that the declination at Shiogama is greater than is given by the formula, and that the declination at Hachinohe is less. These Stations lie respectively at the extreme South and at the extreme North of the region of schists and granites that has just been discussed. Only a number of observations at neighbouring localities could, however, determine whether the peculiarities presented by Shiogama and Hachinohe belong to a general system or are to be regarded as purely local.

Regarding Ishibashi it seems difficult at first to suggest a cause of such a large discrepancy. The Declination observed here was (neglecting the altogether peculiar Hakone) the second smallest observed by the Northern Party. Being the very first station of the whole survey, it was feared for a time that some mistake had been made by the observer. To make sure of this Mr. Nagaoka was despatched towards the end of September to Ishibashi to make a redetermination of the Declination. The observation was made at a slightly different locality; and the declination was measured at 9.45 a. m. by means of a Sun's Azimuth. The result did not differ by one minute from the value as found in June by means of Polaris. Here again, then, there can be no question as to the very peculiar smallness of the Declination at Ishibashi. Geologically considered Ishibashi lies just within the Eastern wing of the "Schaarung" (so called by Süss),* within which lie the volcanic regions of Japan. The boundary between this volcanic region and the non-volcanic region to the East is the continuation to the south of the similar boundary already described as coinciding in position with the Kita-kami-gawa. Now, although to all appearance Ishibashi is situated on alluvial soil, yet, according to the geologists, it just lies within this Schaarung. Hence it is quite probable that volcanic rocks exist hidden from view but so distributed as to cause a distinct magnetic disturbance. The values of the declination obtained by Sekino throughout this region show considerable irregularities, Ishibashi itself being characterised by a declination somewhat smaller than the average. His value for this station (namely, 4° 16′ .6) is, however, much larger than ours. We must therefore either assume a change of 15′ or so in five years, or, what is much more probable, a very local source of disturbance.

If we neglect these three stations (Nos. 1, 5, 12) the mean

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* See Dr. Naumann's Pamphlet already mentioned, page 17; also Professor Kotō's Paper already published in this Volume.

probable error becomes ± 5′ .9—a value by no means considerable in the circumstances.

This seems the natural place to refer to Dr. Naumann's discussion of the iso-magnetic lines of Japan in relation to its geology. Basing on the broad features of Sekino's chart, Naumann finds in the form of the isogonic line of 5° W. a close relation to the so-called *Fossa Magna*. Just where this great break in the geological continuity of the country occurs, there a large sinuosity seemed to show itself on the isogonic line. This *Fossa Magna* almost stretches right across the central part of Japan in a nearly north and south direction. Fujiyama is included in it and so, it is generally supposed, is the line of volcanic islands stretching south-easterly. The *Fossa Magna* hardly reaches the Northern coast of Japan ; but, if continued northwards, it would be found to run between the Peninsula of Noto on the west and the Island of Sado on the east. Now it is just at this region that Sekino's 5° Isogonic line makes a great bend to the north, doubling back just over the island of Sado and then, after an easterly sweep, continuing north-easterly across the country. It is extremely doubtful whether the observations warrant such a delineation of the line of 5° Declination. A careful scrutiny of Sekino's numbers brings out certain discrepancies which should not altogether be neglected. Further, there is a complete lack of observations along the coast to the south and south-west of Sado—just where observations seem most called for. The stations chosen are all inland, and show striking irregularities in the values of the declinations. True, the declinations at the three Stations on Sado are all considerably less than the values at mainland stations immediately to the east ; whereas we should expect to find them greater. But that seems hardly a sufficient reason for making the isogone of the form represented. For it is well known that the isogonic lines at and near islands often present irregularities of quite a local description. Hence, in default of evidence which could only be obtained by a series of observations along the coast of the main island, it seems to me more prudent to draw the isogonic line of 5° fairly normal and represent the disturbance due to Sado by a small isolated contour round that island. In this way it is shown on our charts. In short, knowing as we do that an island is enough by itself to cause considerable disturbances, we are justified in explaining the peculiarities that are as being due to the existence of the Island of Sado rather than to the existence of the *Fossa Magna.* Indeed there does not seem to be any very extraordinary disturbance after all in this region. There are as marked disturbances in the north of Japan, where no *Fossa Magna* exists ; and these disturbances find a sufficient explanation in the presence of volcanic rocks of all kinds. A mountainous volcanic region is certain to present magnetic irregularities ; and in Japan there are two regions specially to be noted as such. A glance at the four charts will at once pick them out. The one is the great central mountainous region, just where the *Fossa Magna* is. The other is the part between the 38th and 40th parallels ; but here there is nothing geologically comparable to the *Fossa Magna.* If peculiarly abnormal irregularities had been found to exist in the central region only, there might have been reason in connecting them with a very peculiar geological structure. But, since the northern region is quite as abnormal magnetically as the central one, the most logical course is to look upon these abnormalities as due to something common to them both. And this common element is simply a prodigious developement of volcanic rocks.

There are six stations which may be said to belong to the central hilly region. These are Sekiyama, Ueda, Takanomachi, Kōfu, Hara, and Hakone—Nos. 36 to 41 inclusive. Excepting Hara, which is on the coast, these stations all lie at considerable elevations. Thus Sekiyama and Kōfu are nearly 1000 feet above the sea-level; Ueda is about 1500; Takanomachi and Hakone about 2500.* It is not surprising then that at the two last-named places the values of the various magnetic elements should be so distinctly abnormal. Takanomachi lies just on the northern side of the water-shed, which here divides the basins of the Fuji-kawa and Shinano-gawa. Immediately to the south the high mountains are crossed by a pass 4,500 feet high; and on the other side of this pass lies Nagasawa (3,100 feet), where an observation of Dip was made. This Dip (see Appendix B) is remarkable for its smallness, being half a degree smaller than the Dip at Takanomachi, and a whole degree smaller than the Dip at Kōfu. In fact, just where it is most mountainous, there are to be found the greatest magnetic irregularities. It is impossible of course in the circumstances of the case to decide as to whether height itself has a direct influence on the values of the magnetic constants. The volcanic nature of the rocks is more than enough to account for all irregularities.

Another very interesting group of stations is the Korean group. Here there are three principal stations, Wakwan, Mēho, and Pusan (Nos. 62, 63, 64); but quite a number of observations were made at points in the near neighbourhood. These are given in the complete lists in Appendix B. Excepting Mēho, all these stations lie on the shores of Pusan Harbour. This harbour is formed by a bay opening to the south with a large island filling up fully half the entrance. On a sharply projecting cape pointing towards the northwest end of the island lies Wakwan, the Foreign Settlement. At the head of the bay, some 3 miles to the north is Pusan itself; while due east from Wakwan about 3 miles across the bay is Kurosaki with Kurosaki Cape

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* These heights are estimated from aneroid observations made during the survey, taken in combination with the daily charts of the meteorological office, which furnish the sea-level readings of pressure for the whole of Japan.

half a mile further south. On the eastern shore of Chearegdow—as the large island already mentioned is called—lies Omizutare, looking over against Kurosaki Cape. A little to the south is Shiinokijima, that is Shiinoki Island, helping to fill in the space between Chearegdow and Kurosaki. Shiinokijima is about half a mile long ; and the observations were taken at the extreme southwestern and northeastern ends. Thus Wakwan, Pusan, Kurosaki, Kurosaki Cape, Shiinokijima Cape, Shiinokijima and Ōmizutare form a circle of points surrounding Pusan Harbour ; and no two of them are further distant from one another than four or five miles. Within this very limited area very striking irregularities exist. The declination varies by nearly a whole degree ; the dip by fully the same amount ; the horizontal force by 1.5 per cent. of the whole value. Perhaps the most striking irregularity of all is that displayed by the value of the dip at Shiinokijima Cape as compared with the values at Shiinokijima proper (half a mile to the south-west) and at Kurosaki Cape (a mile and quarter to the north-north-east). As Mr. Tanakadate has pointed out, the difference of fully a degree in the dips at the two Capes suggests a kind of horseshoe magnet with its poles at these points. The whole series of observations is a very good example of the powerful effect of local disturbances. It should be said that the whole district is quite hilly and craggy.

We shall now follow a very usual custom and group our stations according to the geological character of the rocks in their neighbourhood. This can only be done in a very general way, since the geology of Japan is still known but in the broad. There is, of course, no doubt as to the geological characteristics of some stations ; but there are many regarding which we can, by study of the geological map, draw no very sure inferences. The following grouping of stations is, therefore, only a tentative one. Three groups are distinguished. In the first group stations with undoubted volcanic surroundings are included. In the third we put stations which are as characteristically non-volcanic. The rocks, in this case, may be schist or granite, or stratified rocks of some determinable geologic age, including alluvium. The second group includes what may be termed the doubtful stations. They may be resting on non-volcanic rocks or soil, but so close to rocks of truly volcanic origin as to warrant us in regarding them almost as belonging to the first group. It is highly probable, indeed, that a station lying near the edge of a stretch of volcanic rocks should be characterised by considerable irregularities in its magnetic elements. Hence the doubtful or intermediate second group may easily compare in the magnitude of its mean errors with the first group. The groups are as follows :—

Group I.—Volcanic : Shiogama, Ichinoseki, Hanamaki, Morioka, Gonohe, Nobechi, Aomori, Sapporo, Nemuro, Ōdate, Kariwano, Yokote, Shimo-innai, Shinjō, Yamagata, Ebisu, Sekiyama, Takanomachi, Kōfu, Hakone, Ōtsu, Hōjō, Shimoda, Wakwan, Mēho, Pusan, Nakatsu, Hichiyamura, Nagasaki, Nanao.

Group II.—Intermediate : Yabuki, Matsukawa, Shiraishi, Hachinohe, Hakodate, Hirosaki, Nōshiro, Akita, Kashiwazaki, Ueda, Hara, Hagi, Kanōmura, Koyamamura, Shioya.

Group III.—Non-volcanic : Ishibashi, Ishinomaki, Miyako, Kuji, Kiitup, Sakata, Yonezawa, Oguni, Nakajō, Niigata, Katsuura, Tōgane, Chōshi, Kioroshi, Shimmachi, Ōmiya, Tōkyō, Shimizu, Nagoya, Kamiyashiro, Nagahama, Hyōgo, Tokushima, Kōchi, Minabe, Okayama, Hiroshima, Fukuoka, Saganoseki, Miyazaki, Yatsushiro, Hamada, Matsue, Imaichi, Maizuru, Obama.

The mean probable errors for the different groups are given in the following tables—the first being based on the results for all the stations, the second taking account of the fifty selected stations only.

For all the Stations.

	Group I.	Group II.	Group III.
Dip	14′.3 8′.9	11′.5	8′.4 6′.8
Horizontal Force	.00135 .00095	.00095	.00089 .00082
Total Force	.00142 .00117	.00117	.00130 .00082
Declination	19′.2 10′.3	10′.3	9′.5 6′.7

Where two different values for the mean probable error are given, the second is calculated after those stations, which are characterised by *very large* differences between the observed and calculated values, have been thrown out. Thus in group I, Nos. 39 and 41 are neglected in the calculation of the second values for the Dip and Horizontal Force ; No. 38 for the Total Force ; and Nos. 41 and 64 for the Declination. In Group II. there were no stations prominent by the relative hugeness of their differences. In Group III, No. 73 is neglected for the Dip and Horizontal Force ; Nos. 11 and 18 for the Total Force ; and No. 10 for the Declination.

For the Fifty Stations only.

	Group I.	Group II.	Group III.
Dip	7′.5	13′.4	8′.9
Horizontal Force	.00075	.00084	.00082
Total Force	.00111	.00114	.00074
Declination	11′.0	6′.3	5′.7

The general conclusion to be deduced from both these tables is that the mean probable error is greater the more volcanic the region.

We shall now bring together for ease of reference the values of the elements for the mean station, the directions in which the iso-magnetic lines pass through this station, and the maximum rate of change of each element per kilometre of distance. The tabulation of the declination constants offers some difficulty, as the isogonic lines are not straight but parabolic. If, however, we express the latitude and longitude co-ordinates in kilometres, we obtain the following transformed expression for the declination :—

$$\theta = 4^\circ\ 53'.3 + [.1303\ \varphi - .0732\ \lambda - .000104\ \lambda^2]'$$

From this we may estimate the constants u and r, not only for the mean station, but also for other stations. It is easy to see that the values of u and r will be the same for all points having one and the same longitude. In this way the following table has been constructed; u being, as formerly defined, the angle made by the direction of the iso-magnetic line drawn eastward and the meridian line drawn northward, and r representing the rate of change per kilometre in a direction perpendicular to this line.

The Constants for the Mean Declination at different longitudes.

Longitude of Point.	u	r
130°	114° 37′	.143
134°	83° 39′	.131
138°	55° 39′.9	.158
142°	38° 33′.2	.209
146°	28° 10′.6	.277

And, finally, collecting the results for the mean station (36° 30′ N. lat. and 137° 9′ E. long.), we have the following condensed table of the magnetic constants of the mean station as calculated from Fifty selected stations conveniently distributed over all Japan.

The Magnetic Constants for the Mean Station.

	Mean Value.	u	r
Dip	50° 28′.6	80° 23′.6	0′.626
Horizontal Force	.29482	103° 14′.9	.0000343
Total Force	.46407	59° 16′.5	.0000591
Declination	4° 53′.3	60° 40′.6	0′.149

V.—The Diurnal Variation.

Plates XII to XV show graphically the daily march of the Declination at various Stations, as observed by Mr. Tanakadate. For the earlier curves comparatively few points were taken ; but as the survey progressed the observation of successive declinations was found to be such a simple matter with the electromagnetic declinometer that Mr. Tanakadate made it a special feature of his work. The chief value of such observations in the present case is that from them a thoroughly good mean for the day may be obtained. As a whole, the curves are of a character which speaks well for the accuracy and sensitiveness of Mr. Tanakadate's instrument. The sensitiveness indeed depends simply and solely upon the fineness of graduation on the theodolite circle. In judging of the merits of the curves, we must bear in mind the conditions of the experiment. For not only will any possible magnetic storms disturb the general smoothness of the observations, but also windy and wet weather will almost certainly cause disturbances in measurements made by an instrument mounted on an ordinary tripod under a tent.

Taking the 17 best and most complete sets of observations (see Appendix B), we find for the mean daily range for the three months beginning July 4th the value 8′. This is about 1′ greater than the mean diurnal range obtained by Mr. Wada during his five months of observation in 1883. In the circumstances we may regard the conditions of the diurnal variation as essentially the same in the years 1883 and 1887.

It will be noticed that the curves obtained at Wakwan (No. 62) and Meho (No. 63), two of the Korean Stations, have peculiarly large ranges—nearly 11′ in both cases. The two curves are so similar and so smooth that it is difficult to believe their exceptional character to be other than a real thing. It will be further noticed, however, that during the month of August generally the diurnal range is distinctly greater than the mean just given. We may, indeed, by grouping the different sets of observations according to months, obtain an indication of the annual change of range. These monthly means of diurnal range are as follows :—

Month.	Number of Sets of Observations.	Mean of Diurnal Range.
July....................	4	8′
August	6	9′.5
September	6	6′.9
October	1	6′.5

Even if we were to throw out the two excessive Korean values, the August mean would still be distinctly higher than the July or September mean, being in fact 8′.8. All this is quite in accordance with well established facts.*

There is one other feature presented by Mr. Tanakadate's curves, which seems worthy of remark. It is that the hour of maximum deviation appears to come distinctly earlier in the later curves. This is especially well marked in the curves on Plate XIV. At Hagi, Hamada, Matsue, indeed, the maximum seems to fall at noon instead

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* Compare Table VI. in Art. METEOROLOGY, (Section TERRESTRIAL MAGNETISM), Encyclopaedia Britannica (Ninth Edition.)

of between 1 and 2 p. m. as is usually the case. Whether this is a local peculiarity or not cannot of course be decided from the material to hand; but the otherwise unexceptional character of the observations would lead us to regard this feature also as something that has a real existence. In any case, however, it is of interest to find that satisfactory self-consistent observations of diurnal variation can be made during a rapid magnetic survey, and that, notwithstanding the continual change of locality, the observations are sufficiently precise to indicate the monthly march of the diurnal range. This is, of course, quite to be expected if there is truth in the view so strongly advanced by Balfour Stewart, and supported by Schuster's interesting application of the Gaussian theory—the view that the diurnal variation is chiefly due to electrical movements in the upper regions of the atmosphere. In such a case, local conditions should have a comparatively small influence.

On two occasions the Southern Party took hourly observations of both the Horizontal Force and Dip. The observations are given in detail in the complete tables in Appendix B. As they do not seem to bring out at all distinctly the well known features of the diurnal changes, they can only be regarded as materials for obtaining a specially good mean for the day. They have, consequently, not been shown graphically. The two sets of hourly measurements of the Horizontal Force may be however useful as an indirect means of finding the temperature co-efficients of the moment of the magnet employed. The determination at Hiroshima gave the following expression for the magnetic moment (M) of the magnet in terms of the temperature (t) in degrees centigrade :—

$$M = 438.25 - .286\,(t-28) + .003\,(t-28)^2$$

Section V.

Comparison of Present with Former Results.

This Section will necessarily be a short one, inasmuch as magnetic measurements made in Japan have been somewhat limited in number. Excepting the observations made by Messrs. Sekino and Kōdari, and the few made by Mr. Schütt already referred to, no complete satisfactory observations have been made at any stations out of Tōkyō.

During the various expeditions sent out from year to year by the Tōkyō University for the measurement of the force of gravity by pendulum swinging, attempts were made at the same time to obtain measurements of certain of the magnetic constants. The first expedition of this kind was to the top of Fuji-yama under the direction of Professor Mendenhall. This was in the year 1880. In 1881, Messrs. Tanakadate, Fujisawa, and Tanaka, then students of physics, who had rendered efficient service in the first expedition, proceeded to Sapporo accompanied by Professor Chaplin, and there made like observations on gravity. In 1882, the expedition, consisting of Mr. Tanakadate, and two students of Physics, Messrs. Sakai and Yamaguchi, proceeded to Kagoshima and Naha, in the extreme South-west of Japan. And finally in 1884, Mr. Tanakadate accompanied by Messrs. Sawai, Hayasaki, and Saneyoshi, three students of Physics, proceeded to the Bonin Islands and there swung their pendulums. In all these expeditions magnetic measurements of a kind were made. In the third expedition only was any attempt made to measure the dip. This was done by balancing the inductive action of the earth's field upon an iron wire by means of a current circulating in a helix surrounding the wire. The wire and helix were placed alternately vertical and horizontal ; and the ratio of the current strengths required to effect the balance in the two cases gave the tangent of the angle of dip. In the other expeditions the dip was not measured. Excepting at the Bonin Islands the horizontal force was measured by swinging various magnets which had been already swung at Tōkyō, and which were again swung at Tōkyō on the return of the Party. The declination was observed at Kagoshima and Naha by means of an ordinary theodolite needle, the compass card being graduated only to half-degrees. At the Bonin Islands, however, the measurements of the horizontal force and of the declination were of a much higher order of merit. Here, indeed, Mr. Tanakadate used his first form of electro-magnetic declinometer ; and carried out complete series of deflection and vibration experiments for the determination of the horizontal force. The accounts of these various determinations are given in the Memoirs of the Science Department of the Tōkyō University (Nos. 5 and 7) and the several Appendices to No. 5. For the sake of comparison the results are here reproduced. The Horizontal Forces as given for all except Bonin are calculated on the assumption that the Horizontal Force at Tōkyō was .2964. This was the value obtained by the Bonin Island Party before they started on the expedition, and agrees perfectly with our own value.

Station.	Year.	Dip.	Horizontal Force.	Declination.
Fuji-yama Top	1880.		.2810	
Sapporo	1881.		.2659	
Kagoshima......	1882.	44° 56′	.3131	3° 18′.5 W.
Naha	1882.	38° 19′	.3354	2° 25′.5 „
Bonin	1884.		.3166	2° 3′.13 „

The latitudes and longitudes of the last three stations are as follows :—

	Latitude N.	Longitude E.
Kagoshima............	31° 35′ 30″	130° 30′ 10″
Naha	26 12 6	127 40 0
Bonin	27 4 11	139 45 45

The value of the Horizontal Force on the top of Fuji-yama is about 5 per cent smaller than would be the case at a normal station at its base. In the absence of measurements of Dip it is impossible to interpret the result. The value for Sapporo is distinctly smaller than the value obtained by us ; but it would hardly be safe to draw any conclusion from their comparison. The other stations lie quite outside the region surveyed by us. We may however compare the measurements made with the values given by means of the mean formulae which have been calculated. The results are given in the following table.

	Dip.	Horizontal Force.	Declination.
Kagoshima........	45° 55′.4	.3176	3° 47′.2
Naha	40 13 1	.3396	2° 11′.5
Bonin		.3262	1° 43′.6

If we compare these calculated values with the observed values given above, we see that Naha stands the test best, at least so far as the Horizontal Force and Declination are concerned. Especially as regards the latter, Naha fits in fairly well into the general system.

The circuit of Stations at which Mr. Schütt made his observations in 1880 may be said to touch our route in only one place—and that a very exceptional place, namely, Hakone. A general comparison, however, of the mean values for the district is possible. Thus the Dips give a mean of 49° 41′—about half a degree greater than what is indicated by the isoclinic lines as shown on our chart (Plate VIII) The mean of the declinations is 4° 19′—about 10′ smaller than the value as given by the mean formula. These differences are of a magnitude in no way extraordinary, seeing that the district is so highly volcanic. Hence how much of these differences may be referable to secular variation during eight years, it is quite impossible to say. The mean Horizontal Force obtained by Mr. Schütt for the same region is .30717, the mean of two determinations for Tōkyō being .30743. This value is so much larger than all other values ever observed by different experimentalists, that we are almost forced to regard it as erroneous, and to refer the discrepancy to some uncorrected instrumental error. No other measurement of the Horizontal Force in or near Tōkyō has given a value greater than .3—usually indeed from 1 to 2 per cent smaller.

So far, then, we have no sure evidence of any marked secular variations. It remains to compare the results of the present survey with those obtained by Messrs. Sekino and Kōdari during the winter months of 1882 and 1883. As already mentioned their Survey was not conducted with a due regard to a fair distribution of Stations over the whole country. Many of our Stations accordingly lie quite outside the routes pursued by them. Indeed of our 81 stations only 27 can be regarded as coincident with any of theirs. A few of these are only roughly coincident, but near enough to allow of a comparison being instituted. The following is the list of these 27 Stations. It will be noticed that after some of these, bracketted names are inserted. These bracketted names give Mr. Sekino's stations which are near enough to ours to warrant a comparison being made.

List of Common Stations.

Hakodate, Aomori, Nobechi, Gonohe, Morioka, Hanamaki, Yamagata, Yonezawa, Niigata, Ebisu, Ishinomaki, Shiogama, Shiraishi, Ishibashi, Shimmachi [Takasaki], Shimizu [Okitsu, Shizuoka], Nagoya, Hyōgo [Kōbe], Kōchi, Hiroshima, Fukuoka [Koyanose, Yamae], Saganoseki, Hososhima, Miyazaki, Nagasaki, Yatsushiro [Miyanobama], Shioya [Komegawaki].

The method of comparison was the simplest that could be imagined. Sekino's values of the magnetic elements at any station were subtracted from the corresponding values obtained on the present Survey. This gave a series of differences for each set of elements. The algebraic sum of these differences may then be assumed to give some hint as to the *existence*, at any rate, of a secular variation.

As regards the Dip there is a distinct tendency for the differences to be negative. That is, our values are on the whole smaller than Sekino's. Thus, out of the 27 Stations, there are only four, for which our values of the dip are greater than his. Dividing the algebraic sum of all the differences by the number of stations we get for the average difference —8′.8 or —7′.0, according as we include or neglect Hakodate, for which the difference (as much as —1° 10′.4) is peculiarly large. We may therefore regard this —7′.0 as an indication that the dip is subject to an annual diminution of about 2′ per year. This does not agree with the results of the observations made at the Naval Observatory,* which hint rather at a rate of increase.

As regards the Horizontal Forces, again, there is a marked tendency for the differences to be positive, six only out of the twenty-seven being negative. The mean difference is + .00091 ; or, in other words, our values are greater than Sekinos by fully one-third per cent. This means an annual rate of increase of .00023. This result is in agreement with the result already indicated by the observations made at the Naval Observatory.

The differences obtained by a comparison of the Total Forces are very nearly as often positive as negative. The general drift, however, is in the negative direction ; so that the Total Force seems to be subject to a mean diminution of —.00012 per year.

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* As this paper was passing through the press, this Observatory was incorporated with the University, and is now known as the Tōkyō Observatory.

In discussing the Declinations we come face to face with the objection already touched upon (see Section I), namely, the lack in the earlier survey of any attempt at obtaining a really good mean daily value at every station. If we take the values as they are given in Mr. Sekino's lists, we shall find, on the whole, absolutely no indication of a secular variation. The mean difference is —0′.07, an altogether insignificant quantity. If, however, we apply probable corrections to the observations, so as to reduce them to the daily mean, the mean difference will be + 0′.8,—that is, an increase of 0′.2 per year. As regards the declination, then, we may conclude that, within the period beginning 1883 and ending 1887, there is practically no change, or if there is, it is a very small change indeed. It looks almost as if we were just passing through a time of maximum declination.

Finally, it may be remarked that a comparison of our results with those of other experimenters leads to the conclusion that within the present decade there are but small evidences of secular change in the magnetic elements. There is a suggestion that the Dip is diminishing and the Horizontal Force increasing; but the Declination seems to have reached a stationary point.

Appendix A.

Inō Tadayoshi, the Japanese Surveyor and Cartographer.

Inō (originally Jimbō) Kageyu* was born in 1744 in a small village called Sawaramura in the province of Shimōsa, Japan. Inō was the name he acquired by marrying into a family, in accordance with the very usual Japanese custom.

His father-in-law was a *sake* brewer, conducting a business which had descended from father to son for many generations. On his death, affairs were found to be in a very bad state. Inō thereupon applied himself diligently to the business, and through his untiring efforts, combined with strict economy, he gradually amassed considerable wealth. In his fiftieth year, that is about 1794, he transferred the whole business to his son and began his scientific career.

Astronomy was the study to which he devoted himself. The books at his disposal were all in Chinese and contained many obscure passages which he in vain tried to understand. Ultimately he made his way to Yedo, and sat at the feet of the Takahashis, father and son, astronomers to the Shōgun. The elder Takahashi died in 1804, and it was with the younger Takahashi that Inō had most to do. Certain letters written to him by Inō still exist, and their style is such as would naturally be used by one addressing a former teacher.

In 1800 Inō set out by permission of the Government, to survey the Island of Ezo† at his own expense. In the following year he

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* Inō (伊能) is the *myōji* (名字) or family name, and Kageyu (勘解由) the *tsūshō* (通稱) or common name. His *jitsu-mei* or *na-nori* (實名, 名乘), which means literally *real name* and was used only on important occasions, was Tadayoshi (忠敬) or Chūkei, as some pronounce it.

† In the earlier pages of this paper, the more familiar spelling Yezo is inadvertently used. Ezo, however, is better phonetically, and is the spelling sanctioned by the Romanization Society of Japan. As the former name of Tōkyō is quite obsolete, it is best to adhere to the western historical spelling Yedo—although it too should be Edo.

was instructed to survey all the coasts and islands of Japan. The survey of the north-eastern coast was finished in 1804, and by 1818 his labours in the field were completed. It should be mentioned, perhaps, that certain parts of the coast were surveyed very imperfectly —such as the eastern and the north-western coasts. Exactly when he died is not known certainly, but for some time after the completion of the survey he seems to have been engaged in the construction of his maps.

The instruments which Inō employed in the survey were destroyed by fire; but in 1828 two instruments, said to be exact copies of the original ones, were made by Ōno Yasaburo, the father of the late engineer who constructed the Mint at Ōsaka. These are now in the possession of the Meteorological Office. A compass-needle, made and used by Inō, has however been preserved by his family.

Ōno's instruments are two, one for measuring azimuths and the other for measuring altitudes. The former is simply a horizontal circular disc of copper 19 inches in diameter, graduated by radial lines into degrees. Seven concentric circles are traced near the extremity of the disk at such distances apart that, when a straight line is engraved joining the point where the inmost circle cuts a given radial line to the point where the outmost circle cuts the next radial line, this so-called diagonal gives by its intersections with the intermediate circles angular intervals corresponding to 10′ or one-sixth of a degree. The graduated circular disc rests on three legs provided with levelling screws. From its centre rises an upright wooden pillar which is surmounted by a tube (or perhaps a telescope) for sighting distant objects. The levelling of the circle is accomplished by means of a brass "plummet" hanging down one side of the upright pillar. The pillar rotates freely, and carries with it a horizontal rod resting on the graduated circle. The position of this rod indicates at once the angle to be read.

The instrument for measuring altitudes is a brass quadrant, 19 inches in radius, with a telescope fixed to one of the straight limbs. The whole is mounted on an upright, wooden pillar resting on three legs. The telescope and quadrant, which move together in a vertical plane about a pivot passing approximately through the centre of gravity, can be clamped in any required position. From the angle of the quadrant a "plummet-line," in the form of a brass rod, hangs. The position of this rod, as it hangs just free of the quadrant arc, indicates the angle to be read. The quadrant is graduated in a manner very similar to the azimuth circle, only to a finer degree of division. The radial lines measure to thirds of a degree; and by means of the "diagonal-scale" arrangement, angles might be read to half-minutes. On the azimuth circle again it would be difficult if not impossible to read to minutes even.

With such instruments did Inō carry out his survey. About 1135 direct measurements of latitudes were taken by means of the quadrant. The distances between successive stations were measured by three distinct methods. Ropes were used as our land surveyors use chains; also a kind of wheel or roller, the number of revolutions of which measured the distance travelled. Then with the azimuth instrument in combination with the compass a triangulation by means of prominent hills and land-marks was carried out. From the distances so obtained, the longitudes seem to have been calculated.

The results of Inō's labours are given in the "Dai Nippon Enkai-jis-soku-roku," or, the Record of the True Survey of the Coasts of Japan (1821, 14 volumes). This treatise existed simply in manuscript till 1870 (Meiji, 3), when it was published in proper book form by the Tōkyō University (Hitotsu-bashi)—at that time known as the Daigaku Nankō. Three kinds of maps were constructed, the largest consisting of 30 different sheets, the medium sized of two, and the smallest of one. These maps have been the basis of all subsequent ones; and for many places in Japan Inō's measurements of latitude (and longitude) are the only ones which have as yet been made.

On completion of the survey, Takahashi published an epitome of the results in a book having the title, "Inō's Table of Latitudes and Longitudes." From certain remarks in the preface to this work, it would appear that Inō rather doubted the truth of the magnetic variation, and was inclined to refer its appearance in Europe to carelessness either in the construction or handling of the compass needle. There can be little doubt, however, as to the accuracy of Inō's own observation that in Japan at that time the mean direction of magnetic north coincided practically with the direction of geographical north.

According to Inō the mean length of one degree of latitude is 28.2 *ri*. From a copy of the standard *shaku* used by Inō—the original seems to have been lost by fire—this distance has been estimated as equivalent to 110.7 kilometres. The true value is 111 kilometres. The lengths of a degree of longitude in latitudes 35°, 40°, 44° are given as 23.1 *ri*, 21.6 *ri* and 20.285 *ri* respectively. Reduced to kilometres, these are 90.7, 84.8 and 79.66. The true values are 91.08, 85.18, 79.99, differing in no case from Inō's values by as much as one-half per cent.

When we consider the age at which Inō began his scientific career—an age at which most men are thinking of retiring from the busy field of life—and when further we call to mind the rude instruments with which he did his work, we cannot but feel that we have here a man worthy of a high place amongst the scientific leaders of the last generation. In these days of candid criticism, his work has stood the severest tests and remains a grand monument of his perseverance, patience and accuracy. His greatness is now fully appreciated, and some six or seven years ago received Imperial recognition. The rank of Shō-shi-i (正四位), or Senior 4th class, was at that time conferred on him. Excepting nobles, very few held that rank in the days when Inō flourished, although it is common enough nowadays. Such posthumous honours are, besides, very rare. A stone monument in his honour is very soon to be put up in Tōkyō.

In preparing this short biography of Inō, I have been fortunate in the hearty assistance of Mr. Arai, Superintendent of the Meteorological Office, and of Professor Yamagawa and Mr. Nagaoka of the Imperial University, without whose aid indeed I could have done little or nothing.

Appendix B.

Complete Lists of Observations made.

The following lists contain all the observations made during the survey, together with the dates and hours at which they were taken. The first list contains the Dips, the second the Horizontal Forces, and the third the Declinations.

The only point which calls for remark is in connection with the tabulation of the Horizontal Forces. It will be noticed that for the stations of the Northern Party, an extra column headed M_0 is added. This gives the magnetic moment of the magnet reduced to 0° C. The reductions were made in accordance with the table of corrections supplied by the Kew authorities along with the magnetometer. A glance down the column will show that during the survey the magnet has been subject to a gradual diminution in moment. This is no doubt due largely to the jolting experienced during travelling. On two occasions a somewhat sudden change seems to have occurred—namely between Hakodate and Sapporo, and at Ebisu. In the former case the magnetism of the steamer may have had a permanent effect; while in the latter the cause is no doubt to be traced to the exceptionally high temperature at which the experiments were made. In the circumstances of the case, it is quite probable that the temperature coefficients may have become altered during the survey; and that the table of corrections drawn up at Kew may no longer apply. At Ueda, the value of M_0 differs by one-half per cent. from the values at contiguous stations—much too large a discrepancy to be accounted on any other ground than that of a bad observation. Fortunately Ueda, being in a very hilly and volcanic district, cannot be regarded as an important station.

List I. The Dips.

Station.	Dip.	Date and Hour.		
Ishibashi	50° 7′.3	June	23	7.00 a.m.
Yabuki	50° 57′.3	„	25	6.42 p.m.
Matsukawa	51° 13′.8	„	26	6.35 a.m.
Shiraishi	51° 20′.9	„	28	7.37 a.m.
Shiogama	51° 50′.1	„	29	7.54 a.m.
	51° 46′.6	„	„	2.38 p.m.
	51° 49′.5	„	30	8.03 a.m.
Ishinomaki	51° 41′.9 ?	July	1	7.14 a.m.
	51° 56′.2	„	„	3.26 p.m.
Ichinoseki	52° 32′.0	„	3	6.58 a.m.
Hanamaki	53° 17′.7	„	4	8.26 a.m.
Morioka...	53° 10′.9	„	6	8.10 a.m.
Miyako	53° 36′.0	„	8	5.35 p.m.
Kuji...	54° 7′.4	„	10	3.15 p.m.
Hachinohe	54° 23′.3	„	12	7.38 a.m.
Gonohe	54° 39′.4	„	„	4.48 p.m.
Nobechi...	54° 44′.1	„	13	5.20 p.m.
Aomori	54° 47′.1	„	15	7.43 a.m.
Hakodate	55° 35′.5	„	16	3.27 p.m.
Sapporo...	56° 41′.5	„	19	4.38 p.m.
Kiitup	56° 48′.4	„	24	5.33 p.m.
Nemuro...	57° 7′.1	„	25	4.28 p.m.
Hirosaki	54° 24′.6	„	29	5.21 p.m.
Ōdate	54° 12′.6	„	31	7.45 a.m.
Nōshiro...	54° 17′.8	August	1	5.38 p.m.
Akita	53° 37′.6	„	3	7.15 a.m.
Kariwano	53° 30′.5	„	„	6.50 p.m.
Yokote	53° 5′.0	„	4	afternoon.
Innai	52° 51′.1	„	5	4.05 p.m.

Station.	Dip.	Date and Hour.
Shinjō	52° 37′.2	August 7 6.30 a.m.
Sakata	52° 51′.9	„ 8 6.49 a.m.
Yamagata	52° 1′.6	„ 9 5.20 p.m.
Yonezawa	51° 31′.6	„ 11 4.58 p.m.
Oguni	51° 47′.2	„ 13 7.20 a.m.
Nakajō	51° 49′.2	„ 14 7.15 a.m.
Ebisu	52° 3′.7	„ 15 11.15 a.m.
Niigata	51° 56′.9	„ 16 7.15 a.m.
Kashiwazaki	51° 55′.4	„ 17 5.25 p.m.
Sekiyama	50° 55′.7	„ 18 6.15 p.m.
Ueda	50° 3′.3	„ 20 6.32 p.m.
Takanomachi	49° 40′.6	„ 21 6.15 p.m.
Nagasawa	49° 8′.8	„ 22 6.35 p.m.
Kōfu...	50° 5′.7	„ 23 5.43 p.m.
Hara	48° 33′.3	„ 25 8.01 a.m.
Hakone	47° 25′.7	„ „ 6.31 p.m.
Ōtsu...	48° 33′.8	„ 26 6.15 p.m.
Hōjō...	48° 32′.6	„ 28 7.33 a.m.
Katsuura	48° 30′.6	„ 30 6.53 a.m.
Tōgane	49° 2′.5	„ 31 8.13 a.m.
Chōshi	48° 43′.1	September 1 8.15 a.m.
Kioroshi...	49° 32′.5	„ 2 8.18 a.m.
Shimmachi	49° 56′.0	„ 25 5.43 p.m.
Ōmiya	49° 39′.0	„ 26 11.02 a.m.
Shimoda	47° 57′.4	June 23 8.45 a.m.
	47° 59′.6	„ „ 1.15 p.m.
	48° 1′.5	„ „ night.
Shimizu...	48° 39′.8	„ 25 5.28 p.m.
	48° 43′.5	„ 26 11.15 a.m.
	48° 40′.2	„ „ 8.46 p.m.
	48° 41′.8	„ 27 10.18 a.m.

Station.	Dip.	Date and Hour.			
Nagoya	48° 58′.7	June	29	5.57	p.m.
	48° 57′.7	„	30	10.30	a.m.
	48° 58′.3	„	„	5.12	p.m.
Kamiyashiro	48° 16′.0	July	4	8.03	a.m.
	48° 17′.2	„	„	3.35	p.m.
	48° 17′.2	„	„	7.08	„
Nagahama	49° 15′.6	„	6	11.21	a.m.
	49° 19′.0	„	„	4.30	p.m.
	49° 18′.3	„	7	8.20	a.m.
Hyōgo	48° 42′.9	„	8	3.49	p.m.
	48° 43′.1	„	„	9.22	„
	48° 41′.0	„	9	10.48	a.m.
Tokushima	48° 0′.8	„	10	4.49	p.m.
	48° 1′.3	„	11	8.53	a.m.
	48° 0′.0	„	„	11.10	„
	47° 59′.6	„	„	1.04	p.m.
Kōchi	47° 32′.2	„	17	1.45	a.m.
	47° 33′.2	„	„	6.27	„
	47° 30′.6	„	„	10.25	„
Minabe	47° 46′.8	„	21	7.47	a.m.
	47° 45′.4	„	22	7.33	„
	47° 45′.8	„	„	8.28	„
	47° 46′.3	„	„	9.31	„
	47° 46′.0	„	„	10.30	„
	47° 46′.7	„	„	11.29	„
	47° 46′.5	„	„	0.31	p.m.
	47° 45′.5	„	„	1.28	„
	47° 47′.0	„	„	2.36	„
	47° 46′.2	„	„	3.20	„
	47° 47′.3	„	„	4.27	„
	47° 45′.9	„	„	5.27	„
	47° 46′.5	„	„	7.54	„

Station.	Dip.	Date and Hour.			
Okayama	48° 47′.5	July	26	6.48	a.m.
	48° 47′.3	„	„	0.42	p.m.
	48° 48′.9	„	„	4.38	„
Hiroshima	48° 39′.4	„	28	11.29	a.m.
	48° 40′.4	„	„	5.03	p.m.
	48° 40′.4	„	30	8.05	a.m.
	48° 38′.0	„	„	11.25	„
Wakwan (Korea)	50° 10′.1	August	6	7.33	a.m.
	50° 9′.3	„	„	11.42	„
	50° 8′.5	„	„	4.33	p.m.
Meho (Korea)	50° 27′.0	„	10	7.14	p.m.
	50° 28′.9	„	11	8.29	a.m.
	50° 26′.1	„	„	11.53	„
	50° 26′.0	„	„	3.48	p.m.
Pusan (Korea)	50° 0′.6	„	13	10.36	a.m.
	50° 1′.7	„	„	1.04	p.m.
	50° 1′.4	„	„	4.58	„
Ōmizutare (Korea)	50° 3′.1	„	14	5.37	p.m.
Kurosaki (Korea)	50° 7′.8	„	15	9.50	a.m.
	50° 6′.6	„	„	0.13	p.m.
Kurosaki Cape (Korea)	49° 55′.3	„	„	3.32	p.m.
Shiinokijima Cape (Korea)	51° 2′.7	„	„	5.34	p.m.
Shiinokijima	50° 7′.5	„	„	8.14	p.m.
Fukuoka	48° 8′.3	„	22	8.46	a.m.
	48° 4′.0	„	„	11.31	„
	48° 7′.1	„	„	4.21	p.m.
Nakatsu	48° 1′.6	„	24	2.25	p.m.
	48° 1′.0	„	„	5.02	„
	48° 3′.4	„	25	9.20	a.m.
Saganoseki	47° 21′.6	„	28	7.09	a.m.

Station.	Dip.	Date and Hour.
Saganoseki *(continued)* ...	47° 19′.3	August 28 0.04 p.m.
	47° 21′.7	„ „ 4.19 „
Hichiyamura	46° 26′.6	„ 29 4.39 p.m.
	46° 27′.9	„ 30 9.06 a.m.
	46° 28′.6	„ „ 11.22 „
Miyazaki	45° 50′.0	„ 31 0.52 p.m.
	45° 51′.7	„ „ 4.21 „
	45° 52′.1	September 2 8.16 a.m.
Yatsushiro	46° 39′.8	„ 6 0.04 p.m.
	46° 40′.3	„ „ 5.03 „
	46° 39′.9	„ 7 10.26 a.m.
Nagasaki	46° 57′.1	„ 10 10.33 a.m.
Hagi	48° 44′.6	„ 13 11.39 a.m.
	48° 44′.0	„ „ 1.37 p.m.
	48° 43′.6	„ „ 5.03 „
Hamada...	50° 12′.8	„ 16 5.34 p.m.
	50° 11′.9	„ 17 8.01 a.m.
	50° 11′.9	„ „ 0.15 p.m.
Hamada Bridge	49° 50′.5	„ „
Asaimura Ōte	49° 49′.9	„ „
Kurokawa	50° 4′.8	„ „
Sumiyoshiyama	49° 54′.7	„ „
Matsue	50° 0′.9	„ 20 2.47 p.m.
	50° 1′.6	„ „ 5.52 „
	50° 3′.0	„ 21 7.46 a.m.
Imaichi	50° 14′.2	„ 22 9.35 a.m.
	50° 12′.0	„ „ 0.17 p.m.
	50° 13′.1	„ „ 5.50 „
Kanōmura	49° 42′.3	„ 25 0.53 p.m.
	49° 42′.7	„ „ 5.28 „
	49° 45′.3	„ 26 8.38 a.m.

Station.	Dip.	Date and Hour.
Koyamamura … … … … …	49° 54′.1	September 26 2.12 p.m.
	49° 55′.0	„ „ 5.50 „
	49° 53′.2	„ 27 8.34 a.m.
	49° 53′.0	„ „ 11.56 „
Maizuru… … … … … … …	49° 24′.9	„ 30 0.34 p.m.
	49° 24′.3	„ „ 5.33 „
	49° 25′.2	October 1 8.54 a.m.
Obama … … … … … … …	49° 30′.7	„ 2 0.21 p.m.
	49° 30′.4	„ „ 5.03 „
	49° 30′.2	„ 3 9.22 a.m.
Shioyaura … … … … … …	50° 31′.1	„ 4 2.49 p.m.
	50° 31′.5	„ 5 7.58 a.m.
	50° 31′.8	„ „ 9.17 „
	50° 32′.6	„ „ 9.44 „
	50° 32′.0	„ „ 10.27 „
	50° 33′.6.	„ „ 11.14 „
	50° 32′.9	„ „ 11.50 „
	50° 30′.0	„ „ 0.51 p.m.
	50° 29′.6	„ „ 1.31 „
	50° 29′.6	„ „ 2.12 „
	50° 29′.2	„ „ 2.48 „
	50° 30′.0	„ „ 3.31 „
	50° 29′.0	„ „ 4.20 „
	50° 29′.9	„ „ 4.48 „
	50° 29′.6	„ „ 5.26 „
Nanao … … … … … … …	51° 14′.8	„ 8 1.54 p.m.
	51° 15′.4	„ „ 5.05 „
Tōkyō (W)… … … … … …	49° 10′.8	November 8 11.09 a.m.
	49° 11′.1	„ „ 2.35 p.m.
„ (E) … … … … … …	49° 13′.1	„ 10 11.19 a.m.
	49° 12′.9	„ „ 2.31 p.m.

List II. The Horizontal Forces, Temperatures, and Magnetic Moments.

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour.		
Ishibashi	.29143	937.15	21°.0 c.	944.37	June	23	6.00 a.m.
Yabuki...	.28952	938.60	20°.4	945.54	„	25	8.00 a.m.
Matsukawa	.28785	937.78	20°.0	944.60	„	26	7.00 a.m.
Shiraishi	.28830	936.72	20°.1	943.58	„	28	7.30 a.m.
Shiogama	.28755	935.41	22°.6	943.21	„	29	9.00 a.m.
	.28715	933.79	22°.7	941.59	„	30	6.00 „
Ishinomaki...	.28777	936.53	21°.2	943.82	July	1	8.00 a.m.
	.28728	937.28	22°.3	944.50	„	„	5.30 p.m.
Ichinoseki	.28426	936.20	18°.0	942.65	„	3	7.30 a.m.
Hanamaki	.28032	938.04	18°.4	944.28	„	5	7.30 a.m.
Morioka	.28180	937.26	20°.8	944.39	„	6	8.00 a.m.
Miyako...	.27876	934.70	23°.2	942.76	„	8	4.00 p.m.
Kuji	.27983	935.56	23°.4	943.67	„	10	4.00 p.m.
Hachinohe...	.27687	937.02	22°.2	944.69	„	12	8.00 a.m.
Gonohe...	.27615	933.75	24°.3	942.24	„	„	5.00 p.m.
Nobechi	.27576	934.52	24°.1	942.91	„	13	6.00 p.m.
Aomori...	.27727	935.88	22°.7	943.73	„	15	8.00 a.m.
Hakodate	.27318	935.75	22°.3	943.19	„	16	5.00 p.m.
Sapporo	.26766	931.52	25°.2	940.29	„	19	5.30 p.m.
Kiitup	.26667	933.83	23°.1	941.82	„	24	4.30 p.m.
Nemuro	.26025	931.86	26°.3	941.07	„	25	4.00 p.m.
Hirosaki	.27819	932.97	26°.3	942.19	„	29	4.30 p.m.
Ōdate	.27743	935.34	20°.3	942.24	„	31	6.00 a.m.
Nōshiro	.27854	930.85	31°.0	941.89	Aug.	1	4.00 p.m.
Akita	.28275	932.18	25°.2	941.00	„	3	6.15 a.m.
Kariwano	.28224	934.50	26°.4	943.78	„	4	6.30 a.m.
Yokote...	.28309	932.91	26°.4	942.17	„	5	7.00 a.m.
Innai	.28226	931.47	28°.0	941.35	„	„	4.30 p.m.

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour.
Shinjō	.28524	931.43	27°.4 c.	941.07	Aug. 7 7.00 p.m.
Sakata	.28465	931.94	27°.6	941.65	„ 8 7.00 a.m.
Yamagata	.28651	932.80	25°.4	941.63	„ 10 7.00 a.m.
Yonezawa	.28836	931.28	30°.3	942.04	„ 11 5.30 p.m.
Oguni	.28748	933.58	21°.8	941.02	„ 13 7.00 a.m.
Nakajō	.28762	930.23	28°.3	940.20	„ 14 7.30 a.m.
Ebisu	.28950	923.57	35°.0	936.16	„ 15 noon
Niigata	.28699	928.32	28°.1	938.19	„ 16 7.30 a.m.
Kashiwazaki	.28878	927.66	29°.7	938.17	„ 17 6.00 a.m.
Sekiyama	.29152	930.36	27°.1	939.83	„ 19 8.15 a.m.
Ueda	.29629	936.59	21°.8	944.06	„ 21 6.00 a.m.
Takanomachi	.29502	928.90	26°.6	938.19	„ „ 6.00 p.m.
Kōfu	.29261	926.19	33°.4	938.40	„ 23 4.30 p.m.
Hara	.30150	929.69	25°.0	938.37	„ 25 6.35 a.m.
Hakone	.30490	929.16	25°.4	937.97	„ „ 5.00 p.m.
Ōtsu	.29655	927.19	29°.2	937.45	„ 26 5.00 p.m.
Hōjō	.29639	927.85	27°.3	937.41	„ 28 6.00 a.m.
	.29621	926.75	29°.4	937.10	„ „ 4.00 p.m.
Katsuura	.29607	929.20	25°.2	937.95	„ 29 5.30 p.m.
Tōgane	.29533	929.22	22°.4	936.87	„ 31 6.15 a.m.
Chōshi	.29696	928.60	27°.0	938.02	Sept. 1 7.20 a.m.
Kioroshi	.29377	930.46	23°.8	938.69	„ 2 7.00 a.m.
Shimmachi	.29367	929.65	19°.0	935.86	„ 25 5.00 p.m.
Ōmiya	.29428	928.92	20°.1	935.73	„ 26 10.20 a.m.
Shimoda	.29993	443.54	20°.7		June 23 10.30 a.m.
	.30001	443.42	21°.2		„ „ 3.13 p.m.
	.29980	441.17	21°.8		„ „ 8.21 „
Shimizu	.30164	442.19	21°.3		„ 25 afternoon
	.30024	443.39	21°.4		„ „ „
	.29983	443.19	26°.0		„ 26 2.10 p.m.
	.30013	441.46	25°.2		„ „ 4.31 „

Station.	Horiz. Force.	M.	Temp.	M_o.	Date & Hour.
Shimizu (*continued*)	.29929	441.95	25°.1 c.		June 27 8.48 a.m.
Nagoya	.29874	442.91	26°.9		„ 30 9.02 a.m.
	.29849	442.67	29°.7		„ „ 11.44 „
	.29990	442.11	24°.2		„ „ 6.26 p.m.
Kamiyashiro	.30225	441.58	24°.7		July 4 8.46 a.m.
	.30175	441.89	26°.3		„ „ 11.25 „
	.30196	442.11	24°.8		„ „ 5.25 p.m.
Nagahama	.30050	440.18	26°.8		„ 6 0.53 p.m.
	.30017	441.05	23°.7		„ „ 6.03 „
	.30012	440.81	24°.9		„ 7 9.02 a.m.
Hyōgo	.30280	440.59	29°.3		„ 8 2.07 p.m.
	.30259	441.10	26°.5		„ „ 4.48 „
	.30266	442.545	26°.4		„ 9 9.10 a.m.
	.30373	439.59	31°.6		„ „ 1.20 p.m.
Tokushima	.30730	437.56	27°.8		„ 10 6.51 p.m.
	.30516	440.58	27°.3		„ 11 9.53 a.m.
	.30562	440.29	28°.2		„ „ 0.10 p.m.
Kōchi	.31098	436.69	27°.9		„ 17 0.16 a.m.
	.31066	436.72	29°.0		„ „ 7.48 „
	.30855	439.08	31°.7		„ „ 11.55 „
Minabe	.30476	439.64	31°.6		„ 21 9.57 a.m.
	.30509	439.25	31°.5		„ „ 11.30 „
	.30494	438.86	32°.8		„ „ 2.55 p.m.
	.30496	439.48	30°.7		„ „ 5.56 „
Okayama	.30431	438.90	31°.4		„ 26 9.00 a.m.
	.30461	438.45	34°.2		„ „ 1.28 p.m.
	.30474	438.60	33°.0		„ „ 5.07 „
Hiroshima	.30732	438.76	34°.15		„ 28 0.41 p.m.
	.30678	438.56	35°.2		„ „ 4.13 „
	.30747	441.08	25°.0		„ 29 6.32 a.m.
	.30722	440.95	26°.9		„ „ 7.35 „

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour.
Hiroshima (*continued*)	.30688	440.19	29°.9 c.		July 29 8.37 a.m.
	.307185	439.17	34°.15		„ „ 9.32 „
	.30730	438.34	35°.75		„ „ 10.31 „
	.30719	437.96	37°.0		„ „ 11.35 „
	.30731	438.12	36°.0		„ „ 0.32 p.m.
	.30709	438.11	36°.2		„ „ 1.38 „
	.30724	437.96	35°.75		„ „ 2.32 „
	.30726	438.48	35°.1		„ „ 3.32 „
	.30682	439.18	33°.3		„ „ 4.35 „
	.30712	438.945	30°.5		„ „ 5.32 „
	.30691	439.96	29°.0		„ „ 6.47 p.m.
Wakwan (Korea) ...	.30447	439.68	31°.9		Aug. 6 10.06 a.m.
	.30470	438.87	32°.7		„ „ 1.39 p.m.
	.30485	440.07	27°.6		„ „ 5.19 „
Mēho (Korea)	.30694	440.52	26°.8		„ 11 6.34 a.m.
	.30603	439.33	32°.8		„ „ 11.01 „
	.30691	437.50	36°.1		„ „ 2.08 p.m.
Pusan (Korea)	.30909	438.63	29°.2		„ 13 10.56 a.m.
	.30923	436.81	34°.3		„ „ 2.23 p.m.
	.30891	438.18	29°.2		„ „ 4.06 „
Kurosaki	.30616	437.56	32°.6		„ 15 11.24 a.m.
Shiinokijima	.30518	438.57	28°.3		„ „ 6.40 p.m.
Fukuoka	.31049	438.14	30°.5		„ 22 7.44 a.m.
	.31008	437.29	32°.5		„ „ 10.40 „
	.30999	436.69	34°.0		„ „ 3.24 p.m.
Nakatsu	.30992	436.27	35°.8		„ 24 1.26 p.m.
	.31002	436.78	34°.9		„ „ 4.23 „
	.31006	438.43	28°.8		„ 25 8.27 a.m.
Saganoseki	.31124	437.98	30°.7		„ 28 8.28 a.m.
	.31138	437.80	32°.5		„ „ 11.10 „
	.31148	437.68	30°.4		„ „ 3.37 p.m.

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour.
Hichiyamura	.31392	437.48	31°.4 c.		Aug. 29 3.49 p.m.
	.31349	439.11	27°.8		„ 30 8.07 a.m.
	.31361	437.44	34°.0		„ „ 10.45 „
Miyazaki	.31608	438.035	31°.4		Sept. 1 8.53 a.m.
	.31575	437.41	32°.9		„ „ 9.31 „
	.31567	437.07	34°.8		„ „ 10.12 „
	.31541	436.945	34°.6		„ „ 10.51 „
	.31523	437.01	34°.8		„ „ 11.31 „
	.31530	437.01	34°.8		„ „ 0.11 p.m.
	.31590	437.07	34°.0		„ „ 1.30 „
	.31589	436.14	34°.5		„ „ 2.10 „
	.31549	436.96	33°.8		„ „ 2.50 „
	.31545	437.19	33°.35		„ „ 3.31 „
	.31603	437.05	33°.15		„ „ 4.12 „
	.31567	437.58	31°.6		„ „ 4.49 „
	.31557	437.94	29°.6		„ „ 5.29 „
	.31523	438.44	28°.35		„ „ 6.09 „
Yatsushiro...	.31503	437.26	32°.6		„ 6 10.48 a.m.
	.31504	437.55	31°.8		„ „ 4.20 p.m.
	.31463	437.16	31°.5		„ „ 9.33 „
Nagasaki	.31392	437.055	33°.9		„ 10 9.43 a.m.
Hagi	.30873	437.16	32°.2		„ 13 11.20 a.m.
	.30905	437.77	29°.4		„ „ 0.48 p.m.
	.30881	438.74	26°.1		„ „ 4.18 „
Hamada	.30034	438.88	26°.0		„ 16 4.32 p.m.
	.30039	440.80	18°.9		„ 17 7.12 a.m.
	.30063	437.42	31°.2		„ „ 11.21 „
Matsue...	.30001	438.70	26°.5		„ 20 1.04 p.m.
	.30002	438.65	26°.0		„ „ 4.55 „
	.30016	440.99	19°.9		„ 21 7.00 a.m.
Imaichi...	.29999	438.88	24°.2		„ 22 8.53 a.m.

Station.	Horiz. Force.	M.	Temp.	M_0.	Date & Hour.
Imaichi (*continued*)	.30053	438.23	29°.3 c.		Sept. 22 11.40 a.m.
	.30010	439.03	23°.7		„ „ 5.14 p.m.
Kanōmura	.30161	439.88	21°.9		„ 25 0.09 p.m.
	.30154	440.05	20°.9		„ „ 4.42 „
	.30116	441.96	14°.7		„ 26 7.20 a.m.
Koyamamura	.29978	438.95	24°.3		„ „ 1.51 p.m.
	.29959	439.195	21°.9		„ „ 5.07 „
	.30023	439.48	21°.3		„ 27 7.54 a.m.
	.29976	437.90	28°.7		„ „ 10.26 „
Maizuru	.30092	439.01	25°.3		„ 30 11.49 a.m.
	.30094	439.66	21°.5		„ „ 4.45 p.m.
	.30105	441.08	16°.8		Oct. 1 7.07 a.m.
Obama	.30001	438.87	24°.7		„ 2 11.34 a.m.
	.30039	439.56	21°.2		„ „ 4.33 p.m.
	.30014	441.40	16°.8		„ 3 8.00 a.m.
Shioyaura	.29542	438.56	26°.9		„ 4 0.02 p.m.
	.29549	438.50	26°.0		„ „ 4.53 „
	.29575	439.74	20°.6		„ 5 7.26 a.m.
Nanao	.29379	441.36	16°.8		„ 8 9.05 a.m.
	.29401	440.87	19°.2		„ „ 0.59 p.m.
	.29416	440.00	20°.6		.. „ 4.33 „
Tōkyō (W)...	.29682	438.87	23°.4		Nov. 8 11.52 a.m.
	.29670	438.45	25°.4		„ „ 1.39 p.m.
	.29633	440.49	17°.1		„ „ 4.20 „
„ (E)	.29622	439.73	19°.7		„ 10 9.29 a.m.
	.29638	439.40	22°.1		„ „ 1.01 p.m.
	.29606	441.04	16°.8		„ „ 4.15 „

List III. The Declinations.

Station.	Declin.	How taken.	Date & Hour.			
Ishibashi	4° 1′.6	Polaris	June	23	10.31	p.m.
	3° 59′.7	Jupiter	,,	,,	10.15	,,
Yabuki	4° 29′.5	Sun	,,	25	7.24	a.m.
Matsukawa	4° 29′.6	Polaris	,,	,,	11.09	p.m.
Shiraishi...	4° 33′.7	Sun	,,	28	10.14	a.m.
Shiogama...	5° 9′.0	Jupiter	,,	29	9.29	p.m.
	5° 5′.5	Polaris	,,	,,	9.42	,,
	5° 10′.2	Sun	,,	30	6.37	a.m.
Ishinomaki	4° 56′.5	Sun	June	30	6.00	,,
	5° 3′.3	,,	July	1	9.00	a.m.
	5° 5′.0	Spica	,,	,,	8.54	p.m.
Hanamaki...	5° 25′.2	Polaris	,,	4	8.50	p.m.
Morioka	4° 59′.9	Polaris	,,	5	8.40	p.m.
	5° 5′.0	Sun	,,	,,	5.20	,,
Miyako	5° 51′.0	Polaris	,,	8	9.42	p.m.
	5° 46′.0	Sun	,,	,,	5.01	,,
	5° 44′.0	,,	,,	,,	7.05	a.m.
Kuji	4° 38′.5	Sun	,,	10	5.36	p.m.
	4° 36′.8	Venus	,,	,,	8.24	,,
Hachinohe	4° 32′.6	Polaris	,,	11	11.10	p.m.
Gonohe	4° 57′.7	Polaris	,,	12	9.32	p.m.
	5° 12′.9	Sun	,,	,,	3.32	,,
Nobechi	5° 31′.7	Polaris	,,	13	8.55	p.m.
Aomori	5° 22′.2	Polaris	,,	14	9.20	p.m.
Hakodate...	5° 33′.7	Sun	,,	17	5.13	p.m.
	5° 31′.3	Polaris	,,	21	10.12	,,
Sapporo	5° 59′.0	Sun	,,	20	6.36	a.m.
Kiitup...	4° 46′.0	Sun	,,	24	4.03	p.m.
Nemuro	4° 21′.3	Polaris	,,	25	9.31	p.m.

Station.	Declin.	How taken.	Date & Hour.		
Hirosaki	5° 23′.3	Polaris	July	29	8.11 p.m.
Ōdate	5° 15′.7	Polaris	,,	30	8.09 p.m.
Nōshiro	5° 32′.3	Polaris	August	1	9.13 p.m.
Akita	5° 9′.3	Polaris	,,	2	9.34 p.m.
Kariwano	5° 9′.2	Polaris	,,	3	8.40 p.m.
Yokote	5° 23′.1	Polaris	,,	4	8.17 p.m.
Innai	5° 9′.7	Sun	,,	6	7.08 a.m.
Shinjō	4° 56′.9	Sun	,,	7	8.09 a.m.
Sakata	5° 11′.0	Polaris	,,	7	8.45 p.m.
Yamagata	4° 32′.6	Polaris	,,	9	9.06 p.m.
Yonezawa	4° 32′.6	Polaris	,,	11	7.56 p.m.
Oguni	4° 51′.4	Polaris	,,	12	8.19 p.m.
Nakajō	5° 0′.3	Polaris	,,	13	9.56 p.m.
Ebisu	5° 4′.3	Sun	,,	15	11.47 a.m.
Niigata	5° 9′.4	Polaris	,,	,,	9.05 p.m.
Kashiwazaki	5° 3′.4	Polaris	,,	17	10.14 p.m.
Sekiyama	4° 36′.2	Polaris	,,	19	3.36 a.m.
Takanomachi	4° 3′.8	Sun	,,	21	3.53 p.m.
Kōfu	4° 32′.4	Polaris	,,	23	8.24 p.m.
Hara	4° 29′.4	Polaris	,,	24	8.00 p.m.
Hakone	2° 24′.0	Sun	,,	25	4.13 p.m.
Ōtsu	4° 19′.2	Polaris	,,	26	8.40 p.m.
Hōjō	4° 23′.4	Polaris	,,	27	8.18 p.m.
Katsuura	4° 1′.5	Polaris	,,	29	8.18 p.m.
Tōgane	4° 13′.6	Polaris	,,	30	8.31 p.m.
Chōshi	4° 19′.2	Polaris	,,	31	10.45 p.m.
Kioroshi	4° 25′.9	Polaris	September	1	10.55 p.m.
Shimmachi	4° 45′.7	Polaris	,,	25	7.28 p.m.
Ōmiya	4° 35′.9	Sun	,,	26	9.51 a.m.
Shimoda	4° 14′ 8″		June	23	11.30 a.m.
	4° 17′13″		,,	,,	1.33 p.m.

Station.	Declin.	Date & Hour.			
Shimoda (*continued*) ...	4° 13′ 5″	June	23	5.40	p.m.
Shimizu	4° 0′ 58″	,,	25	6.08	p.m.
	3° 59′ 30″	,,	27	7.55	a.m.
	4° 1′ 58″	,,	,,	10.43	,,
Nagoya	4° 31′ 58″	,,	29	8.03	p.m.
	4° 26′ 38″	,,	30	8.04	a.m.
	4° 26′ 53″	,,	,,	11.00	,,
	4° 34′ 8″	,,	,,	0.17	p.m.
	4° 35′ 45″	,,	,,	2.55	,,
	4° 36′ 33″	,,	,,	7.25	,,
Kamiyashiro	4° 19′ 29″	July	4	9.01	a.m.
	4° 22′ 52″	,,	,,	10.28	,,
	4° 27′ 2″	,,	,,	0.25	p.m.
	4° 19′ 22″	,,	,,	6.07	,,
	4° 24′ 2″	,,	,,	11.00	,,
Nagahama	4° 49′ 48″	,,	6	1.23	p.m.
	4° 48′ 45″	,,	,,	2.52	,,
	4° 42′ 58″	,,	,,	7.59	,,
	4° 42′ 46″	,,	7	8.41	a.m.
	4° 46′ 1″	,,	,,	10.11	,,
	4° 47′ 26″	,,	,,	10.49	,,
Hyōgo...	4° 33′ 46″ ?	,,	8	1.08	p.m.
	4° 33′ 51″	,,	,,	7.24	,,
	4° 33′ 36″	,,	,,	8.51	,,
	4° 33′ 34″	,,	9	10.05	a.m.
	4° 38′ 52″	,,	,,	2.07	p.m.
	4° 38′ 22″	,,	,,	4.16	,,
Tokushima	4° 26′ 52″	,,	10	5.36	p.m.
	4° 24′ 9″	,,	11	9.24	a.m.
	4° 28′ 57″	,,	,,	11.29	,,
	4° 28′ 34″	,,	,,	4.09	p.m.

Station.	Declin.	Date & Hour.			
Kōchi	4° 19′ 44″	July	16	11.20	p.m.
	4° 18′ 31″	,,	17	9.03	a.m.
	4° 24′ 59″	,,	,,	0.16	p.m.
Minabe	4° 30′ 35″	,,	21	9.13	a.m.
	4° 34′ 10″	,,	,,	10.44	,,
	4° 34′ 2″	,,	,,	2.26	p.m.
	4° 30′ 27″	,,	,,	6.24	,,
	4° 27′ 20″	,,	22	6.56	a.m.
	4° 27′ 2″	,,	,,	7.48	,,
	4° 27′ 10″	,,	,,	8.40	,,
	4° 29′ 10″	,,	,,	9.45	,,
	4° 31′ 20″	,,	,,	10.43	,,
	4° 33′ 5″	,,	,,	11.43	,,
	4° 34′ 20″	,,	,,	0.48	p.m.
	4° 35′ 00″	,,	,,	1.42	,,
	4° 33′ 45″	,,	,,	2.51	,,
	4° 32′ 27″	,,	,,	3.44	,,
	4° 30′ 50″	,,	,,	4.40	,,
	4° 30′ 37″			?	
	4° 31′ 2″	,,	,,	7.34	,,
Okayama	4° 36′ 28″	,,	25	5.42	p.m.
	4° 37′ 28″	,,	,,	7.06	,,
	4° 35′ 6″	,,	26	7.14	a.m.
	4° 36′ 1″	,,	,,	10.02	,,
	4° 31′ 31″	,,	,,	11.35	,,
	4° 39′ 3″	,,	,,	3.51	p.m.
	4° 36′ 51″	,,	,,	5.33	,,
Hiroshima	4° 31′ 17″	,,	28	11.57	a.m.
	4° 29′ 54″	,,	,,	3.50	p.m.
	4° 28′ 32″	,,	,,	9.35	,,
	4° 27′ 22″	,,	29	5.33	,,

Station.	Declin.	Date & Hour.
Hiroshima (*continued*)	4° 23′ 39″	July 29 7.57 a.m.
	4° 25′ 37″	„ „ 9.52 „
	4° 30′ 14″	„ „ 11.54 „
	4° 31′ 57″	„ „ 1.54 p.m.
	4° 30′ 39″	„ „ 2.53 „
	4° 28′ 9″	„ „ 4.53 „
	4° 28′ 37″	„ „ 7.07 „
Wakwan … … … …	4° 20′ 47″	August 6 8.07 a.m.
	4° 20′ 37″	„ „ 8.31 „
	4° 26′ 28″	„ „ 10.32 „
	4° 30′ 33″	„ „ 0.05 p.m.
	4° 31′ 23″	„ „ 2.03 „
	4° 26′ 8″	„ „ 4.34 „
	4° 24′ 33″	„ „ 6.02 „
	4° 24′ 43″	„ „ 9.51 „
Mēho … … … … …	4° 42′ 9″	„ 10 7.32 p.m.
	4° 41′ 52″	„ 11 5.50 a.m.
	4° 38′ 42″	„ „ 7.59 „
	4° 38′ 32″	„ „ 8.45 „
	4° 44′ 2″	„ „ 10.41 „
	4° 48′ 37″	„ „ 1.29 p.m.
	4° 46′ 47″	„ „ 2.30 „
	4° 44′ 34″	„ „ 4.07 „
Pusan … … … … …	3° 34′ 30″	„ 13 9.04 a.m.
	3° 38′ 52″	„ „ 11.18 „
	3° 40′ 20″	„ „ 1.19 p.m.
	3° 40′ 18″	„ „ 1.46 „
	3° 38′ 45″	„ „ 2.42 „
	3° 36′ 20″	„ „ 5.16 „
	3° 36′ 58″	„ „ 9.00 „
Kurosaki … … … …	4° 35′ 15″	„ 15 11.39 a.m.

Station.	Declin.	Date & Hour.			
Kurosaki (*continued*)...	4° 36′ 15″	August	15	1.19	p.m.
Shiinokijima	4° 2′ 40″	„	„	7.04	p.m.
Fukuoka	4° 18′ 39″	„	21	9.37	p.m.
	4° 17′ 42″	„	„	10.09	„
	4° 14′ 47″	„	22	7.16	a.m.
	4° 14′ 49″	„	„	8.28	„
	4° 17′ 26″	„	„	9.25	„
	4° 20′ 44″	„	„	11.00	„
	4° 22′ 42″	„	„	1.57	p.m.
	4° 21′ 27″	„	„	2.52	„
	4° 18′ 54″	„	„	4.33	„
Nakatsu	4° 27′ 35″	„	24	11.51	a.m.
	4° 27′ 28″	„	„	1.50	p.m.
	4° 26′ 23″	„	„	2.40	„
	4° 24′ 55″	„	„	3.54	„
	4° 23′ 50″	„	„	9.54	„
	4° 19′ 55″	„	25	7.31	a.m.
	4° 19′ 13″	„	„	8.50	„
	4° 19′ 50″	„	„	9.54	„
Saganoseki	4° 8′ 21″	„	28	7.30	a.m.
	4° 8′ 31″	„	„	8.44	„
	4° 12′ 46″	„	„	10.08	„
	4° 16′ 9″	„	„	11.29	„
	4° 17′ 11″	„	„	1.43	p.m.
	4° 15′ 14″	„	„	3.07	„
	4° 12′ 36″	„	„	4.36	„
Hichiya	4° 1′ 20″	„	29	2.54	p.m.
	3° 59′ 30″	„	„	4.45	„
	3° 58′ 23″	„	„	10.58	„
	3° 57′ 15″	„	30	6.26	a.m.
	3° 56′ 13″	„	„	7.32	„

Station.	Declin.	Date & Hour.			
Hichiya (*continued*) ...	3° 58′ 48″	August	20	8.38	a.m.
	4° 1′ 38″	„	„	9.22	„
	4° 4′ 23″	„	„	11.38	„
Miyazaki	4° 3′ 21″	„	31	11.34	a.m.
	4° 3′ 8″	„	„	0.05	p.m.
	4° 2′ 9″	„	„	1.39	„
	3° 59′ 26″	„	„	2.59	„
	3° 58′ 26″	„	„	4.00	„
	3° 57′ 34″	„	„	4.36	„
	3° 58′ 4″	„	„	6.15	„
	3° 55′ 34″	September	1	5.59	a.m.
	3° 56′ 44″	„	„	6.36	p.m.
	3° 55′ 36″	„	2	7.37	a.m.
	3° 55′ 51″	„	„	8.30	„
	3° 57′ 16″	„	„	9.05	„
	3° 59′ 38″	„	„	9.43	„
	4° 1′ 16″	„	„	10.30	„
	4° 2′ 6″	„	„	11.13	„
Yatsushiro	4° 4′ 2′,	„	6	9.52	a.m.
	4° 5′ 15″	„	„	10.20	„
	4° 6′ 20″	„	„	11.07	„
	4° 5′ 38″	„	„	0.14	p.m.
	4° 3′ 43″	„	„	1.18	„
	4° 1′ 50″	„	„	2.17	„
	3° 59′ 38″	„	„	3.29	„
	3° 58′ 33″	„	„	4.37	„
	3° 58′ 43″	„	„	5.20	„
	3° 56′ 1″	„	7	7.55	a.m.
	3° 56′ 25″	„	„	8.26	„
	3° 57′ 55″	„	„	9.08	„
	4° 3′ 5″	„	„	10.46	„

Station.	Declin.	Date & Hour.
Nagasaki	3° 31′ 54″	September 10 9.12 a.m.
	3° 35′ 36″	„ „ 10.04 „
	3° 37′ 13″	„ „ 10.48 „
	3° 37′ 58″	„ „ 11.24 „
Hagi	4° 29′ 37″	„ 14 5.52 p.m.
	4° 30′ 32″	„ „ 7.56 „
	4° 30′ 5″	„ 15 0.22 a.m.
	4° 28′ 27″	„ „ 4.09 „
	4° 28′ 3″	„ „ 6.15 „
	4° 27′ 42″	„ „ 6.45 „
	4° 27′ 42″	„ „ 7.24 „
	4° 27′ 27″	„ „ 7.52 „
	4° 27′ 37″	„ „ 8.32 „
	4° 29′ 3″	„ „ 9.15 „
	4° 30′ 23″	„ „ 9.44 „
	4° 32′ 0″	„ „ 10.16 „
	4° 33′ 8″	„ „ 10.46 „
	4° 33′ 38″	„ „ 11.15 „
	4° 33′ 40″	„ „ 11.47 „
	4° 33′ 40″	„ „ 0.14 p.m.
	4° 33′ 30″	„ „ 0.43 „
	4° 32′ 30″	„ „ 1.15 „
	4° 31′ 20″	„ „ 2.09 „
*	4° 31′ 30″	„ „ 2.17 „
(a stone removed) *	4° 31′ 10″	„ „ 2.24 p.m.
	4° 29′ 58″	„ „ 2.56 „
	4° 29′ 38″	„ „ 3.15 „
	4° 29′ 33″	„ „ 3.43 „
	4° 29′ 20″	„ „ 4.12 „
	4° 29′ 35″	„ „ 4.43 „
	4° 30′ 13″	„ „ 5.18 „

Station.	Declin.	Date & Hour.			
Hagi (*continued*) … …	4° 30′ 48″	September	15	7.04	p.m.
	4° 30′ 45″	"	"	7.55	"
	4° 30′ 15″	"	"	11.03	"
Hamada … … … …	4° 34′ 58″	"	16	3.34	p.m.
	4° 35′ 5″	"	"	4.52	"
	4° 36′ 8″	"	"	5.48	"
	4° 37′ 8″	"	"	7.27	"
	4° 35′ 40″	"	17	7.29	a.m.
	4° 36′ 15″	"	"	8.15	"
	4° 37′ 10″	"	"	8.51	"
	4° 39′ 43″	"	"	9.40	"
	4° 41′ 5″	"	"	10.25	"
	4° 42′ 20″	"	"	10.42	"
	4° 43′ 42″	"	"	11.45	"
	4° 43′ 7″	"	"	0.28	p.m.
	4° 42′ 5″	"	"	1.10	"
	4° 40′ 42″	"	"	1.42	"
	4° 39′ 45″	"	"	2.08	"
	4° 38′ 37″	"	"	2.40	"
	4° 37′ 56″	"	"	3.12	"
	4° 37′ 37″	"	"	3.41	"
	4° 37′ 20″	"	"	4.08	"
	4° 37′ 31″	"	"	4.39	"
	4° 37′ 37″	"	"	5.09	"
	4° 38′ 5″	"	"	5.38	"
	4° 39′ 2″	"	"	6.30	"
	4° 39′ 35″	"	"	7.06	"
	4° 39′ 0″	"	"	7.42	"
	4° 39′ 0″	"	"	8.12	"
	4° 38′ 50″	"	"	8.42	"
	4° 38′ 57″	"	"	9.25	"

Station.	Declin.	Date & Hour.
Hamada (*continued*) ...	4° 38′ 5″	September 18 2.02 a.m.
	4° 36′ 42″	„ „ 5.53 „
	4° 36′ 17″	„ „ 6.18 „
	4° 36′ 16″	„ „ 6.39 „
Matsue	4° 56′ 3″	„ 20 0.21 p.m.
	4° 55′ 52″	„ „ 0.32 „
	4° 55′ 19″	„ „ 1.25 „
	4° 54′ 22″	„ „ 2.24 „
	4° 53′ 7″	„ „ 3.02 „
	4° 51′ 52″	„ „ 3.48 „
	4° 51′ 2″	„ „ 4.28 „
	4° 51′ 9″	„ „ 5.13 „
	4° 51′ 17′	„ „ 6.02 „
	4° 51′ 22″	„ „ 7.55 „
	4° 51′ 12″	„ 21 0.35 a.m.
	4° 50′ 9′	„ „ 5.57 „
	4° 49′ 49″	„ „ 6.41 „
	4° 49′ 22″	„ „ 7.18 „
	4° 48′ 39″	„ „ 7.58 „
	4° 48′ 41″	„ „ 8.28 „
	4° 50′ 16″	„ „ 9.25 „
	4° 51′ 24″	„ „ 9.56 „
Imaichi	4° 45′ 51″	„ 22 8.29 a.m.
	4° 46′ 53″	„ „ 9.10 „
	4° 48′ 41″	„ „ 9.50 „
	4° 50′ 1″	„ „ 10.23 „
	4° 51′ 7″	„ „ 10.53 „
	4° 52′ 1″	„ „ 11.16 „
	4° 53′ 21″	„ „ noon
	4° 53′ 31″	„ „ 0.32 p.m.
	4° 52′ 58″	„ „ 0.55 „

Station.	Declin.	Date & Hour.			
Imaichi (*continued*) ...	4° 52′ 16″	September	22	1.58	p.m.
	4° 51′ 26″	,,	,,	2.49	,,
	4° 50′ 56″	,,	,,	3.26	,,
	4° 49′ 23″	,,	,,	3.59	,,
	4° 48′ 26″	,,	,,	4.42	,,
	4° 47′ 51″	,,	,,	5.32	,,
	4° 48′ 11″	,,	,,	6.05	,,
	4° 48′ 33″	,,	,,	7.28	,,
	4° 48′ 18″	,,	,,	8.01	,,
	4° 48′ 18″	,,	,,	9.23	,,
	4° 48′ 6″	,,	23	0.40	a.m.
	4° 47′ 18″	,,	,,	6.09	,,
	4° 46′ 56″	,,	,,	7.24	,,
	4° 46′ 43″	,,	,,	7.47	,,
Kanōmura...	5° 9′ 15″	,,	25	11.11	a.m.
	5° 9′ 50″	,,	,,	11.44	,,
	5° 10′ 9″	,,	,,	0.32	p.m.
	5° 9′ 54″	,,	,,	1.07	,,
	5° 9′ 39″	,,	,,	1.52	,,
	5° 9′ 0″	,,	,,	2.38	,,
	5° 8′ 8″	,,	,,	3.23	,,
	5° 7′ 58″	,,	,,	4.03	,,
	5° 8′ 48″	,,	,,	5.04	,,
	5° 8′ 34″	,,	,,	5.46	,,
	5° 7′ 40″	,,	,,	7.31	,,
	5° 8′ 19″	,,	,,	10.06	,,
	5° 8′ 15″	,,	26	5.55	a.m.
	5° 10′ 42″	,,	,,	6.45	,,
	5° 12′ 41″	,,	,,	7.43	,,
	5° 12′ 35″	,,	,,	8.23	,,
	5° 12′ 56″	,,	,,	8.56	,,

Station.	Declin.	Date & Hour.			
Koyamamura	5° 12′ 33″	September	26	0.41	p.m.
	5° 8′ 54″	„	„	1.16	„
	5° 5′ 58″	„	„	2.08	„
	5° 7′ 3′	„	„	2.37	„
	5° 6′ 57″	„	„	3.25	„
	5° 7′ 25″	„	„	4.08	„
	5° 4′ 42″	„	„	4.36	„
	5° 1′ 43″	„	„	5.24	„
	5° 2′ 30″	„	„	6.10	„
	5° 4′ 28″	„	„	7.28	„
	5° 1′ 35″	„	„	8.40	„
	5° 3′ 10′	„	„	9.30	„
	5° 1′ 43″	„	„	11.15	„
	5° 3′ 20″	„	27	5.47	a.m.
	5° 3′ 0″	„	„	6.20	„
	5° 2′ 55″	„	„	6.54	„
	5° 3′ 28″	„	„	7.16	„
	5° 3′ 37″	„	„	7.30	„
	5° 3′ 55″	„	„	8.12	„
	5° 4′ 28″	„	„	8.48	„
	5° 4′ 24″	„	„	9.24	„
	5° 4′ 25″	„	„	9.58	„
	5° 5′ 27″	„	„	10.44	„
	5° 7′ 4″	„	„	11.22	„
	5° 6′ 43″	„	„	11.54	„
Maizuru	5° 1′ 54″	„	30	11.21	a.m.
	5° 2′ 25″	„	„	0.10	p.m.
	5° 1′ 53″	„	„	0.46	„
	5° 1′ 49″	„	„	1.35	„
	5° 1′ 11″	„	„	2.15	„
	4° 59′ 53″	„	„	3.01	„

Station.	Declin.	Date & Hour.			
Maizuru (*continued*) ...	4° 59′ 12″	September	30	3.39	p.m.
	4° 58′ 23″	,,	,,	4.18	,,
	4° 58′ 4″	,,	,,	5.05	,,
	4° 57′ 21″	,,	,,	5.47	,,
	4° 58′ 16″	,,	,,	7.18	,,
	4° 59′ 21″	,,	,,	8.16	,,
	4° 58′ 51″	,,	,,	9.50	,,
	4° 58′ 47″	October	1	0.15	a.m.
	4° 58′ 44″	,,	,,	3.22	,,
	4° 58′ 4″	,,	,,	4.47	,,
	4° 58′ 29″	,,	,,	6.22	,,
	4° 57′ 54″	,,	,,	7.30	,,
	4° 58′ 13″	,,	,,	8.16	,,
	4° 58′ 21″	,,	,,	8.57	,,
	4° 59′ 3″	,,	,,	9.36	,,
	4° 59′ 53″	,,	,,	10.01	,,
	5° 0′ 36″	,,	,,	10.18	,,
Obama...	4° 54′ 16″	,,	2	9.39	a.m.
	4° 54′ 51″	,,	,,	10.14	,,
	4° 55′ 25″	,,	,,	10.56	,,
	4° 55′ 58″	,,	,,	11.56	,,
	4° 56′ 41″	,,	,,	0.34	p.m.
	4° 56′ 51″	,,	,,	1.13	,,
	4° 56′ 18″	,,	,,	1.51	,,
	4° 55′ 26″	,,	,,	2.52	,,
	4° 54′ 10″	,,	,,	3.50	,,
	4° 53′ 43″	,,	,,	4.52	,,
	4° 53′ 42″	,,	,,	5.26	,,
	4° 54′ 47″	,,	,,	6.44	,,
	4° 54′ 31″	,,	,,	7.22	,,
	4° 54′ 40″	,,	,,	8.51	,,

Station.	Declin.	Date & Hour.			
Obama (*continued*) ...	4° 54′ 36″	October	2	10.53	p.m.
	4° 53′ 51″	„	3	2.19	a.m.
	4° 52′ 46″	„	„	6.34	„
	4° 52′ 16″	„	„	7.26	„
	4° 52′ 42″	„	„	8.23	„
	4° 52′ 55″	„	„	9.05	„
	4° 53′ 47″	„	„	10.02	„
Shioya...	4° 59′ 26″	„	4	10.58	a.m.
	5° 0′ 54″	„	„	11.30	„
	5° 2′ 49″	„	„	0.22	p.m.
	5° 2′ 38″	„	„	1.33	„
	5° 1′ 20″	„	„	2.23	„
	4° 59′ 36″	„	„	3.16	„
	4° 58′ 21″	„	„	4.22	„
	4° 58′ 31″	„	„	5.13	„
	4° 59′ 19″	„	„	6.09	„
	4° 59′ 28″	„	„	9.01	„
	4° 59′ 34″	„	„	9.50	„
	4° 58′ 29″	„	5	7.00	a.m.
	4° 57′ 14″	„	„	8.15	„
	4° 56′ 41″	„	„	9.04	„
	4° 56′ 46″	„	„	9.54	„
	4° 57′ 49″	„	„	10.41	„
	5° 0′ 10″	„	„	11.27	„
	5° 1′ 49″	„	„	0.31	p.m.
	5° 2′ 8″	„	„	1.00	„
	5° 1′ 53″	„	„	1.47	„
	5° 0′ 16″	„	„	2.59	„
	4° 58′ 29″	„	„	4.16	„
	4° 58′ 30″	„	„	4.55	„
	4° 58′ 49″	„	„	5.39	„

Station.	Declin.	Date & Hour.			
Shioya (*continued*) ...	4° 59′ 46″	October	4	6.36	p.m.
Nanao	5° 5′ 38″	„	7	10.43	p.m.
	5° 4′ 9″	„	8	0.52	a.m.
	5° 4′ 56″	„	„	4.31	„
	5° 5′ 5″	„	„	7.35	„
	5° 5′ 21″	„	„	8.21	„
	5° 4′ 34″	„	„	9.24	„
	5° 5′ 18″	„	„	10.09	„
	5° 5′ 49″	„	„	10.42	„
	5° 6′ 8″	„	„	11.41	„
	5° 6′ 11″	„	„	11.45	„
	5° 6′ 50″	„	„	0.35	p.m.
	5° 7′ 16″	„	„	1.18	„
	5° 7′ 15″	„	„	2.09	„
	5° 7′ 21″	„	„	3.08	„
	5° 6′ 45″	„	„	4.01	„
	5° 5′ 46″	„	„	5.16	„
	5° 5′ 6″	„	„	6.05	„
	5° 5′ 6″	„	„	6.53	„
	5° 5′ 9″	„	„	7.29	„
	5° 5′ 34″	„	„	9.32	„
	5° 5′ 25″	„	„	9.50	„
Tōkyō (W)	4° 18′ 56″	November	8	10.23	a.m.
	4° 19′ 43″	„	„	11.29	„
	4° 20′ 27″	„	„	0.13	p.m.
	4° 20′ 15″	„	„	1.17	„
	4° 19′ 15″	„	„	2.20	„
	4° 18′ 35″	„	„	3.10	„
	4° 18′ 12″	„	„	4.41	„
	4° 17′ 17″	„	„	6.05	„
	4° 17′ 36″	„	„	7.38	„

Station.	Declin.	Date & Hour.			
Tōkyō (W) (*continued*)	4° 17′ 54″	November	8	8.30	p.m.
	4° 18′ 52″	”	„	9.25	„
	4° 18′ 30″	”	„	10.17	„
	4° 17′ 48″	”	9	0.14	a.m.
	4° 17′ 54″	”	„	6.31	„
	4° 19′ 30″	”	„	8.04	„
	4° 22′ 4″	”	„	8.49	„
	4° 19′ 45″	”	„	9.49	„
	4° 19′ 15″	”	„	10.28	„
	4° 19′ 23″	”	„	11.21	„
	4° 19′ 43″	”	„	1.02	p.m.
	4° 19′ 28″	”	„	2.05	„
	4° 17′ 49″	”	„	3.45	„
	4° 18′ 4″	”	„	5.38	„
Tōkyō (E)	4° 24′ 17″	”	10	9.55	a.m.
	4° 24′ 34″	”	„	10.51	„
	4° 24′ 14″	”	„	11.35	„
	4° 25′ 1″	”	„	0.44	p.m.
	4° 24′ 46″	”	„	2.09	„
	4° 23′ 8″	”	„	3.10	„
	4° 22′ 18″	”	„	4.37	„
	4° 23′ 28″	”	„	4.54	„
	4° 24′ 13″	”	„	6.34	„
	4° 22′ 3″	”	„	7.26	„
	4° 23′ 13″	”	„	8.10	„
	4° 23′ 31″	”	„	8.57	„
	4° 24′ 41″	”	„	9.53	„
	4° 23′ 9″	”	„	10.33	„
	4° 23′ 51″	”	11	1.00	a.m.
	4° 23′ 41″	”	„	7.06	„
	4° 22′ 43″	”	„	8.08	„

Station.	Declin.	Date & Hour.
Tōkyō (E) (*continued*)	4° 22′ 51″	November 11 9.02 a.m.
	4° 23′ 9″	„ „ 10.02 „
	4° 23′ 38″	„ „ 11.05 „
	4° 24′ 17″	„ „ noon
	4° 24′ 11″	„ „ 1.57 p.m.

* * *

Specimen Page of Observations for Finding the Horizontal Force.

Torsion after Exp^{nt}.
82 91
123 133
102·5 − 112 = 8·5
4·75

after 20 Vibr^{ns}. 42^{m} 14·0^{s}
„ 30 „ 43 18·4
„ 40 „ 44 23·0

For arc and torsion 1 div. corresponds to the arc
2′·466

Observer,

Vibration Experiment.

	Temp.	Arc	Torsion.
Initial	30.03 C	81 to 134	
Final	30.00 C	85 to 129	
Mean	30.15 C	24.25	4.75
		59′.8	11′.70

Time.

Final.		Initial.			Difference.
m	s	h	m	s	s
45	27.5	16	40	5.2	322.3
	34.0			11.6	.4
	40.6			18.0	.6
	47.0			24.5	.5
	53.5			30.9	.6
	59.9			37.5	.4
46	6.3			44.0	.3
	12.7			50.3	.4
	19.1			56 5	.6
	25.6		41	3.1	.5
	32.1			9.6	.5

No. of Vibr^{ns}. 50 322.46

Time of single Vibration, T_0 3.2246

Log. Tab.	Log. T_0	(1)	0.50848
Tab. I.	Log. $\left(1 \pm \frac{s}{86400}\right)$	(2)	$\bar{1}.99879$
Tab. II.	Log. $\left(1 - \frac{a^2}{10}\right)$	(3)	$\bar{1}.99999$
Tab. III.	Log. $\sqrt{1 + \theta/(2\pi - \theta)}$	(4)	0.00012
Tab. IV.	Log. $\sqrt{1 + \mu H/M}$	(5)	0.00056
(1) + … + (5)	Log. T.	(6)	0.50794
	Log. $\pi \sqrt{I}$		1.57806
	Log. $\sqrt{MH}$		1.07012
Tab. V.	Log. $(1 + \alpha t)$		0.00014
	Log. $\sqrt{MH}$		1.07026

Place, Miyazaki. 1887. Sep. 1.2

Ended 17^{h} 0^{m}.9
Mean of times
16^{h} 50^{m}.5

Deflection Experiment.

Temperature.	Initial	Final	Mean
	29°.0 C	29°.0 C	29°.0 C

Mean Temp^{r}. 29°·6

	$r_1 =$		$-r_1 =$	
	a	b	a	b
Dir.	53° 49′20	233° 49′10	53° 49′10	233° 49′20
Rev.	41° 46′50	221° 47′10	41° 54′40	211° 54′50
Dif.	12° 02′30	12° 02′00	11° 54′30	11° 54′30

φ_1
11° 58′22.5
5° 59′11.3

	$r_2 =$		$-r_2 =$	
	a	b	a	b
Dir.	61° 21′30	241° 21′30	61° 20′20	241° 20′30
Rev.	34° 08′20	214° 08′40	34° 30′20	214° 30′30
Dif.	27° 13′10	27° 12′50	26° 50′00	26° 50′00

φ_2
27° 01′30
13° 30′45

Tab. VI	Log. r_1^5	(1)	7.38749
Log. Tab.	Log. sin φ_1	(2)	$\bar{1}.01825$
(1) + (2)	Log. $r_1^5 \cdot \sin \varphi_1$	(3)	6.40874
Tab. VI	Log. r_2^5	(4)	6.81279
Log. Tab.	Log. sin φ_2	(5)	$\bar{1}.36858$
(4) + (5)	Log. $r_2^5 \sin \varphi_2$	(6)	6.18137
Log. Tab.	Log. $\left(\frac{r_1^5 \sin \varphi_1}{r_2^5 \sin \varphi_2} - 1\right)$	(7)	$\bar{1}.83019$
Tab. VI	Log. $1/2\,(r_1^2 - r_2^2)$	(8)	$\bar{3}.13014$
Tab. VI	Log. $\left\{1 - 2\mu/r_1 r_2 (r_1 + r_2)\right\}$	(9)	$\bar{1}.99991$
Tab. VII	Log. $(1 + 3\alpha t)$	(10)	0.00071
(6) + … + (10)	Log. M/H	(11)	3.14232
	Log. $\sqrt{M/H}$	(12)	1.07026
	Log. $\sqrt{M/H}$	(13)	1.57116
(12) − (13)	Log. H.		$\bar{1}.49910$
(12) + (13)	Log. M.		2.64142

(3) — (6)
0.22475

$H =$ .31557

$M =$ 437.95

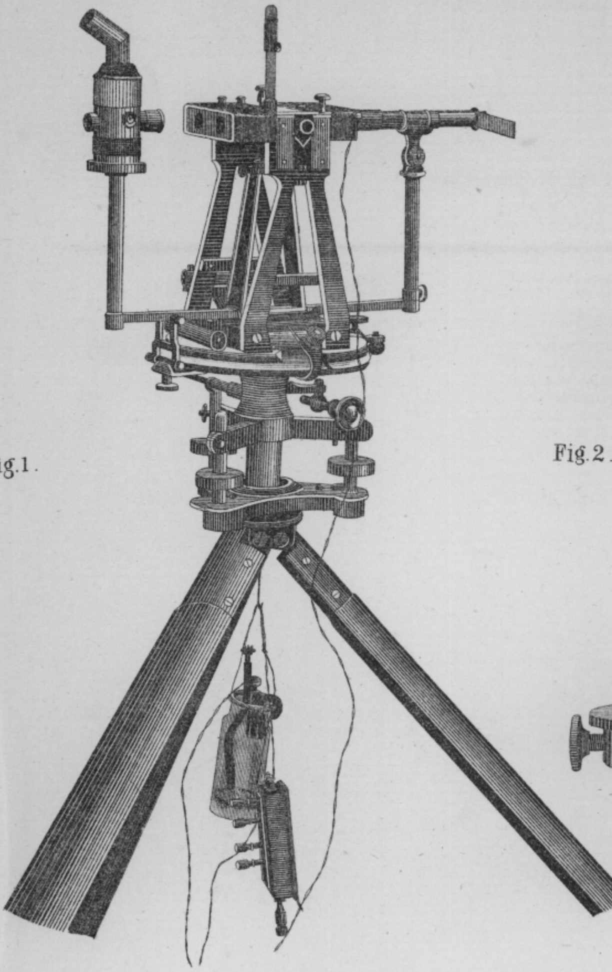


Fig. 1.

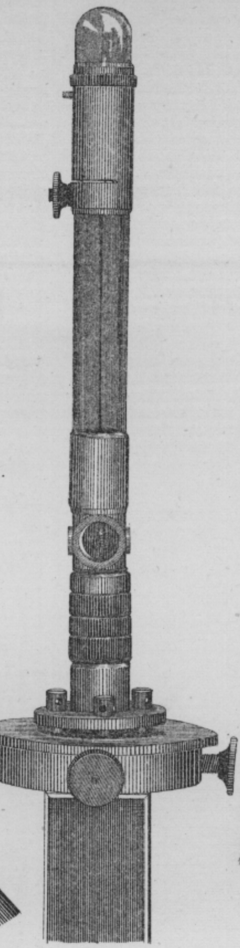


Fig. 2.

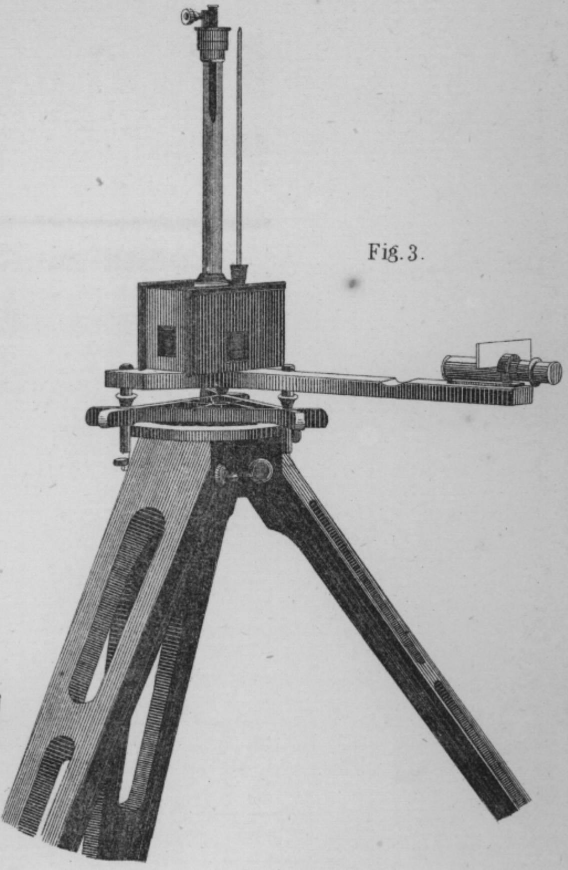


Fig. 3.

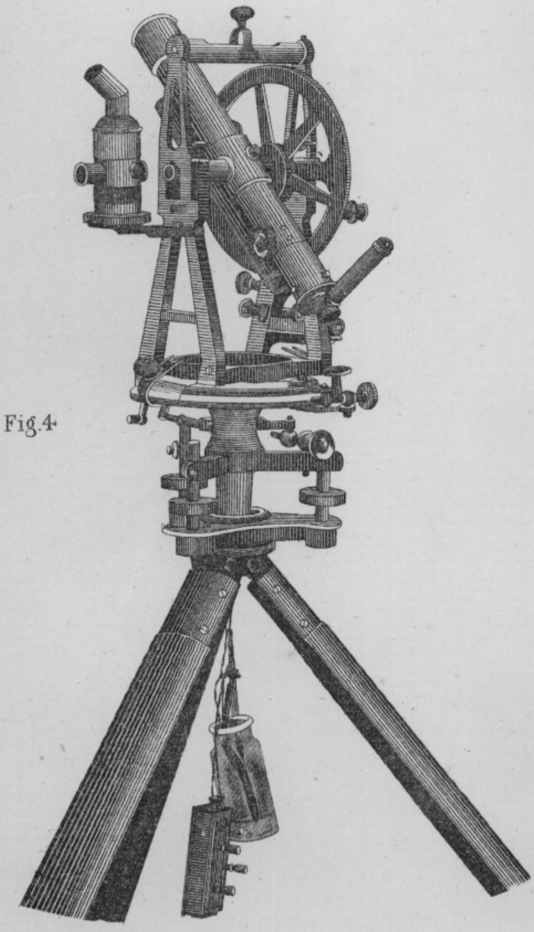


Fig. 4.

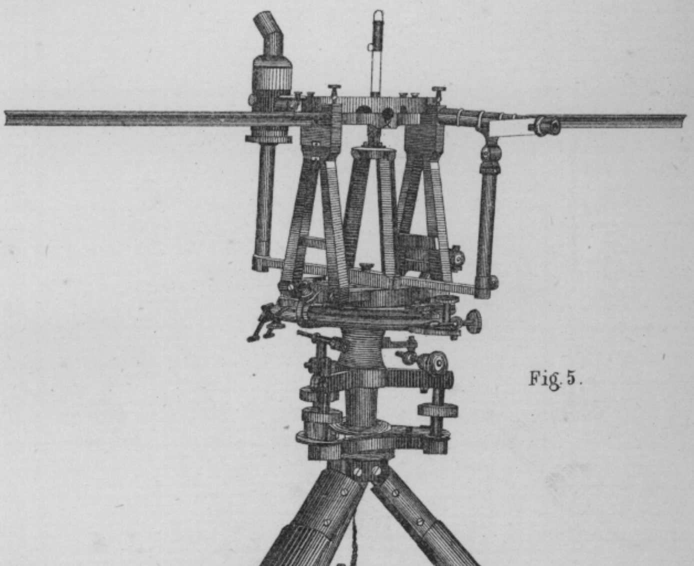


Fig. 5.

Fig.1.

Fig.2.

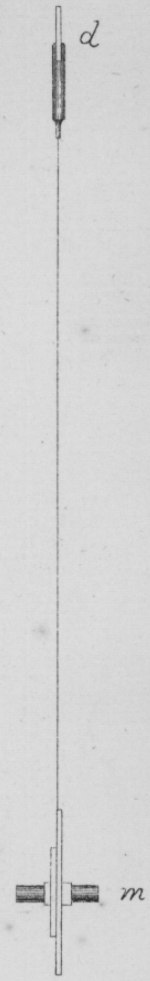
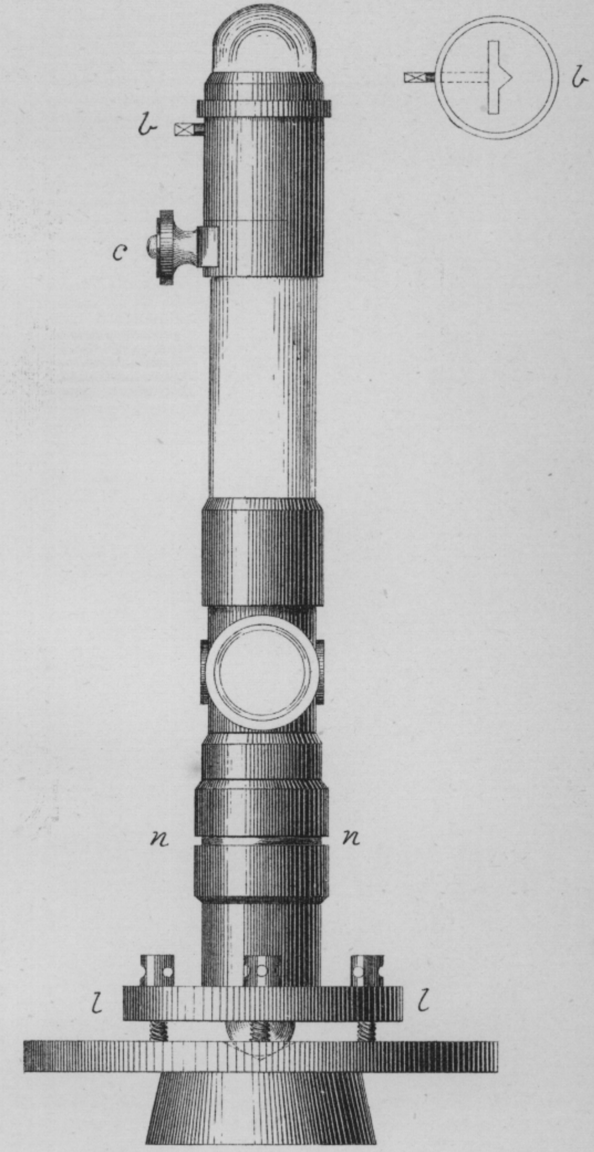


Fig.3.



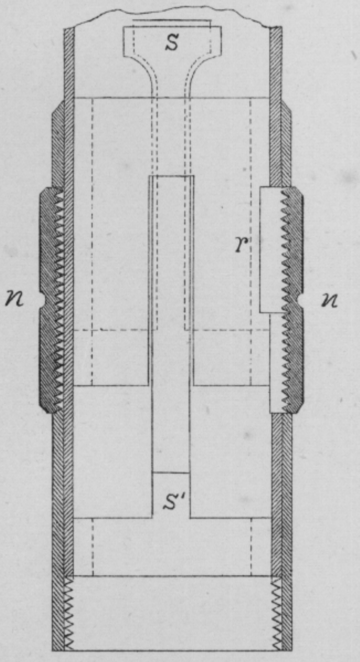


Fig.4.

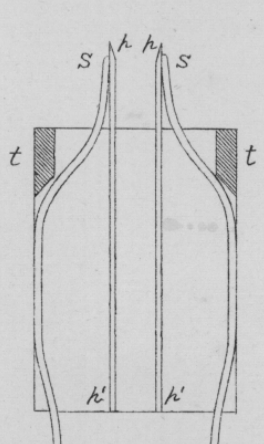


Fig.5.

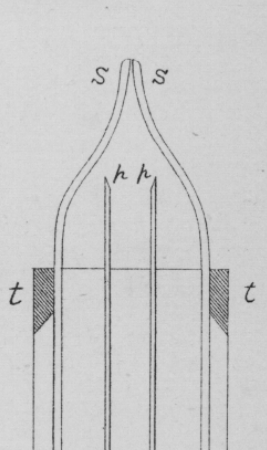
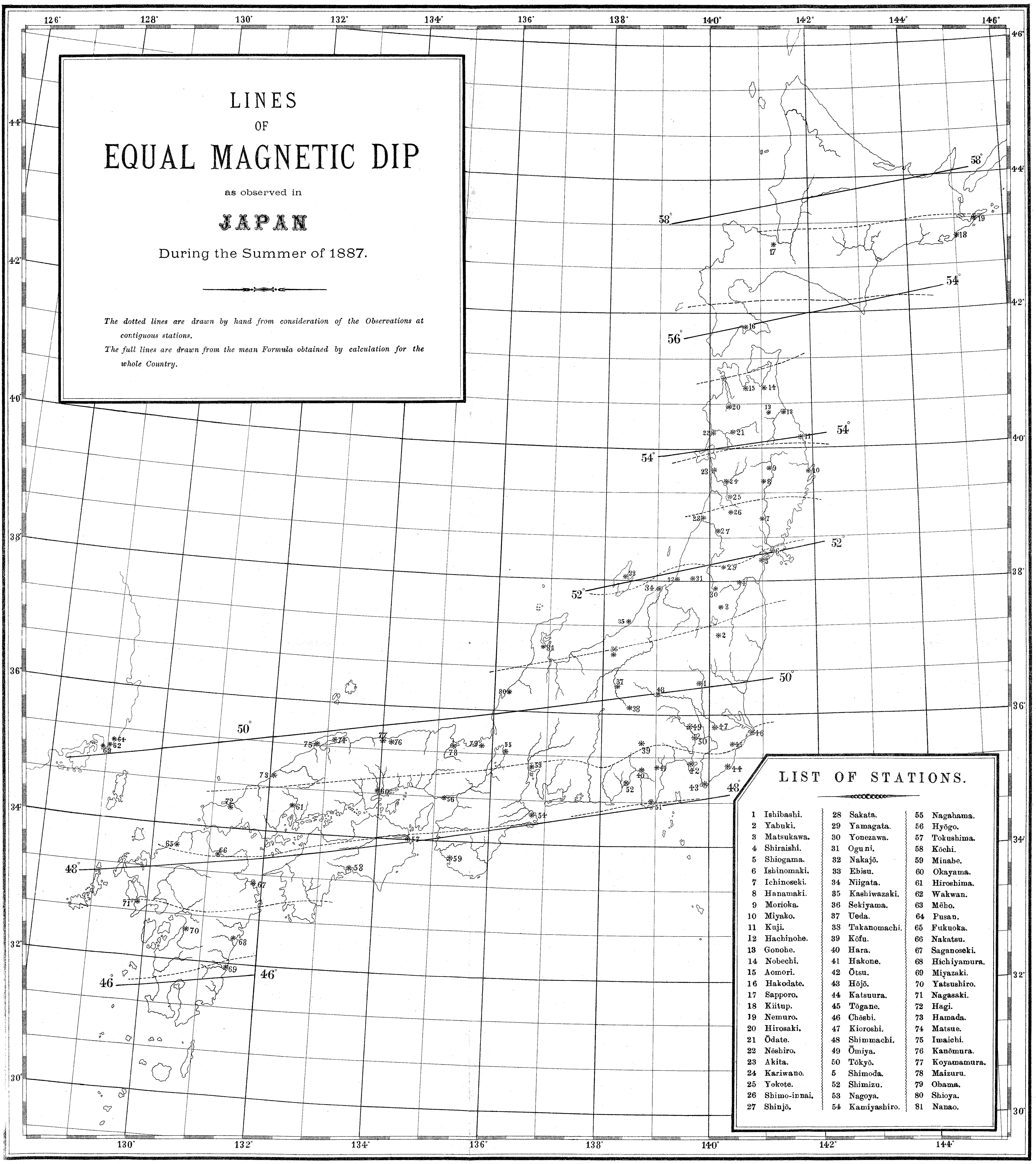


Fig.6.



LINES
OF
EQUAL MAGNETIC DIP

as observed in

JAPAN

During the Summer of 1887.

The dotted lines are drawn by hand from consideration of the Observations at contiguous stations.

The full lines are drawn from the mean Formula obtained by calculation for the whole Country.

LIST OF STATIONS.

1	Ishibashi.	28	Sakata.	55	Nagahama.
2	Yabuki.	29	Yamagata.	56	Hyōgo.
3	Matsukawa.	30	Yonezawa.	57	Tokushima.
4	Shiraishi.	31	Oguni.	58	Kōchi.
5	Shiogama.	32	Nakajō.	59	Minabe.
6	Ishinomaki.	33	Ebisu.	60	Okayama.
7	Ichinoseki.	34	Niigata.	61	Hiroshima.
8	Hanamaki.	35	Kashiwazaki.	62	Wakwan.
9	Morioka.	36	Sekiyama.	63	Mēho.
10	Miyako.	37	Ueda.	64	Pusan.
11	Kuji.	38	Takanomachi.	65	Fukuoka.
12	Hachinohe.	39	Kōfu.	66	Nakatsu.
13	Gonohe.	40	Hara.	67	Saganoseki.
14	Nobechi.	41	Hakone.	68	Hichiyamura.
15	Aomori.	42	Ōtsu.	69	Miyazaki.
16	Hakodate.	43	Hōjō.	70	Yatsushiro.
17	Sapporo.	44	Katsuura.	71	Nagasaki.
18	Kiitup.	45	Tōgane.	72	Hagi.
19	Nemuro.	46	Chōshi.	73	Hamada.
20	Hirosaki.	47	Kioroshi.	74	Matsue.
21	Ōdate.	48	Shimmachi.	75	Imaichi.
22	Nōshiro.	49	Ōmiya.	76	Kanōmura.
23	Akita.	50	Tōkyō.	77	Koyamamura.
24	Kariwano.	5	Shimoda.	78	Maizuru.
25	Yokote.	52	Shimizu.	79	Obama.
26	Shimo-innai.	53	Nagoya.	80	Shioya.
27	Shinjō.	54	Kamiyashiro.	81	Nanao.

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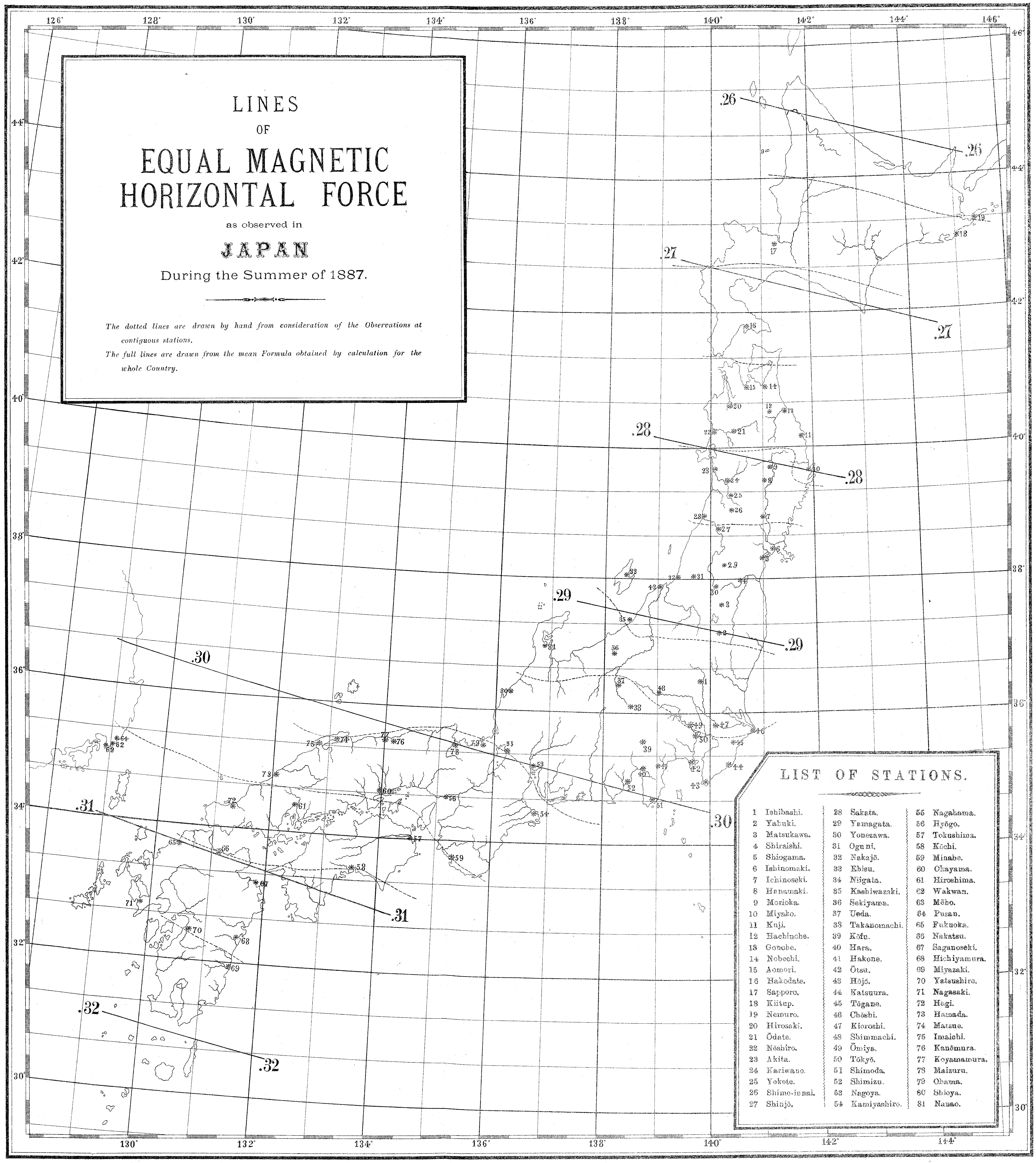


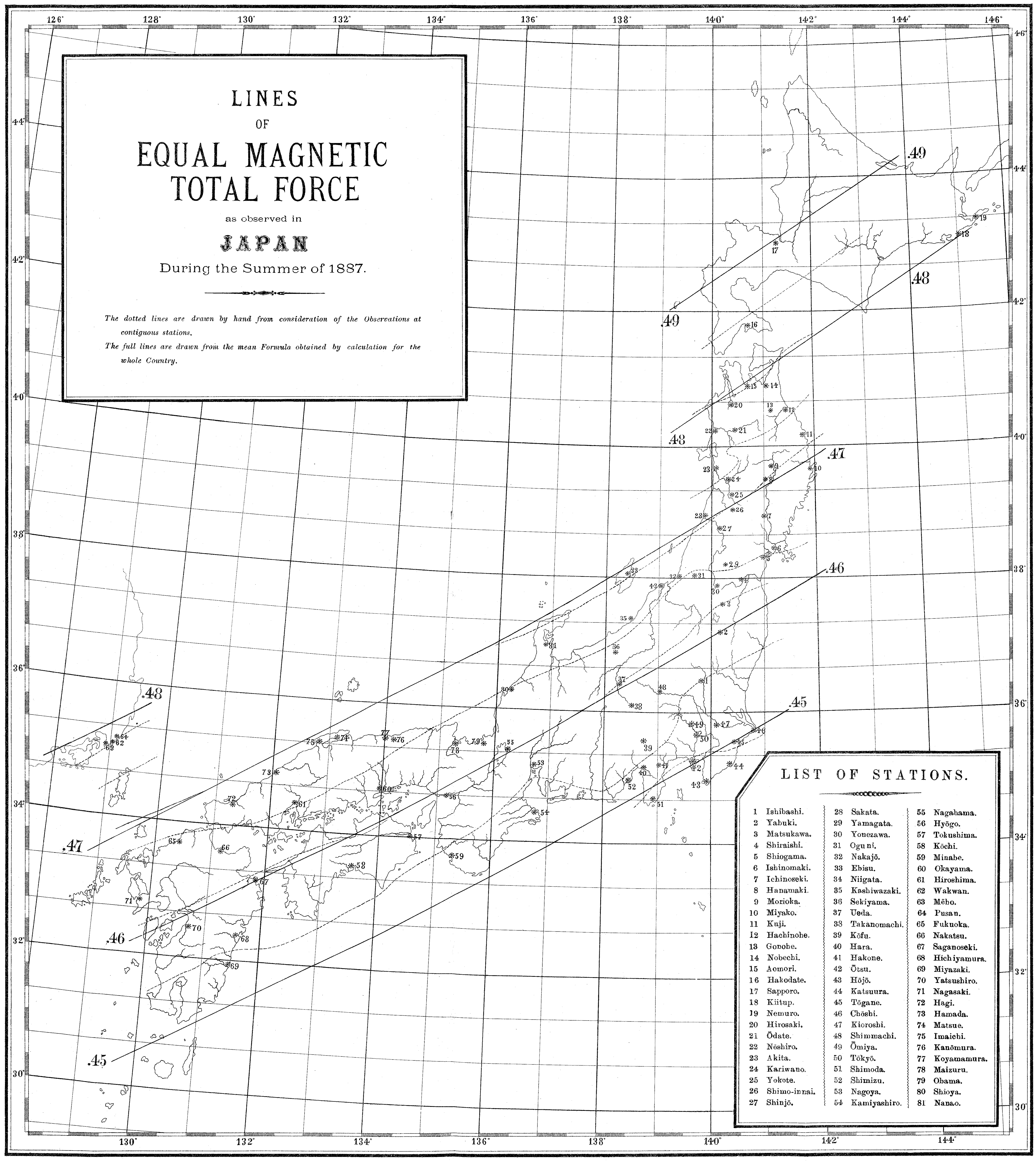
LINES
OF
EQUAL MAGNETIC HORIZONTAL FORCE
as observed in
JAPAN
During the Summer of 1887.

The dotted lines are drawn by hand from consideration of the Observations at contiguous stations.

The full lines are drawn from the mean Formula obtained by calculation for the whole Country.

LIST OF STATIONS.

1	Ishibashi.
2	Yabuki.
3	Matsukawa.
4	Shiraishi.
5	Shiogama.
6	Ishinomaki.
7	Ichinoseki.
8	Hanamaki.
9	Morioka.
10	Miyako.
11	Kuji.
12	Hachinohe.
13	Gonohe.
14	Nobechi.
15	Aomori.
16	Hakodate.
17	Sapporo.
18	Kiitup.
19	Nemuro.
20	Hirosaki.
21	Ōdate.
22	Nōshiro.
23	Akita.
24	Kariwano.
25	Yokote.
26	Shimo-innai.
27	Shinjō.
28	Sakata.
29	Yamagata.
30	Yonezawa.
31	Oguni.
32	Nakajō.
33	Ebisu.
34	Niigata.
35	Kashiwazaki.
36	Sekiyama.
37	Ueda.
38	Takanomachi.
39	Kōfu.
40	Hara.
41	Hakone.
42	Ōtsu.
43	Hōjō.
44	Katsuura.
45	Tōgane.
46	Chōshi.
47	Kioroshi.
48	Shimmachi.
49	Ōmiya.
50	Tōkyō.
51	Shimoda.
52	Shimizu.
53	Nagoya.
54	Kamiyashiro.
55	Nagahama.
56	Hyōgo.
57	Tokushima.
58	Kōchi.
59	Minabe.
60	Okayama.
61	Hiroshima.
62	Wakwan.
63	Mōho.
64	Pusan.
65	Fukuoka.
66	Nakatsu.
67	Saganoseki.
68	Hichiyamura.
69	Miyazaki.
70	Yatsushiro.
71	Nagasaki.
72	Hagi.
73	Hamada.
74	Matsue.
75	Imaichi.
76	Kanōmura.
77	Koyamamura.
78	Maizuru.
79	Obama.
80	Shioya.
81	Nanao.



LINES
OF
EQUAL MAGNETIC TOTAL FORCE

as observed in

JAPAN

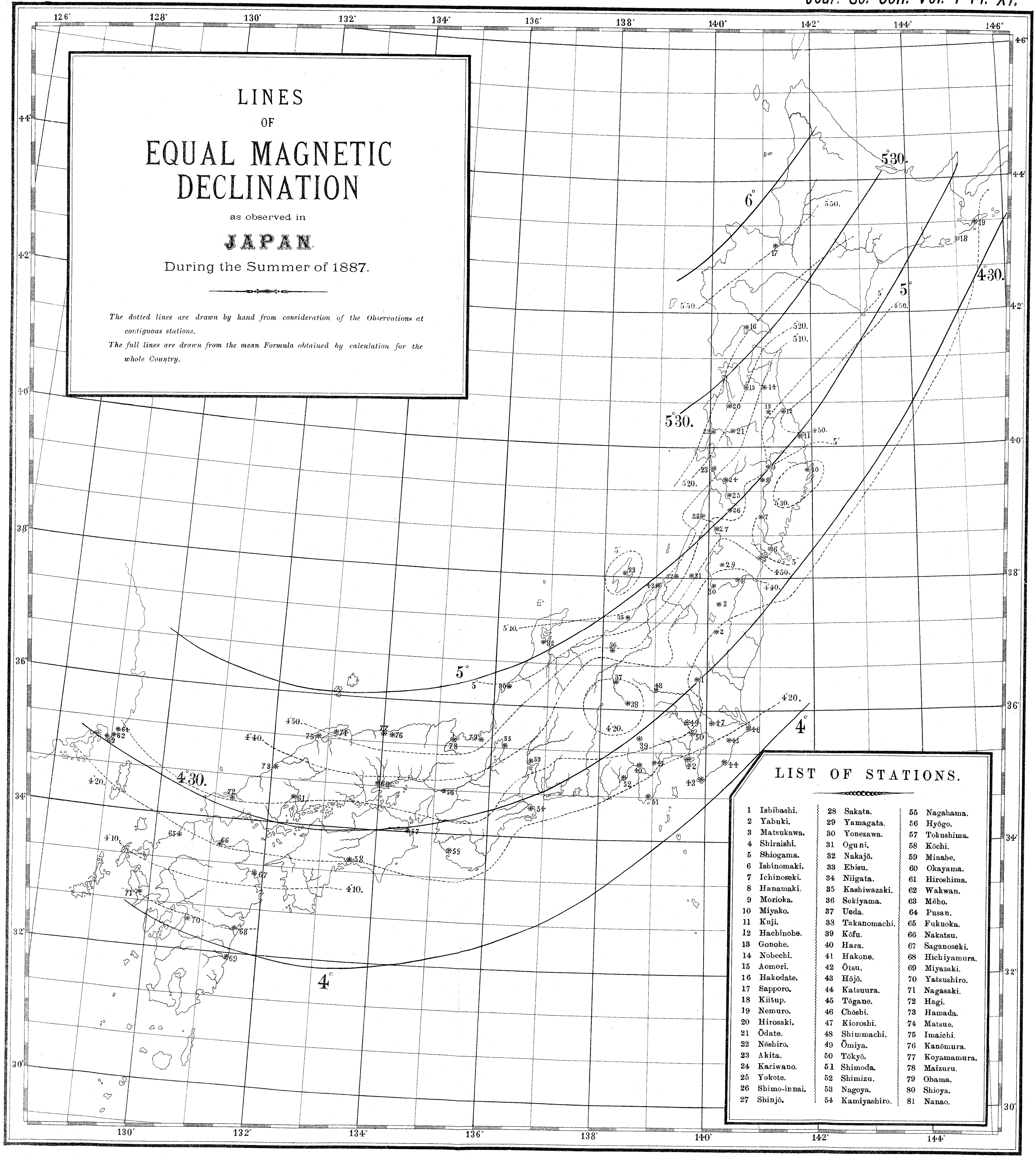
During the Summer of 1887.

The dotted lines are drawn by hand from consideration of the Observations at contiguous stations.

The full lines are drawn from the mean Formula obtained by calculation for the whole Country.

LIST OF STATIONS.

1 Ishibashi.
2 Yabuki.
3 Matsukawa.
4 Shiraishi.
5 Shiogama.
6 Ishinomaki.
7 Ichinoseki.
8 Hanamaki.
9 Morioka.
10 Miyako.
11 Kuji.
12 Hachinohe.
13 Gonohe.
14 Nobechi.
15 Aomori.
16 Hakodate.
17 Sapporo.
18 Kiitup.
19 Nemuro.
20 Hirosaki.
21 Ōdate.
22 Nōshiro.
23 Akita.
24 Kariwano.
25 Yokote.
26 Shimo-innai.
27 Shinjō.
28 Sakata.
29 Yamagata.
30 Yonezawa.
31 Oguni.
32 Nakajō.
33 Ebisu.
34 Niigata.
35 Kashiwazaki.
36 Sekiyama.
37 Ueda.
38 Takanomachi.
39 Kōfu.
40 Hara.
41 Hakone.
42 Ōtsu.
43 Hōjō.
44 Katsuura.
45 Tōgane.
46 Chōshi.
47 Kioroshi.
48 Shimmachi.
49 Ōmiya.
50 Tōkyō.
51 Shimoda.
52 Shimizu.
53 Nagoya.
54 Kamiyashiro.
55 Nagahama.
56 Hyōgo.
57 Tokushima.
58 Kōchi.
59 Minabe.
60 Okayama.
61 Hiroshima.
62 Wakwan.
63 Mēho.
64 Pusan.
65 Fukuoka.
66 Nakatsu.
67 Saganoseki.
68 Hichiyamura.
69 Miyazaki.
70 Yatsushiro.
71 Nagasaki.
72 Hagi.
73 Hamada.
74 Matsue.
75 Imaichi.
76 Kanōmura.
77 Koyamamura.
78 Maizuru.
79 Obama.
80 Shioya.
81 Nanao.



LINES
OF
EQUAL MAGNETIC DECLINATION
as observed in
JAPAN.
During the Summer of 1887.

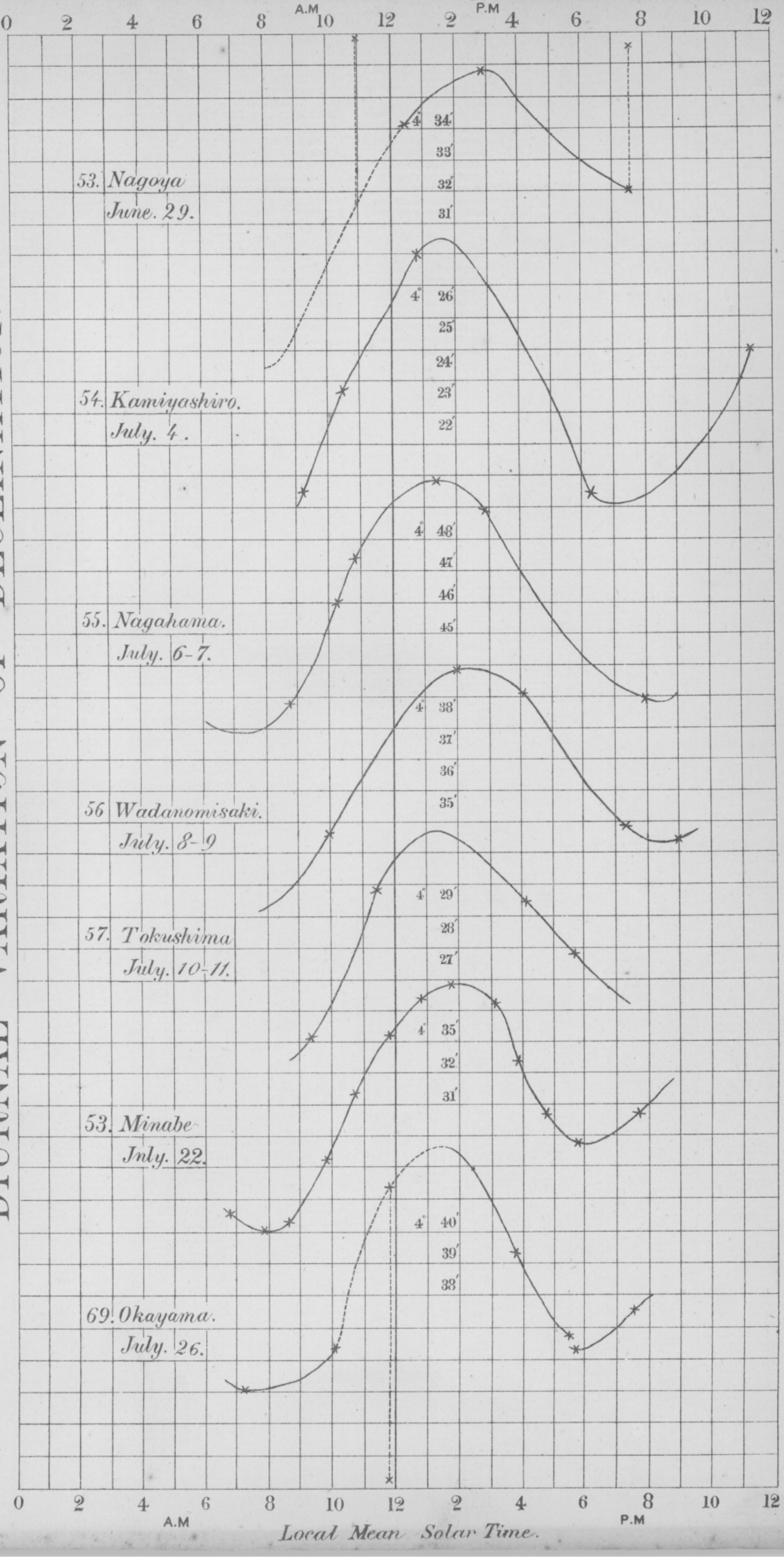
The dotted lines are drawn by hand from consideration of the Observations at contiguous stations.

The full lines are drawn from the mean Formula obtained by calculation for the whole Country.

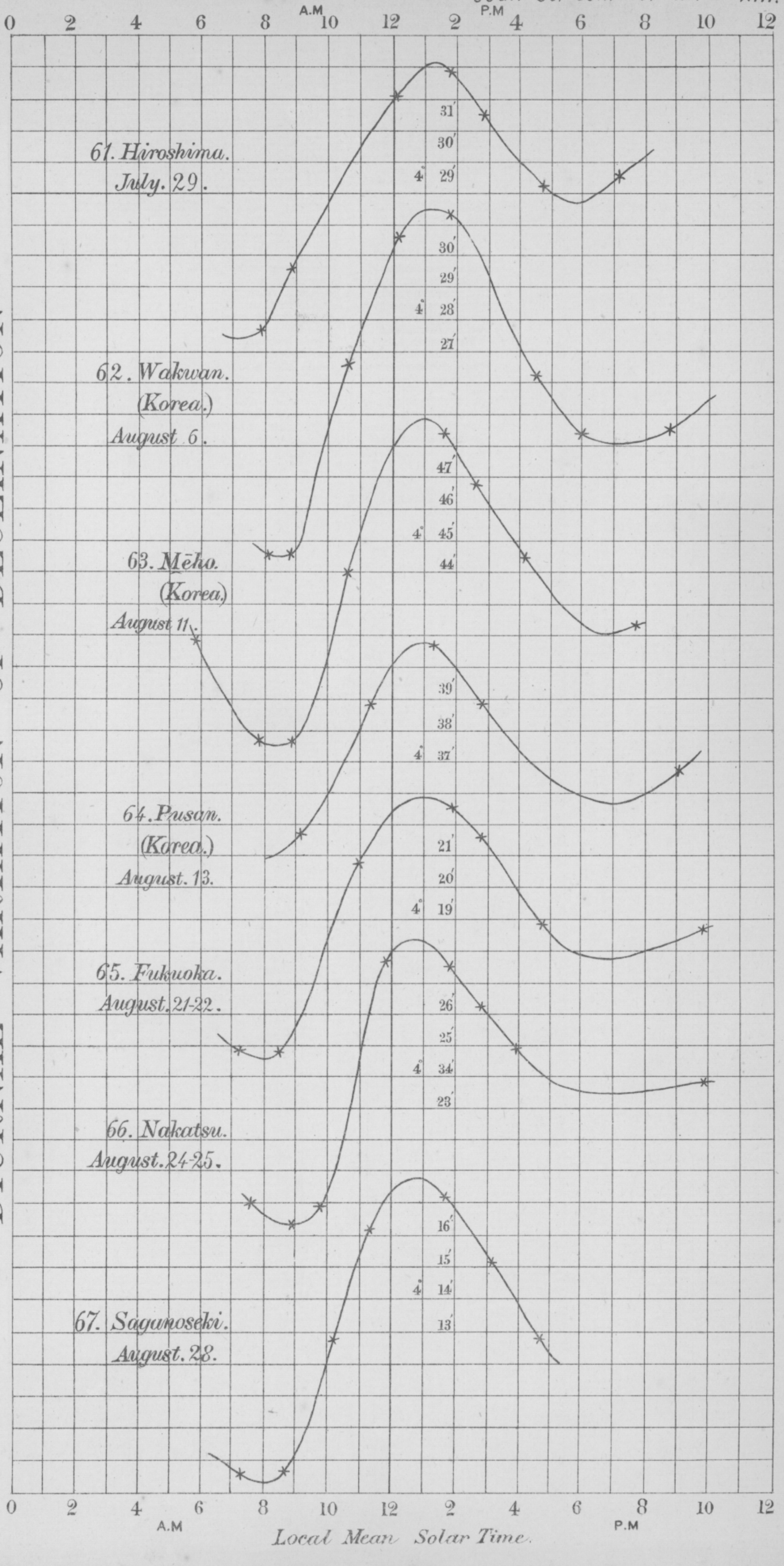
LIST OF STATIONS.

1	Ishibashi.
2	Yabuki.
3	Matsukawa.
4	Shiraishi.
5	Shiogama.
6	Ishinomaki.
7	Ichinoseki.
8	Hanamaki.
9	Morioka.
10	Miyako.
11	Kuji.
12	Hachinohe.
13	Gonohe.
14	Nobechi.
15	Aomori.
16	Hakodate.
17	Sapporo.
18	Kiitup.
19	Nemuro.
20	Hirosaki.
21	Ōdate.
22	Nōshiro.
23	Akita.
24	Kariwano.
25	Yokote.
26	Shimo-innai.
27	Shinjō.
28	Sakata.
29	Yamagata.
30	Yonezawa.
31	Oguni.
32	Nakajō.
33	Ebisu.
34	Niigata.
35	Kashiwazaki.
36	Sekiyama.
37	Ueda.
38	Takanomachi.
39	Kōfu.
40	Hara.
41	Hakone.
42	Ōtsu.
43	Hōjō.
44	Katsuura.
45	Tōgane.
46	Chōshi.
47	Kioroshi.
48	Shimmachi.
49	Ōmiya.
50	Tōkyō.
51	Shimoda.
52	Shimizu.
53	Nagoya.
54	Kamiyashiro.
55	Nagahama.
56	Hyōgo.
57	Tokushima.
58	Kōchi.
59	Minabe.
60	Okayama.
61	Hiroshima.
62	Wakwan.
63	Mēho.
64	Pusan.
65	Fukuoka.
66	Nakatsu.
67	Saganoseki.
68	Hichiyamura.
69	Miyazaki.
70	Yatsushiro.
71	Nagasaki.
72	Hagi.
73	Hamada.
74	Matsue.
75	Imaichi.
76	Kanōmura.
77	Koyamamura.
78	Maizuru.
79	Obama.
80	Shioya.
81	Nanao.

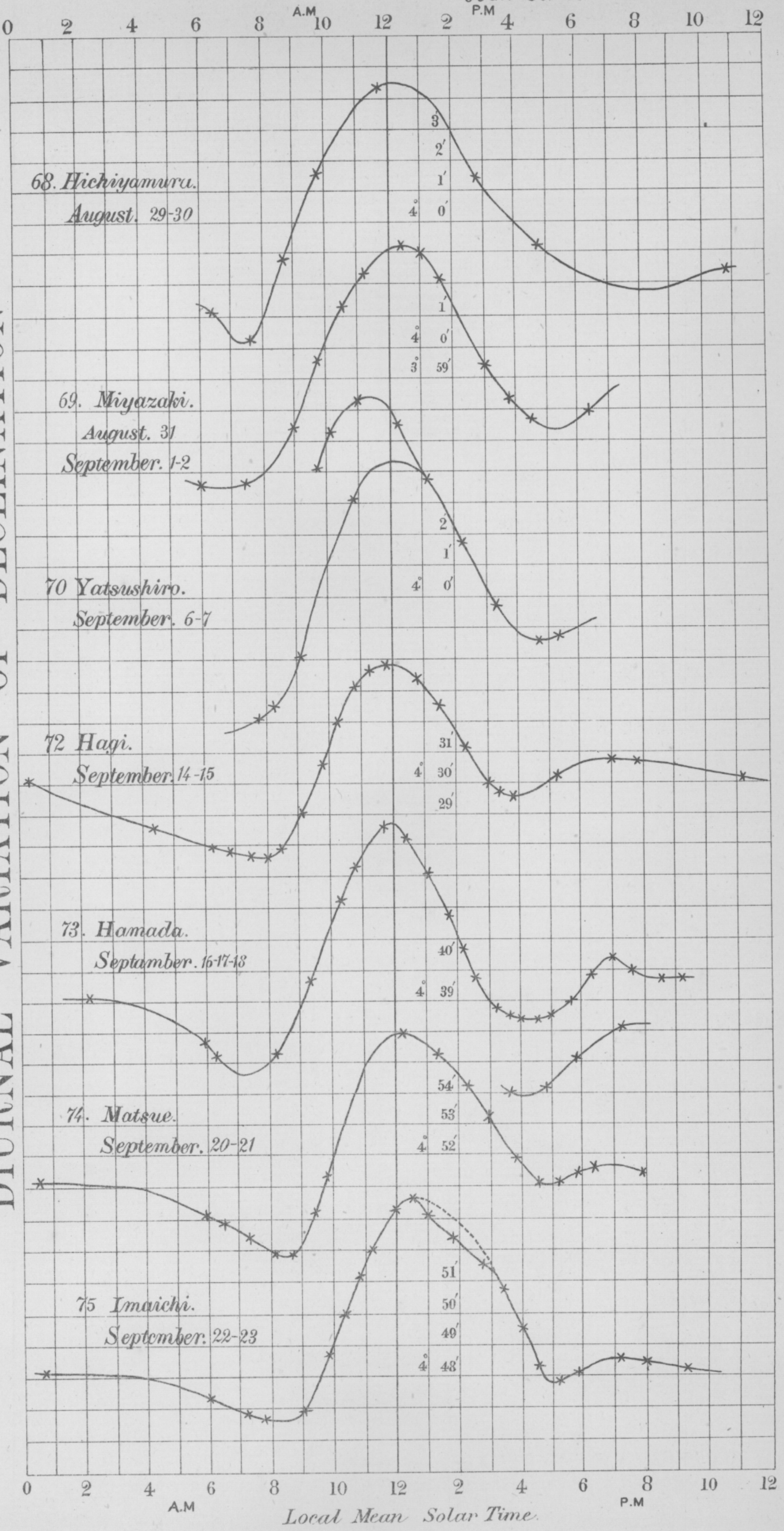
DIURNAL VARIATION OF DECLINATION



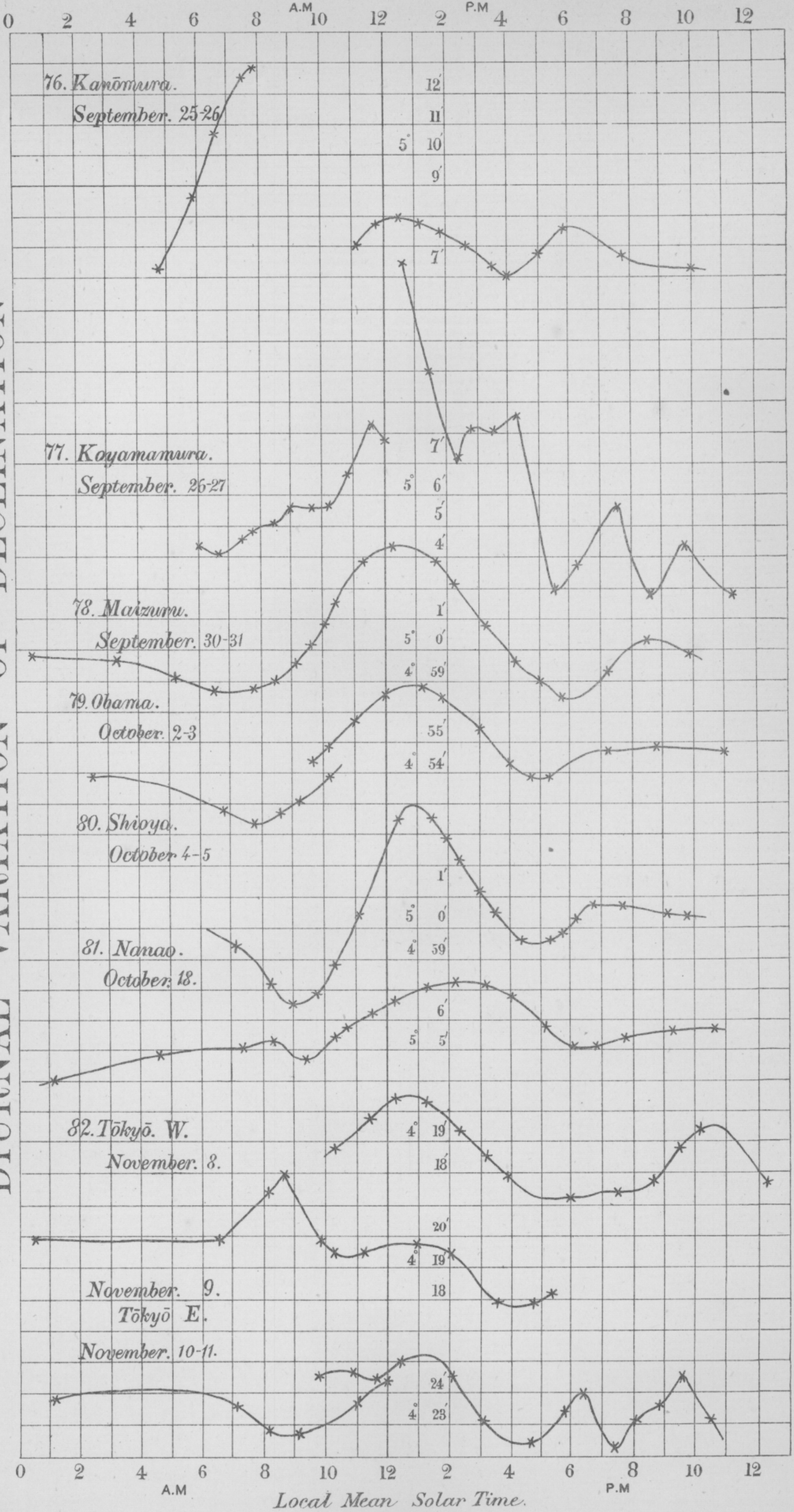
DIURNAL VARIATION OF DECLINATION



DIURNAL VARIATION OF DECLINATION



DIURNAL VARIATION OF DECLINATION



Errata.

Page 170, 11th line from bottom, for "20th" read "22nd"
,, 186, 8th ,, ,, bottom, ,, "in" ,, "is."
Specimen Page opposite page 190, line marked (12), for "Log. $\sqrt{M/H}$" read "Log. $\sqrt{M\ H}$."
Page 192, 10th line from top, for "Yahrbuch" read "Jahrbuch."
,, 246, 13th ,, ,, ,, for "Spica" read "Arcturus."