JOINT MEETING OF THE GEOLOGICAL SOCIETY OF SOUTH AFRICA AND THE CHEMICAL, METALLURGICAL AND MINING SOCIETY OF SOUTH AFRICA, HELD AT KELVIN HOUSE, 100, FOX STREET, JOHANNESBURG, ON MONDAY, 27th JANUARY, 1936, AT 8 P.M. MR. G. CARLETON JONES (PRESIDENT, GEOLOGICAL SOCIETY OF SOUTH AFRICA) WAS IN THE CHAIR.

The Minutes of the Ordinary Monthly Meeting of members of the Geological Society of South Africa, held on the 14th October, 1935, were taken as read, and it was agreed by members present that they be confirmed by the Chairman.

The following gentlemen were elected Members of the Geological Society: Capt. C. R. Robbins, M.C., Messrs. Philip Rudolph Botha and F. O. S. Dobell.

Dr. Rudolph Krahmann read a paper entitled "The Geophysical Magnetometric Investigations on West Witwatersrand Areas between Randfontein and Potchefstroom, Transvaal," which was illustrated by latern slides and a number of diagrams.

THE GEOPHYSICAL MAGNETOMETRIC INVESTIGATIONS ON WEST WITWATERSRAND AREAS BETWEEN RANDFONTEIN AND POTCHEFSTROOM, TRANSVAAL.

By RUDOLF KRAHMANN, M.E., D.E.

Introduction and Index.

This paper deals with the geophysical[1] magnetometric prospecting carried out on the south-westerly extension of the Witwatersrand goldfields. This was the first serious attempt in recent years to prove the extension of these goldfields to the south-west, and also the first time that a geophysical method of prospecting had been applied on a large scale to investigation on the Witwatersrand.

The paper is divided into three chapters:—

(1) Geophysical Investigations.
(2) Physical Interpretations, and
(3) Geological Deductions.

The first chapter embraces geophysical and other field investigations, and is subdivided as follows:—

A.—Short Description of the Area under Investigation and of Previous Prospecting.
B.—Application of Magnetometric Investigations on the Witwatersrand, First Experiments and their Results.
C.—Principal Magnetic Anomalies in the Lower Witwatersrand System.
D.—Statistical Data about the Magnetometric Fieldwork.
E.—Topographical, Aerial and Geological Surveys.

The second chapter deals more especially with physical factors, including the interpretations of geophysical data obtained in the field. It is sub-divided as follows:—

A.—Instruments Used, their Constants, Method of Observation and Control.
B.—Various Magnetic Variations.
C.—Susceptibilities and Magnetism of Lower Witwatersrand Magnetic Shale Beds.
D.—Calculated Theoretical Anomaly Curves.
E.—Calculating of Average Curves.
F.—New Method of Interpretation by Comparing Actual Observed with Calculated Curves.

The third chapter deals with the geological deductions obtained from the interpreted results as above and their application to further prospecting by drilling in the following:—

A.—Geological Deductions from the Magnetic Survey in the Eastern Section.
B.—Geological Deductions from the Magnetic Survey in the Western Section.
C.—Method of Calculating Borehole Sites.
D.—Borehole Results.
E.—Magnetometric Core Tests.
F.—Acknowledgments.
G.—Index of Literature referred to.

Before I go into the matter itself, I wish to express my sincere indebtedness to the late Dr. Leopold Reinecke, whose very untimely death occurred early last year, and I wish to thank my assistants, Dr. R. Reichenbach, Dr. F. Bahnemann, Mr. E. A. Ermert and Mr. P. J. Rossouw, of the Geological Department of New Consolidated Gold Fields, Limited, for their valuable contributions, especially to the second chapter of this paper.

I.—Geophysical Investigations.

A.—Short Description of the Area under Investigation and of Previous Prospecting :

The very first magnetometric experiments were carried out on outcrops of the Lower Witwatersrand System, north-east and east of Krugersdorp, and on the dolomite covered area near Tarlton Station, about eight miles west of Krugersdorp (see Fig. No. 2). Further experiments were carried out west and south of Randfontein, especially on the farm Middelvlei No. 6 and on the extensive outcrops of Lower Witwatersrand System, which are shown in the most westerly portion of Dr. E. T. Mellor's Geological Map of the Witwatersrand Gold Field (see Lit. No. 1).

After that a widespread magnetometric reconnaissance survey was made, covering an area with the approximate boundaries as follows :—

North : Main road, Krugersdorp-Ventersdorp.

East : The farms Middelvlei No. 6, Gemsbokfontein No. 1 and Libanon No. 28.

South : The Gatsrand Range-Potchefstroom-Klerksdorp.

West : Klerksdorp-Ventersdorp.

After this reconnaissance survey had been completed, a far more detailed magnetic survey was carried out, and restricted to the option area of the then formed West Witwatersrand Areas, Limited, covering the following farms from east to west (see Fig. No. 1).

Middelvlei No. 6 (portion),
Gemsbokfontein No. 1 (portion),
Venterspost No. 27,
Libanon No. 28,
Orange Grove No. 162,
Uitval No. 26,
Blaauwbank No. 41,
Doornkloof No. 155 (portion),
originally called Western Rand Estates Limited, then Western Areas, Ltd. ;
Driefontein No. 105 (portion),
Driefontein No. 118,
Vlakplaats No. 78,
Twyfelvlakte No. 8,
Blyvooruitzicht No. 71 (portion),
Varkenslaagte No. 46 (portion),
Doornfontein No. 139,
Deelkraal No. 63 (portion),
Kleinfontein No. 36,
Turffontein No. 90,
Kiel No. 85,
Gerhardminnebron No. 4 (portion).

The property held by West Witwatersrand, Areas, Ltd., extends from Randfontein towards the south-west for a length of 36 miles, up to the Mooi River, with an average width of about five miles and a total area of about 60,000 morgen.

The area lies in the broad valley of the Wonderfontein Spruit, and its greater portion is virtually a plain. The spruit itself is a drainage channel typical of the dolomite country. To the north the ground rises gently. To the south the plain ends rather abruptly against a line of hills (Gatsrand Range), which lies parallel to the spruit and about four miles south of it.

To the north of the eastern portion of West Witwatersrand Areas are outcrops of Lower Witwatersrand Beds, from the Orange Grove Quartzites up to the Government Reef Series. In the centre of the farm Middelvlei No. 6 there exists an inlier of Witwatersrand sediments. The exact horizon to which these belong has been a subject of controversy, and they will be referred to again. Except for three inliers of Lower Witwatersrand rocks on the farms Venterspost No. 27 and Blaauwbank No. 41, the whole plain is underlain by the Dolomite Series with the underlying Black Reef Quartzites outcropping along the north-eastern edges. The line of the Gatsrand Hills along the south of the area is formed of the Pretoria Series overlying the dolomite. In the dolomite-covered area there occur occasionally small remnants of Karroo sediments.

Between the years 1898 and 1904 nine boreholes were drilled in the Eastern Section on the farms Middelvlei No. 6, Gemsbokfontein No. 1, Venterspost No. 27 and Libanon No. 28 by the former owners, the Western Rand Estates, Limited (see Figs. Nos. 1 and 2). In each case the boreholes traversed a cover of overlying formations and entered the underlying Witwatersrand Beds. In six of these boreholes gold-bearing conglomerates of the Witwatersrand System were intersected, and shaft sinking was commenced, but various adverse factors, including the difficulties experienced at that time in sinking through water-bearing dolomite, contributed to the abandonment of the project. In 1913 Dr. E. T. Mellor (Lit. No. 1), mapping the Witwatersrand for the Union's geological survey, decided that the reefs in the Middelvlei Inlier and in these boreholes belonged to the Elsburg Series, which lie at the top of the Witwatersrand System.

In the western section of West Witwatersrand Areas, four boreholes were drilled also more than 30 years ago, namely, No. 10 on Doornkloof No. 155, No. E 4 and "Brayshaw's Borehole" on Driefontein No. 118, and Twyfelvlakte Borehole on Twyfelvlakte No. 8 (see Fig. No. 2). Borehole No. 10 (drilled by Western Rand Exploration, Limited) intersected 1,311 feet of Pretoria Series, 3,290 feet of dolomite (including the Black Reef Series) and 1,060 feet of Witwatersrand quartzites, most likely belonging to the Kimberley Series. Borehole No. E 4 (drilled by Goertz & Company in 1903) and "Brayshaw's Borehole" did not penetrate below the overlying dolomite cover. Twyfelvlakte Borehole, at a depth of 1,250 feet, entered an horizon of the Witwatersrand System that lies in section far below the Main Reef conglomerate.

B.—The Application of Magnetometric Investigations on the Witwatersrand, First Experiments and their Results:

The theory governing magnetometric surveying will be dealt with in Chapter II. In this connection I would like to refer to a paper entitled "Magnetometric Investigations as an Aid to Economic Geology," which I read before our Geological Society in July, 1930 (see Lit. No. 2). Another paper on this subject was given in April, 1934, by Mr. O. Weiss to a joint meeting of the Geological and the Chemical, Metallurgical and Mining Societies (see Lit. No. 3), and two months ago Mr. R. S. G. Stokes summarised the geophysical surveying in his paper, entitled "Recent Developments in Mining Practice on the Witwatersrand" (see Lit. No. 15).

In June, 1930, I conceived the idea of mapping the sub-outcrop of certain magnetite-bearing shales in the Lower Witwatersrand System with a magnetometric field balance in areas where these beds were covered by other formations. I reasoned that if known horizons of such shales could be accurately mapped by this means, it would be possible to calculate the position of the Main Reef also in covered areas, and so narrow down the ground that had to be prospected by drilling.

In order to obtain the necessary fundamental information about the magnetic properties of the various Witwatersrand Beds, preliminary field experiments were carried out on two traverse lines, the one on the old road from Krugersdorp to Muldersdrift, the other on a line north and south of the railway crossing on the Main Reef Road east of Krugersdorp. On these two profiles practically all strata of the Lower Witwatersrand System outcrop in normal succession, so that the ascertained magnetic anomalies could be directly linked up to the beds causing them. Five major anomalies of the vertical component of the earth's magnetic field were recognised at this stage. They are connected with the magnetite-bearing beds of the Water Tower Slates, Contorted Bed, Promise Beds, West Rand Shales and Upper Government Reef Shales. In order to prove the possibility of detecting and differentiating the same magnetite-bearing beds in areas where they are covered and hidden by younger formations, a third traverse line was surveyed on the farm Vlakplaats No. 20 on the main road connecting Krugersdorp and Rustenburg. Here, according to the geological map of E. T. Mellor (see Lit. No. 1), the Water Tower Slates and Contorted Bed could be expected to underlie the cover of Dolomite and Black Reef Series.

The graph of magnetic intensity obtained on this third section was compared with the graph on the first outcrop-traverse, with the result that three anomalies in the new graph could be definitely ascribed to the Water Tower Slates, Contorted Bed and Lower Hospital Hill Shales. The comparison of these two sections, Nos. I and III, is shown in Fig. No. 3. On account of the overlying cover of dolomite, these anomalies are of a minor amplitude, but are undoubtedly identical with the corresponding anomalies on the first outcrop-traverse. The positions of all magnetic traverses referred to can be seen on the plan in Fig. No. 2.

At the same time the third traverse proved that, fortunately, the overlying cover of Dolomite and Black Reef Series does not enclose any magnetically disturbing beds.

Further experimental sections were surveyed on the farm Roodepoort No. 43, east of Krugersdorp and elsewhere, traversing the Kimberley Shales which outcrop there. No magnetic anomalies were detected in these sections, which indicates that the Kimberley Shales do not contain any large quantities of magnetite.

Generally speaking, these experiments demonstrated that the magnetometric mapping of many of the horizons in the Lower Witwatersrand System is a practical possibility, even in areas where the formations lie under deep cover.

These results of the preliminary investigations, which were conducted as private experiments, were communicated to Mr. G. Carleton Jones, consulting engineer of the New Consolidated Gold Fields, Limited, by the late Dr. Leopold Reinecke.

As the questions of establishing possible mining extensions of the Witwatersrand between Randfontein and Klerksdorp had been under consideration, the New Consolidated Gold Fields took this new line of geophysical investigations as a fresh impetus to start an extensive investigation into the possibilities of discovering the main reef horizon in what had been looked upon as closed territory for many years.

C.—The Principal Magnetic Anomalies in the Lower Witwatersrand System:

After the first experiments had indicated the principles on which further and more extended investigations required to be carried out, the fundamental correlation between the different major and minor magnetic anomalies and the different strata of the Lower Witwatersrand System had to be established in more detail.

In Fig. No. 4 is shown the average geological section on the Far West Rand as compiled by Dr. L. Reinecke from carefully detailed plane table work carried out mainly on the large outcrops on Witfontein No. 29.

Magnetometric traverses were surveyed in detail along the same section line as the geological plane table survey. From these traverses the principal magnetic anomalies in the Lower Witwatersrand System were determined and correlated as follows :—

Type of Anomaly.	No. of feet above base of Orange Grove Quartzites.	Distances between Anomalies.	Correlated to	Typical Anomalies shown in Fig. Nos.
	Feet.	Feet.		
(1) Major anomaly ..	894		Water Tower Slates.	3, 23, 24
		1,509		
(2) Major anomaly ..	2,403		Contorted Bed.	3, 23, 24
		1,714		
(3) Minor anomaly ..	4,117		Lower Hospital Hill Shales.	3, 24
		2,398		
(4) Minor anomaly ..	6,515		Middle Hospital Hill Shales.	24
		1,354		
(5) Minor anomaly ..	7,869		Upper Hospital Hill Shales	24
		1,698		
(6) Major anomaly ..	9,567		Promise Beds.	24
		(4,074) 2,300 }		
(7) Major anomaly ..	13,641		West Rand Shales.	5, 12, 13 19, 21, 25.
		2,081		
(8) Major anomaly ..	15,722		Government Reef Shales.	12, 13, 21, 2
		2,461		
(9) Minor anomaly ..	18,183 (20,451)		Jeppestown Series. (Main Reef, base).	12, 20, 21, 25
		2,268		
No anomaly	22,541		Kimberley Shales, base.	

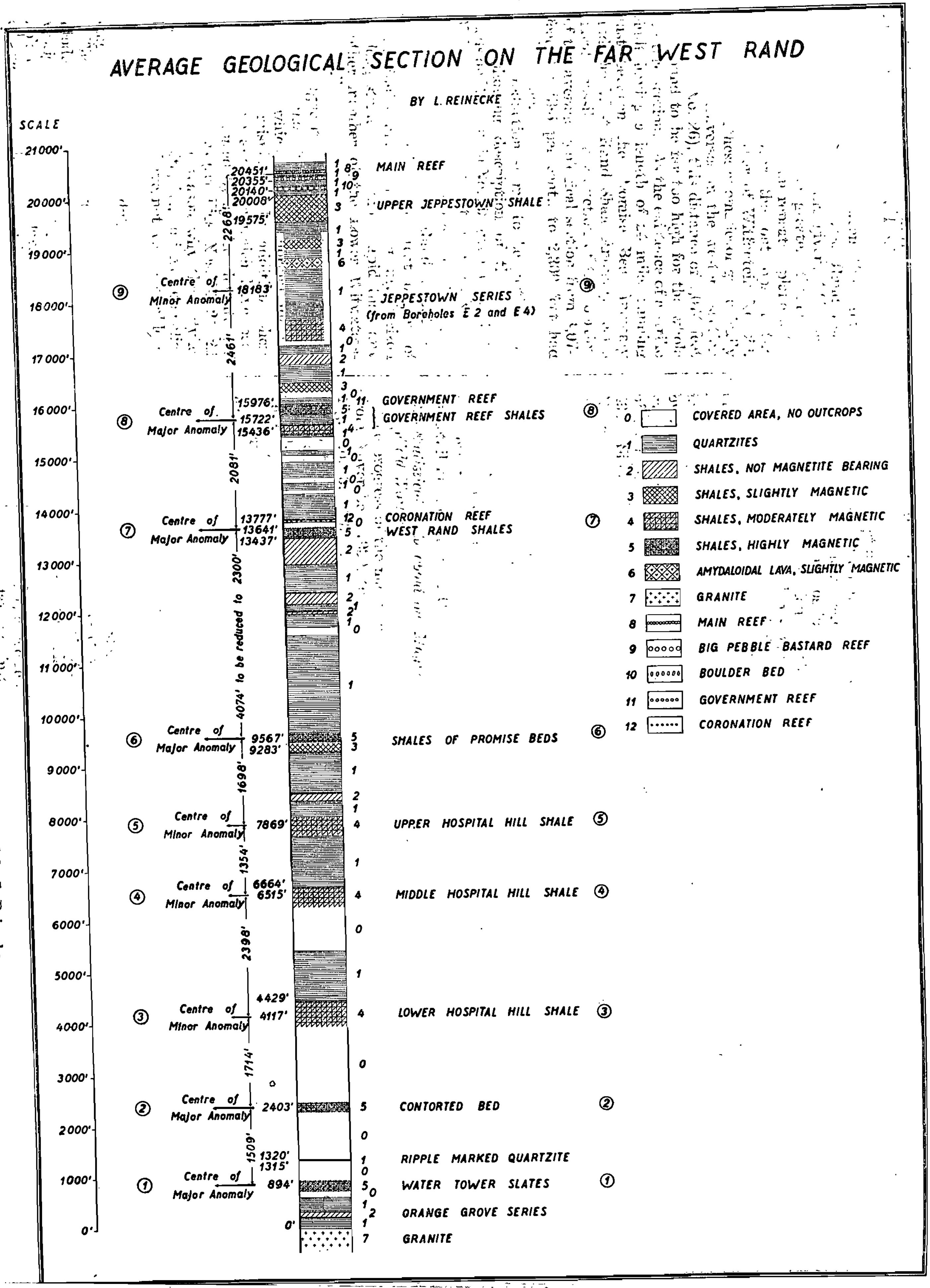

Fig. No. 4 (Plate IV.)—Average Geological Section on the Far West Rand, by L. Reinecke.

On the plan in Fig. No. 2, these anomalies are outlined and marked with the same numbers as above.

For the distance between the Promise Bed Anomaly and the West Rand Shale Anomaly, two figures are given, 4,074 feet and 2,300 feet. The greater distance of 4,074 feet is based on repeated plane table measurements over the outcrops in the south-eastern corner of Witfontein No. 29. But in plotting these anomalies on geologically calculated traverses in the western section (see Fig. No. 26), this distance of 4,074 feet was found to be far too high for the whole western section. As the existence of a strike fault having a length of 24 miles running just between the Promise Bed Anomaly and the West Rand Shale Anomaly seems hardly possible, a reduction of this portion of the average geological section from 4,074 feet, by 43·5 per cent., to 2,300 feet had to be made.

This reduction seems to be justified by the following description of the Promise Beds on Witfontein No. 29, given by Dr. E. T. Mellor for this very locality (see Lit. No. 4).

"Very great increase in thickness; compared with Central Rand, about 100 per cent. Beds show great degree of variability and variation of any horizon along strike, much more rapid than any other member of the Lower Witwatersrand."

The magnetite-bearing shales of the Lower Witwatersrand System give rise to negative anomalies, which effect is normal for the southern hemisphere. In addition, there occur positive anomalies which have been found to be caused by syenite, dolerite and granophyre dykes (see Figs. Nos. 14, 21, 22, 24 and 25). The reason why these dykes give rise to opposite, *i.e.*, positive anomalies, is a problem we have not yet been able to solve.

The older Diabase dykes do not cause magnetic anomalies.

The Ventersdorp lava likewise does not produce anomalies in the area of our investigations. Magnetometric tests on bore-hole cores of Ventersdorp lava—the method of such tests will be described in a later paragraph—revealed only traces of magnetic material.

The same applies to the Amygdaloidal lava interbedded in the middle portion of the quartzites of the Jeppestown Series, the results of core tests of which are shown in Fig. No. 28.

With the exception of the West Rand Shale Anomaly, practically none of the different anomalies show a curve sufficiently distinctive to make it possible to identify them from its shape alone. The West Rand Shale Anomaly shows two minima near to each other, provided that dip and overburden are not too great. On account of this feature, one anomaly in the Western Section, four examples of which are shown in Fig. No. 5, was considered to be caused by West Rand Shales long before this anomaly was connected with the actual outcrops of West Rand Shales on Elandsfontein No. 494. Similar typical shapes of the West Rand Shale Anomaly in the Eastern Section are shown in Fig. No. 21.

The shape of the curve representing the magnetic anomaly caused by any particular ferruginous shale horizon is furthermore very different, depending on whether it is actually exposed at the surface or is detected as a sub-outcrop beneath even a thin cover of overlying rocks. This will be explained in detail in paragraph II C.

D.—Statistical Data about the Magnetometric Field Work:

The progress of the magnetometric survey from November, 1930, to date is shown in Fig. No. 6. The hatched graph (middle curve) represents the number of observations made on West Witwatersrand Areas every month. The rise of this curve in April, 1931, was due to the engagement of an assistant geophysicist. The drop of the curve in July, 1932, is due to increased office work. The increase of observations in January, 1933, was caused by the commissioning of a second magnetic field balance.

The drop of the curve for August and September, 1933, March, 1934, and the last quarter of 1934 and June, 1935, is due to the fact that the instruments were used for magnetic surveys outside West Witwatersrand Areas, mainly on the East Rand (see Lit. No. 5).

The cross-hatched (lower) curve represents the monthly number of days per instrument on which actual field work was carried out. The increase of efficiency is illustrated by the white graph (upper curve), which represents the number of observations made

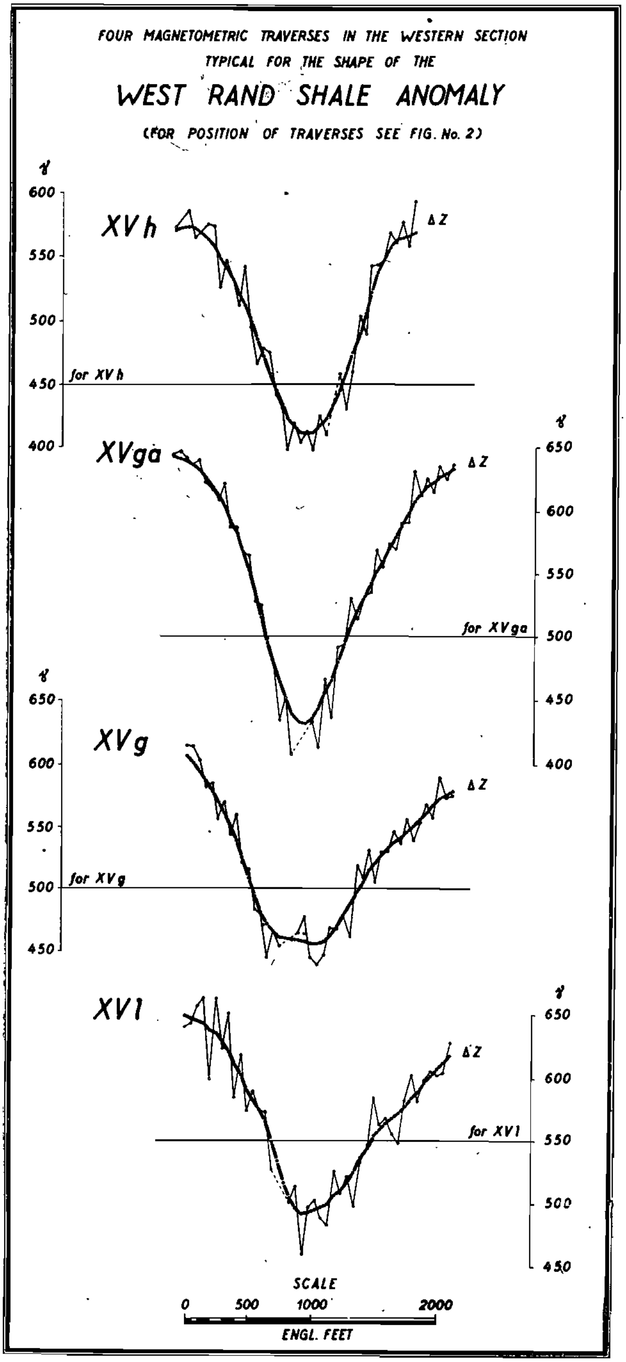

FIG. No. 5—Four Magnetometric Traverses in the Western Section Typical for the Shape of the West Rand Shale Anomaly.

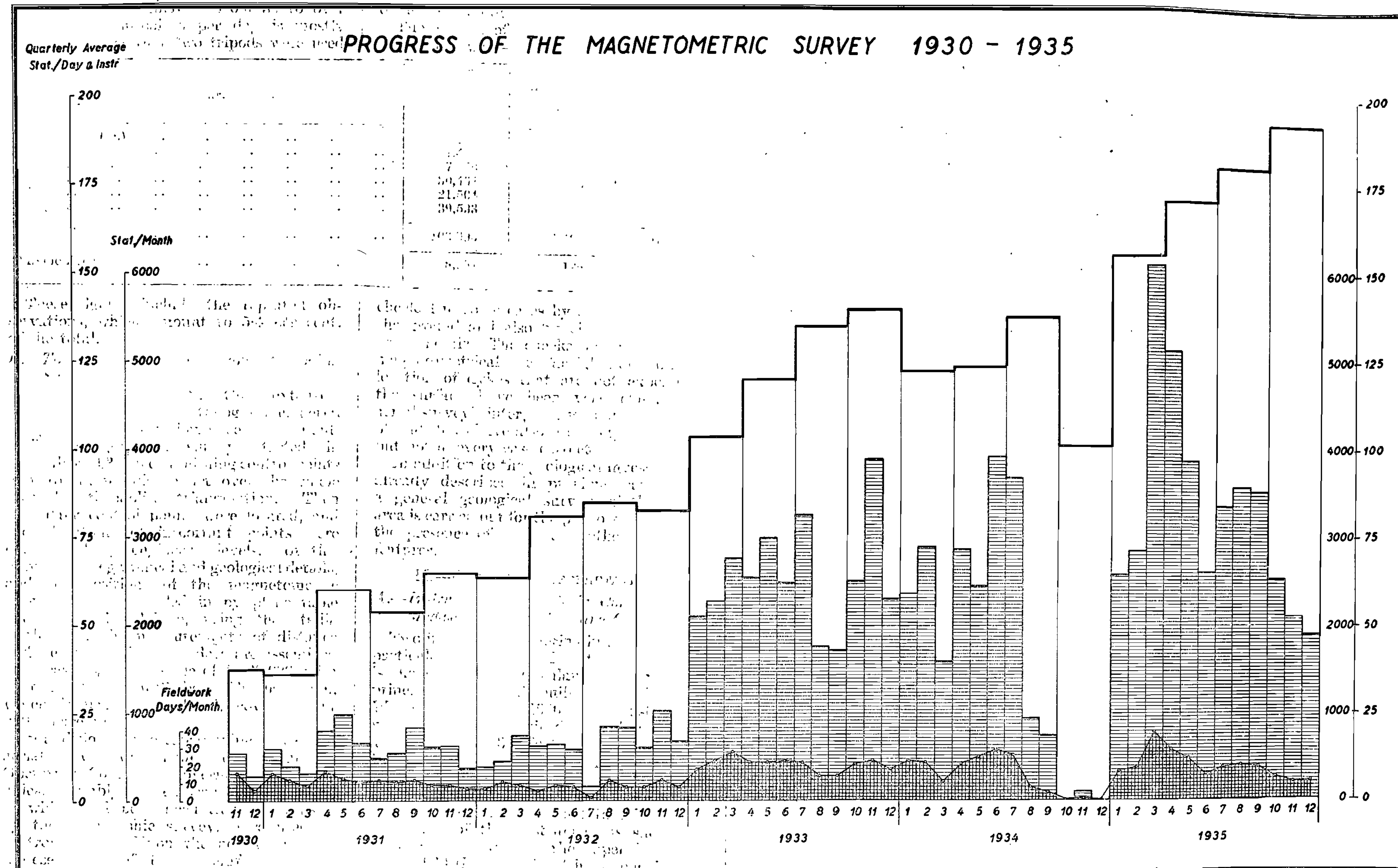

Fig. No. 6 (Plate V.)—Progress of the Magnetometric Survey, 1930-1935.

per day per instrument in quarterly averages. The considerable increase from 30 to over 190 observation-points per day is mostly due to the fact that two tripods were used for each instrument, and that the number of readings on every point could be reduced.

The number of observations for each year was as follows :—

Year.	Observations.	Length of Traverses (miles).	Coretests.
1930 (Nov., Dec.)	711	8	—
1931	7,454	224	—
1932	7,339	123	—
1933	30,454	273	—
1934	21,504	189	3,483
1935	39,533	614	6,688
Total	106,995	1,431	10,171
Outside Areas	8,957	125	300

These figures include the repeated observations, which amount to 5·4 per cent. of the total.

E.—Topographical, Aerial and Geological Surveys :

In conjunction with this extensive magnetrometric survey, topographic, aerial and geological surveys have been carried out.

The topographical survey started in December, 1932, in establishing control points four to seven miles apart over the whole area by theodolite triangulation. Then secondary control points were located, and the elevations of important points were determined by engineers' levels. In this network, topographical and geological details, and the positions of the magnetometric traverse lines are filled in by plane table and telescopic alidade, using the stadia method for the measurements of distance and elevation. All these data are assembled on a base map on a scale of 1 : 20,000, with contour intervals of 25 feet. This base map, which is nearly completed, covers about 380 square miles.

In addition to the topographic survey, an aerial survey was made by the Aircraft Operating Company, covering 470 square miles. Suitably marked beacons, the location of which had been accurately determined by the topographic survey, were used as control points. Upon the aerial map the representative of the Aircraft Operating Company marked his own interpretation of such geological and structural features as can be deduced from the aerial survey.

Conclusions were drawn largely from the examination of photographs, and these were checked in some cases by examination from the ground and also by visual examination from the air. The checks obtained by both magnetometrical and aerial work on the location of dykes that are not exposed at the surface have been very close. The aerial survey's interpretations of the location of fault lines have also been very suggestive, but not in every case correct.

In addition to the geological investigations already described in previous paragraphs, a general geological survey of the whole area is carried out for the purpose of revealing the presence of faults and other structural features.

II.—Physical Interpretations.

A.—Instruments Used, their Constants, Methods of Observation and Control :

Two instruments differing in certain minor particulars are used. The first instrument is the magnetic field balance (Ad. Schmidt principle) No. 98583, built by the Askania-Werke in Berlin in 1930. This instrument was adjusted for a latitude 26°12′ South and a longitude 28°3′ East by the Magnetic Observatory in Potsdam. The same observatory determined the scale value $\epsilon = 30{\cdot}1\ \gamma$, and the temperature-correction $\kappa = 4{\cdot}2\ \gamma/°$ C. ($1\ \gamma$ is equal to $1{\cdot}10^{-5}$ cgs). A picture of this instrument is shown in Figs. Nos. 1 and 2, in the paper I read in July, 1930 (Lit. No. 2). The second instrument, in commission since January, 1933, is the magnetic field balance No. 116996 (Ad. Schmidt principle), built by the Askania-Werke in 1932. This new type of instrument can be used for measurements of both the vertical and horizontal components of the earth's magnetic intensity. The new magnet systems are temperature-compensated. The instrument was adjusted for the same latitude and longitude, and the constants were determined as follows :—

(a) Magnet system for vertical intensity, scale value, $\epsilon=30{\cdot}1\ \gamma$; temperature correction $\kappa=0{\cdot}0\ \gamma/^\circ$ C.

(b) Magnet system for horizontal intensity, scale value, $\epsilon=10{\cdot}0\ \gamma$; temperature correction, $\kappa=0{\cdot}0\ \gamma/^\circ$ C.

In order to keep the scale values under control, an electrical apparatus for determining scale values (Askania No. 117,735/111,701) is used (see Fig. No. 8 in the paper I read in July, 1930 ; Lit. No. 2).

The scale values are redetermined about every month, and occasionally the temperature-correction for the old instrument is checked.

The magnetic moments of the auxiliary magnets were also determined by the Magnetic Observatory in Potsdam, but all permanent magnets tend to lose magnetism in time, and, therefore, in every case where the use of the auxiliary magnets is necessary, their actual magnetic moment is redetermined. This is effected by decreasing the distance between observation points until a complete series of observations enables us to calculate the effect of all auxiliary magnets used.

General methods and technique of magnetometric investigation have been described in detail by O. Weiss (see Lit. No. 3). In order to save time, we decreased the number of readings on every observation point from six to two, provided that the difference between these two readings did not exceed 10 γ. The accuracy of the results, though somewhat lessened, is still quite sufficient for our purposes, on account of the strength of our anomalies. Another great advantage is to use two tripods for every field balance instead of one, so that the instrument is transferred from one tripod to the next one without being put back into the box. By this means the number of points daily observed was nearly doubled.

To link up the results of one day's survey with those of the previous and the following day, and to keep the base value of the instrument under control, repeated measurements are made either on certain base points or at the ten last points observed the day before. The number of such repeated observations amounts to 5·4 per cent. of the total observations.

As the earth's magnetic field is negative in the Southern Hemisphere, such geological conditions as tend to increase this field are represented by negative anomalies. In the Northern Hemisphere, the same conditions would produce a positive anomaly.

In order to keep the records concerning magnetometric investigations uniform, the method of reading and drawing curves, taking the normal field as negative, is applied.

B.—Various Magnetic Variations :

The vertical magnetic field balance is so adjusted as to compensate the effect of the earth's magnetic field in the region where it is to be used, and it is, therefore, the deviation from this normal field, due to the presence of magnetised bodies, which is registered by this instrument, allowance being made for minor magnetic disturbances due to other causes.

Research work carried out by all civilised nations during the last century has solved some of the most important problems regarding the earth's magnetic field, such as the magnetic declination, inclination and horizontal intensity in various parts of the globe. In addition, measurements spread over many years reveal the fact that such magnetic values measured at a certain locality are not constant, but vary slowly with time, a fact which is known as the secular variation. To give an idea of the order of magnitude of the secular variation in South Africa, we have plotted, in Fig. No. 7, the variation of the normal values of the vertical intensity at Capetown and Mauritius. The observatory at Mauritius is known to lie in a regional anomaly (see Lit. No. 6), which may affect the secular variation, and explain the somewhat different behaviour as compared with that of Capetown. The changes due to secular variation are too slow to affect measurements with the ordinary field instrument. An accurate determination of the elements of the earth's magnetic field in an area where magnetometric surveying is to be carried out is desirable, as it enables the magnetic field balance to be properly calibrated. This is by no means essential, however, as any suitable station within the area may be adopted as a standard and all others tied on to it, as it is relative changes in magnetic

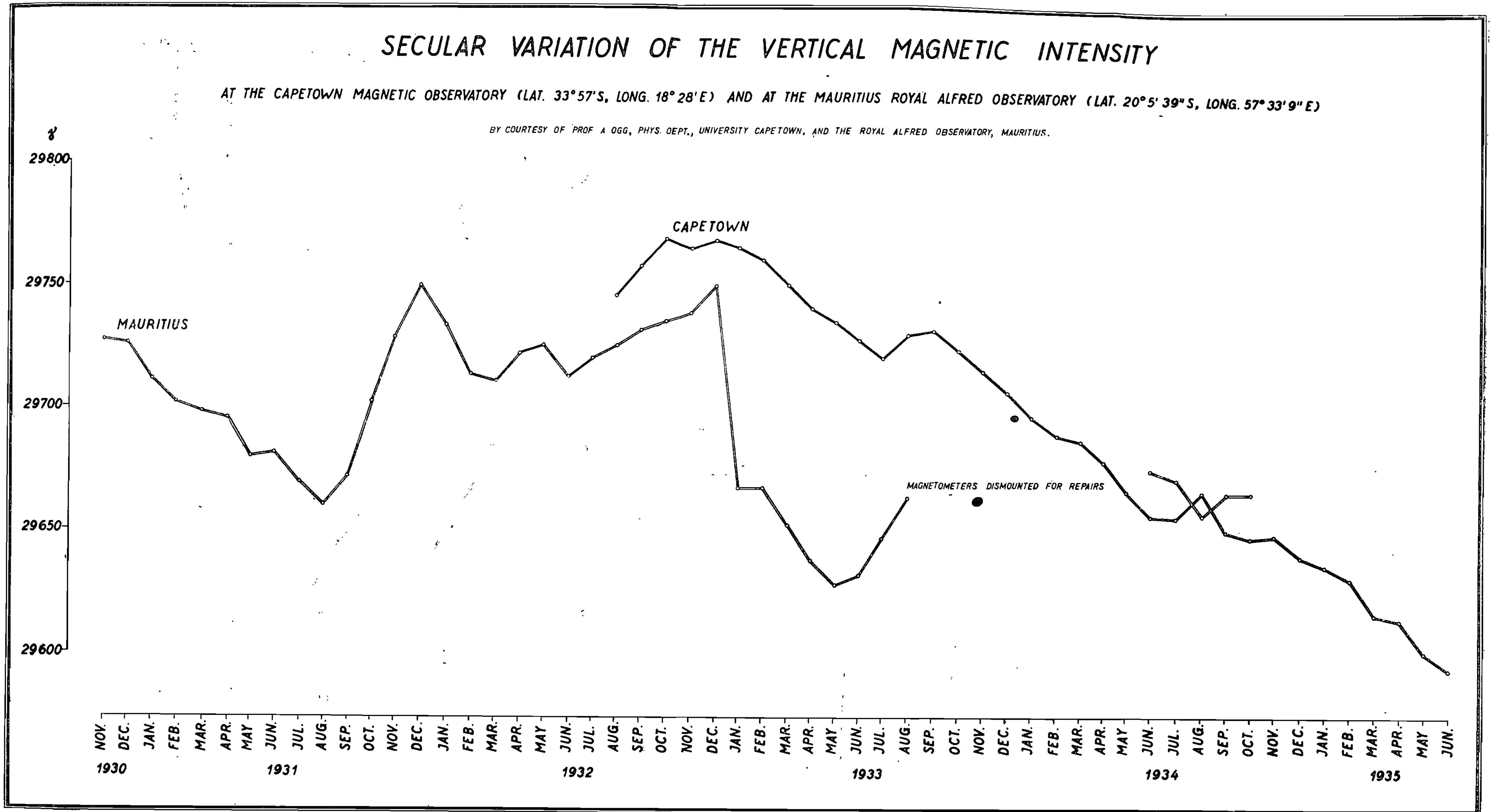

FIG. No. 7 (Plate VI.)—Secular Variation of the Vertical Magnetic Intensity at the Capetown Magnetic Observatory and at the Mauritius Royal Alfred Observatory.

intensity rather than absolute values that are of importance in magnetometric prospecting. In the case of West Witwatersrand Areas, however, the absolute values of the elements of the earth's magnetic field were actually ascertained at a point within the area by Mr. R. H. Mansfield, observer for the Carnegie Institution of Washington, and gave the following values :—

Declination	16°35·0′ W
Inclination	62° 8·6′
Horizontal Intensity	15,867 gamma.
Vertical Intensity ..	30,023 gamma.

The earth's magnetic field is, in addition to secular variation, subject to other fluctuations. The most important of these are the daily variation and the so-called magnetic storms. Fig. No. 8 shows the daily variation of the vertical intensity at Mauritius and at Capetown for every month in the years 1932 and 1933 respectively. The maximum variation amounts to about 35 gamma during five hours. As the maximum deviation from the mean value is only 18·20 gamma, a survey during the time of such a variation would be subject to this error, recording in an otherwise undisturbed region an anomaly of that magnitude.

It is a great disadvantage for every worker with the field balance in the greater part of the Union, especially in the Transvaal, that there are no records of the daily variation available, so that we must either neglect it entirely or rely on the records of such remote stations as Capetown, where the instruments of the Carnegie Institution are registered under the supervision of Professor Ogg, or the Royal Alfred Observatory at Mauritius. On the Witwatersrand we are fortunate, in that the more important magnetic shale beds are so strongly magnetised that in most cases it is possible to neglect the influence of the daily variation. We have, nevertheless, endeavoured to obtain the best possible approximation by estimating the value for Johannesburg by interpolating between the values of the vertical intensity as recorded at Capetown and Mauritius, making the usual assumption that the daily variation is a function of latitude and local time. Fig. No. 9 shows the mean values of the daily variation for the month of September, 1932, as recorded at Capetown and at Mauritius, and the estimated values for Johannesburg.

Of far greater importance is the disturbing effect produced by the so-called

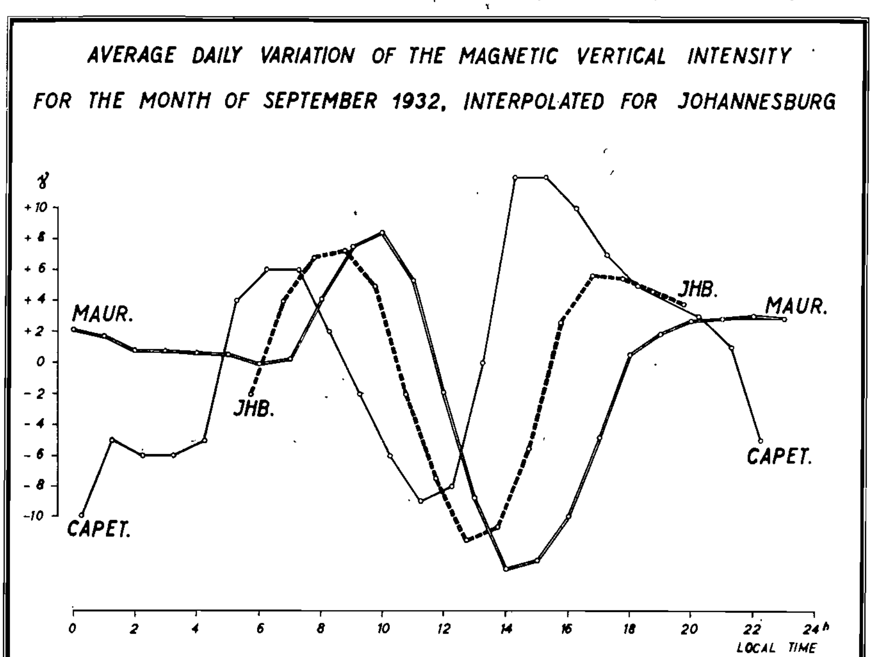

Fig. No. 9—Average Daily Variation of the Magnetic Vertical Intensity for September, 1932, Interpolated for Johannesburg.

an outcrop of which occurs in the northern portion of the farm Venterspost No. 27.

A magnetic section VGW was run across the strike, observations being taken at intervals of 5 feet, and a trench was then dug along this same line for the purpose of obtaining a detached geological section. In Fig. No. 12 the vertical and horizontal intensities are shown together with the geological section. The graph of the vertical component shows sharp changes of intensity and sign, which characterise all outcrop sections of magnetic shales, whereas the graph of the horizontal intensity exhibits a much more uniform behaviour. A comparison of the values of the vertical intensity shows a fairly good agreement with the geological findings.

In order to gather more information about the magnetic properties of the shales, samples were taken at intervals of 5 feet along the trench; these were crushed down to forty mesh and the powder put through an electro-magnetic separator. The percentages of magnetic material so found, which are naturally only relative since a certain amount of non-magnetic particles adheres to the magnetic matter, have been plotted together with the results of the magnetic field survey in Fig. No. 13. The values of the vertical component have been plotted regardless of sign, so that they show in this case only changes of intensity.

Comparing the graphs of the magnetic separation and of the field survey, one may detect some similarity in the shape of the two curves, but this is hardly sufficient to explain the rapid changes of the field curve. The comparatively smooth curve, representing the relative percentage of magnetic material, seems to indicate that the characteristic rapid changes of intensity as denoted in the curve of the magnetic field survey depends not so much on differences in the content of magnetic matter, but perhaps to a greater degree on the shape of magnetic bodies themselves and their distance from the instrument. It must be remembered that the effect of finite magnetic bodies goes with the second or third power of the distances, and especially in the case of an outcrop where the instrument is close to these bodies, and in consequence small variations of distance produce large variation of intensity. Even variations in the sign may be produced, especially if these magnetic bodies vary in depth. The whole problem is a three dimensional one, and, therefore, very complicated, and as will be seen later, its solution is not important for our main problem, namely, to study the behaviour of the magnetic shales at depth. The above-mentioned magnetic bodies may be represented by parts of the shales, which contain exceptionally more magnetic material than neighbouring parts. Such irregularities are likely to be emphasised in those parts of the shales which are exposed to the action of weathering, *i.e.*, the first few yards from the surface. The effect of weathering has decisively been disclosed by measurements of the susceptibility of some samples from the above-mentioned trench, the method employed having been the so-called ballastic method (see Lit. No. 12).

The results are plotted in Fig. No. 13. Very different values of the susceptibility were found, which fact by itself is nearly sufficient to explain the observed sharp changes of intensity. Further, the order of magnitude was much lower, only one-sixth to one-tenth of what could be anticipated. An estimate, based mainly on the value of the maximum obtained over West Rand Shales lying under a cover of several hundred feet, has led us to a figure of $\kappa = 65{,}000 \cdot 10^{-6}$, whereas the values found in the laboratory ranged from 5,000 to $8{,}000 \cdot 10^{-6}$. This discrepancy may be explained on the assumption that the magnetic effect observed is mainly due to permanent magnetism, this permanent magnetism being irregularly spread over the whole extension of the shales. In this case the determination of the susceptibility would not help much in explaining the nature of the magnetic disturbance. On the other hand, we have evidence that it is not feasible to extrapolate the magnetic properties found on the surface to the magnetic objects at depth, where "depth" means at least the thickness of weathered surface soil. Observations made on pieces of fresh rock out of boreholes which had penetrated the magnetic band of the Jeppestown Shales disclosed the fact that all corepieces, representing many hundred feet of shales, were magnetically soft, *i.e.*, that we have to deal not with permanent magnetism, but with induced magnetism. Besides, wherever we found West Rand Shales under cover, their magnetic effect as regards the direction of the field was the

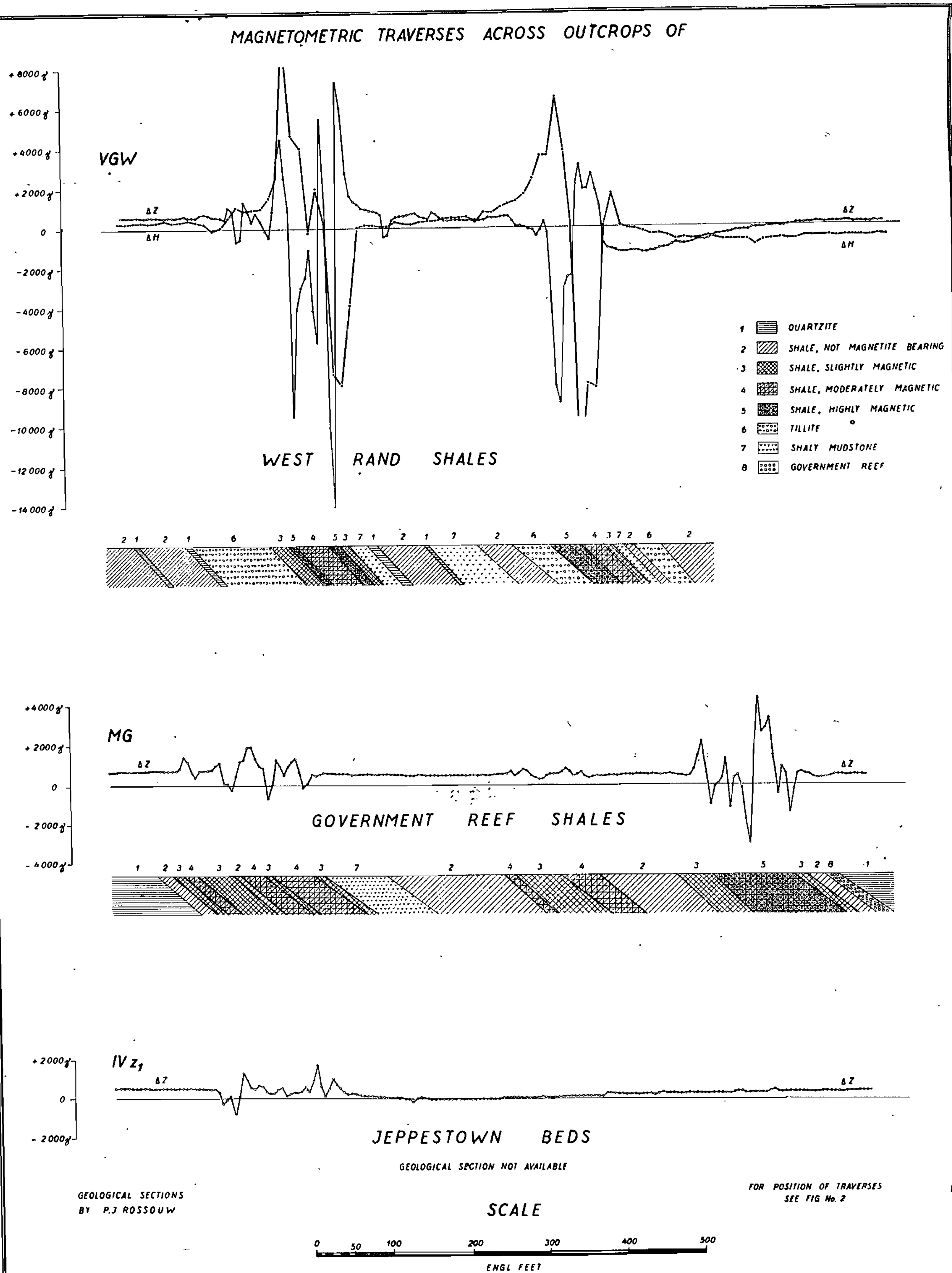

Fig. No. 12—(Plate IX.)—Magnetometric Traverses across Outcrops of West Rand Shales, Government Reef Shales and Jeppestown Beds.

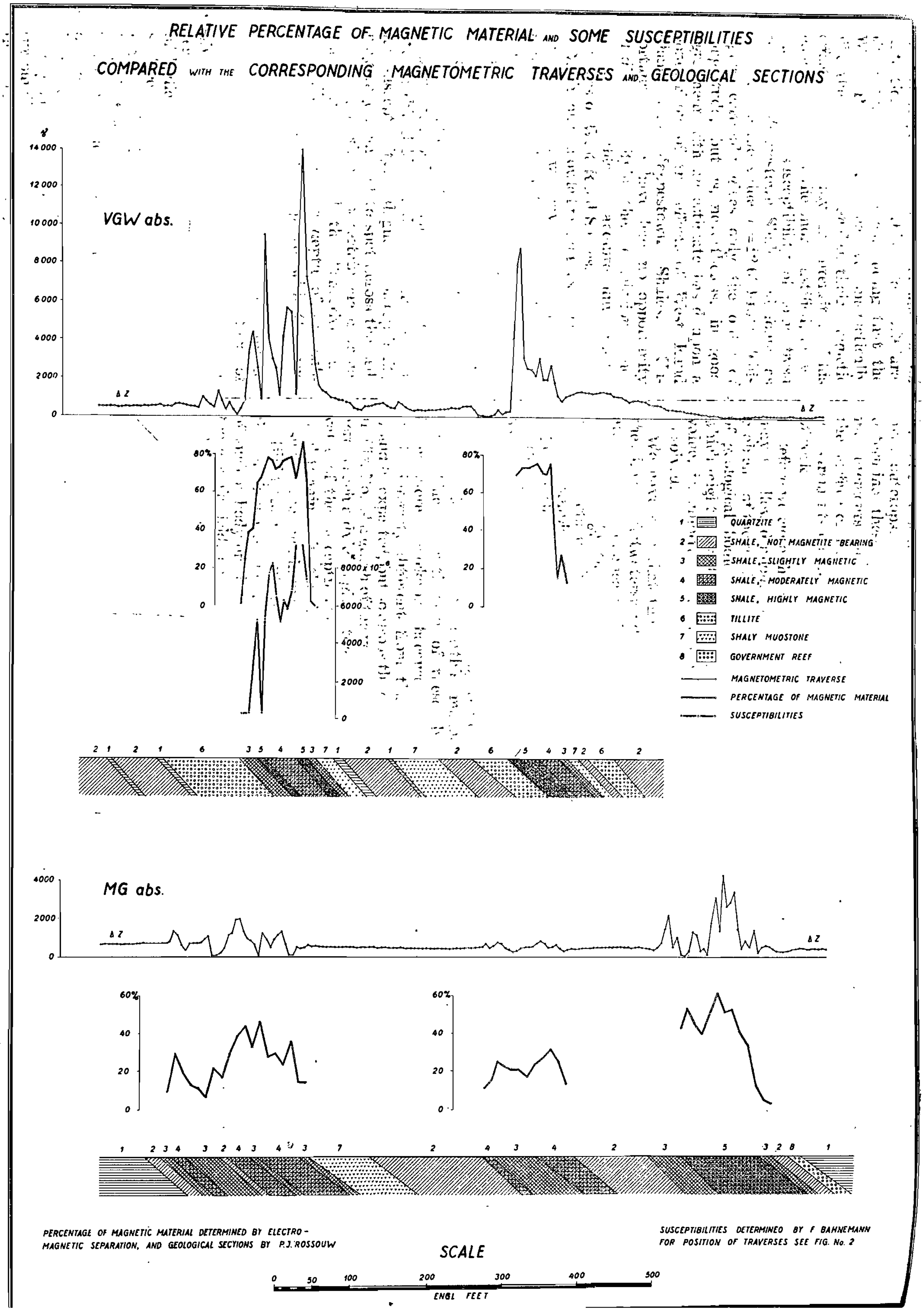

Fig. No. 13 (Plate X.)—Relative Percentage of Magnetic Material Determined by Electro-magnetic Separation and some Susceptibilities compared with the Corresponding Geological Sections and Magnetometric Traverses.

same as observed over Jeppestown Shales, *i.e.*, corresponding to the assumption of induction by the earth's field. We are, therefore, justified in concluding that the West Rand Shales behave magnetically like the Jeppestown Shales, their magnetic effects differing only in intensity. This conclusion seems the more justified, as we measured the susceptibility of some fresh pieces of Jeppestown Shales and found as an average the value $\kappa = 12{,}000 \cdot 10^{-6}$. This figure certainly gives only the order of magnitude, but is, nevertheless, in good agreement with an estimate based upon a comparison of the effects of West Rand Shales and Jeppestown Shales. Unfortunately, we have had no opportunity of directly verifying these conclusions, since we were unable to acquire unweathered samples of West Rand Shales.

With our knowledge and experience up to the present, we may make the following statements about such cases of measurements over outcrops.

In the first instance we have to consider the weathered layer, the magnetism of which is very irregularly spread across the thickness and in depth. Then we must regard the unweathered bed, which is magnetised by the earth's field according to the value of its susceptibility. Magnetic susceptibility may vary from spot to spot across the bed, but it approximates a certain mean value, which we may call the "effective susceptibility," when the depth of the sub-outcrop is great compared with the true thickness of the bed.

Vertical intensity measurement is by no means the most advantageous method of dealing with outcrop conditions, as it may give a thoroughly wrong impression of the real conditions by exaggerating the effects of bodies which are lying very near to the surface. On the other hand, this very reason makes it a well-adapted method for investigating magnetic bodies at depth. The measurement of the horizontal intensity, on the other hand, can be profitably employed in case of outcrop, as the horizontal intensity at any point is more equally affected by all surrounding bodies, and not only by those that may happen to be in the immediate neighbourhood of the point of measurement, as was shown in Fig. No. 12.

In conclusion, it is impossible to determine the magnetic properties of such bodies as occur in the Lower Witwatersrand Shales by measurements of the vertical intensity over outcrops. It is useless, likewise, to determine these properties by laboratory measurements on pieces which come from the surface or from shallow depths. These measurements require absolutely fresh pieces of rock.

Before we close this chapter, some remarks may be allowed about the purely theoretical problems of the causes for the magnetisation of geological bodies. This main problem, which might prove to be of extreme practical value, is, unfortunately, in many cases left unsolved.

We have seen that the magnetisation of the Lower Witwatersrand Shales in our area is in accordance with the assumption of induction by the earth's magnetic field. Measurements of the susceptibility carried out on samples of the Jeppestown Shales point to the same assumption. Contrary to this normal behaviour, however, there have been detected in the same area dykes of the Pilansberg System, the magnetisation of which cannot be explained by the effect of induction from the earth's magnetic field. The magnetisation of these dykes is the more remarkable, because not only is the intensity different from that which would be expected, but so also is the direction. In Fig. No. 14 a graph of the vertical intensity across such a dyke is given together with the value of the susceptibility of some samples as determined in the laboratory. If one assumes the maximum value of the susceptibility to be about $1{,}700 \cdot 10^{-6}$ an calculates the maximum disturbance over an outcrop of such a body on the basis of induction by the earth's field, one arrives at a value of —320 gamma against the observed value of +2,300 gamma. These figures show clearly the strange magnetic behaviour of these rocks. A fact which may be connected with this anomalous magnetisation is that the direction of strike is nearly north-south, whereas the Witwatersrand Beds strike east-west. But it must not be overlooked that this fact may be accidental, since as yet we have no possibility of connecting it with any known causes of magnetisation.

Another very important feature is the persistent character of this magnetisation. A calculation of the magnetisation for the dyke, the magnetic disturbance of which is shown in Fig. No. 14, leads to a value for $Irn=3{,}66 \cdot 10^{-3}$. The magnetisation calculated on the basis of induction, taking the total field as 0·3318 Oe, gives $Ik=5{,}64 \cdot 10^{-4}$.

A recent publication by Koenigsberger (Lit. No. 7), in which the author gives an account of investigations carried out with the object of establishing a connection

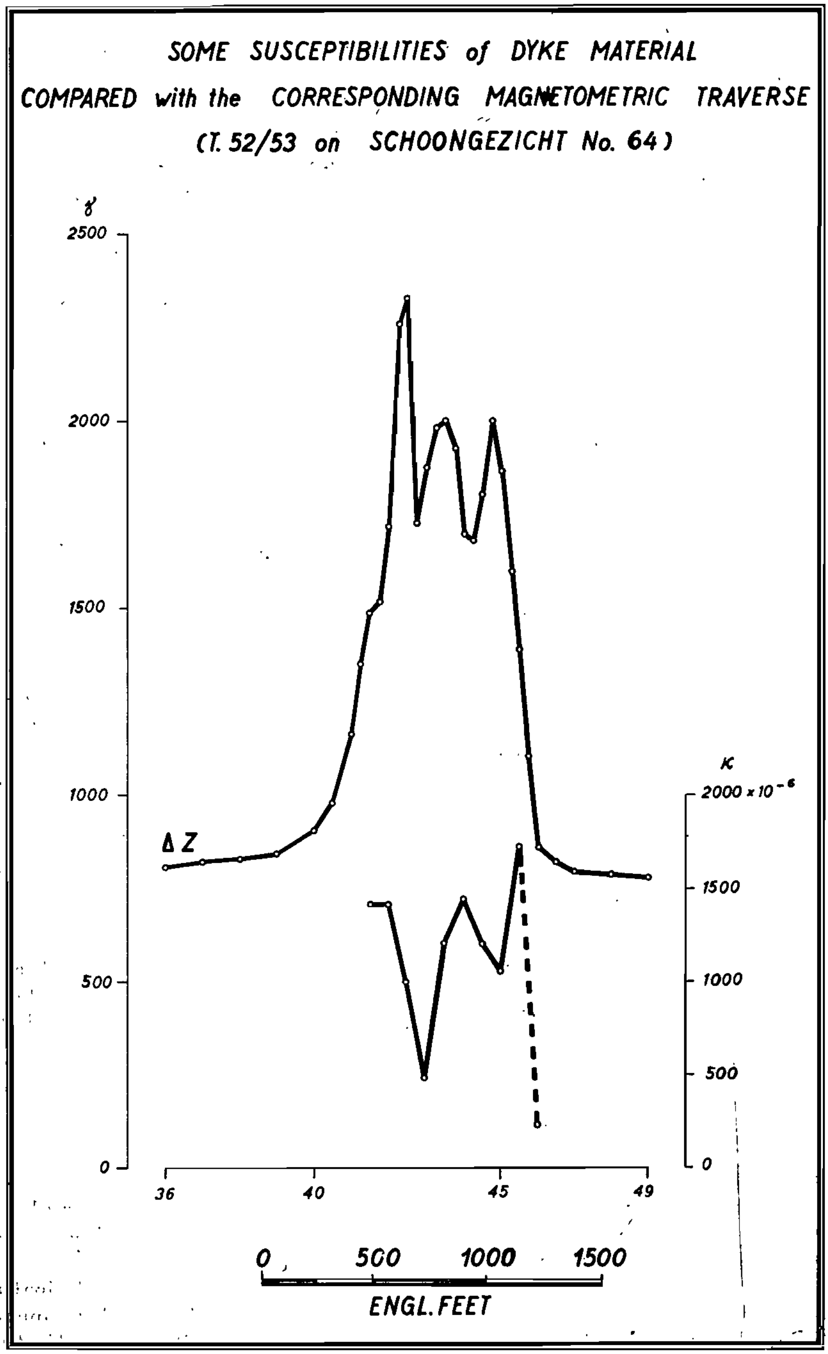

FIG. No. 14 —Some Susceptibilities of Dyke Material compared with Corresponding Magnetometric Traverse.

between the natural remanent magnetism of igneous rocks and their age and composition, shows values of Irn for several samples of basalts similar to that given above. The parameter which has been used to demonstrate the remanent magnetism as a function of the age is the quotient $Q_n = \frac{Irn}{Ik}$ which in our case is about 7. For igneous rocks in Central Europe, the rule has been found that rocks older than Permian show a magnetisation which is mainly due to induction, Qn being small (1 or smaller than 1). It would be of great practical value if a similar rule could be established for South Africa.

Further work is necessary to explain the abnormal direction of magnetisation, which may be due to the effect of cooling processes and perhaps more to mechanical forces. From a physical point of view, considerations about the magnetic energy may be helpful also to clear up this problem.

D.—Calculated Theoretical Anomaly Curves:

From our field observations we ascertain the variation of the vertical magnetic intensity on the surface, from which we must endeavour to ascertain the nature of the body which causes these variations. The perfect solution would give the position, the size and the magnetic constants of the disturbing body. In this ideal form, the solution of the problem is practically impossible, or, in other words, the number of possible solutions is infinite. The reverse problem, namely, to predict the variations of the magnetic intensity on the surface, if the constants of the body are known, is, on the other hand, capable of a definite solution. These statements show the procedure to be followed in order to arrive at a solution of a special problem, or at least to a useful approximation. Each case must be treated separately, according to our knowledge of some of the characteristic constants of the body concerned; let us, therefore, sum up our knowledge about the magnetic bodies in the Lower Witwatersrand System:—

(1) These bodies can be described as being slablike.
(2) Their true thickness is very small compared with their other dimensions.
(3) Their strike can be followed for many miles, and is in most cases great as compared with the depth of their sub-outcrop.
(4) The extension of these bodies in depth is great compared with the depth to the sub-outcrop.
(5) Their magnetic effects are regular over the whole length of strike, and their magnetism is similar and points out to induction from the earth's magnetic field.

The above-mentioned five points define the shape and the dimensions of the body, and localise the seat of the magnetism. To treat the problem mathematically, one must replace the real body by an ideal structure; the simplest of all structures which could take the place of our body would be a so-called "single pole," or several "single poles," as proposed in a previous paper (Lit. No. 3). That this procedure cannot give a suitable representation of our case becomes clear if we consider that the free magnetism of our shales is not confined to one point, but can be taken to be distributed over a line of almost infinite length. The principle of the single-pole method regarding the interpretation can, nevertheless, be extended to our case by comparing the effect of a straight line, the elements of which are single poles, with the observed values. For this purpose we must integrate over the whole length of the line, and omitting the details of the derivation we arrive at the following expression for the vertical intensity exercised by such a line on a traverse perpendicular to the strike (taking the length as infinite):

$$Z = 2C \frac{t}{x^2 + t^2}$$

The meaning of the notations may be taken from Fig. No. 15. Taking t as the unit of distance and $2C = 1$, we deduce the graph shown in Fig. No. 15. From this graph it will be seen that the effect, produced by such bodies as the magnetic shales, differs from that produced in the case of a single pole. The whole method of interpretation, which in our case aims at the determination of the depth of the sub-outcrop, remains unchanged, as given by Nippoldt (Lit. Nos. 8 and 9). We may stress the following interesting differences in the properties of the "single pole" and the "line." For the latter, the distance from the point of the maximum to the point of the half-value is equal to the depth, whereas for the "single pole" the depth is equal to the distance from the maximum to a value which is 0·3535 times the maximum. Still more important is the fact that the maximum value for the intensity for different depths is inversely proportional, not to the second, but to the first power of the depth, so that if we double the depth we still have half the intensity, instead of one-fourth as for the single pole. The same reason accounts for the greater extension on the surface of the disturbance caused by a body which can be approximated by such a line. A further important point, which holds equally good for the single pole, is that we can arrive at a good approximation of the depth without having any knowledge of the magnetic constants. The method does not take into account any special value for the magnetisation, provided the magnetisation is mainly parallel to the dip. Even in cases where this is not so, this method helps to arrive at the right value for the direction of the magnetisation by comparing the theoretical symmetrical curve with the observed asymmetrical curve, and so establishing the amount of the asymmetry. We would have to write a text-book if we were to go into every detail of the method of interpretation, and in any event every case has to be treated separately.

It is interesting to compare this formula with another one, $Z=2b\dfrac{a\ \text{M par.}-x\ \text{M perp.}}{a^2+x^2}$, derived for a similar body under different circumstances (Lit. Nos. 10 and 11). In this case the direction and intensity were known, and the total magnetisation was resolved in components parallel (M par.) and perpendicular (M perp.) to the dip. It is apparent that for M perp.$=0$ the formula for the line and for the slablike body are the same. What we called C in the first formula is here b M par. This shows again that the effect of distance is not a function of the magnetic constants, but essentially of the shape of the body. This formula is still valid, even in the case of an exceptionally large M perp., and even in the case that only the shape of the body is known, and may be applied even with complete lack of knowledge of the thickness b and the components of magnetisation M par. and M perp. This is an extreme case, and by trying out several values it would be possible to arrive at the best one for the quotient $\dfrac{\text{M par.}}{\text{M perp.}}$, and from this to calculate the depth. After having established the depth, it may be possible to calculate the thickness or the susceptibility if the body is magnetically soft. For our purpose, the knowledge of the thickness and the susceptibility is of little value, since we are not concerned with the shales as an orebody, but as a leader.

Nevertheless, the knowledge of the susceptibility can be used together with the findings of the field survey (that the magnetisation is according to the earth's field)

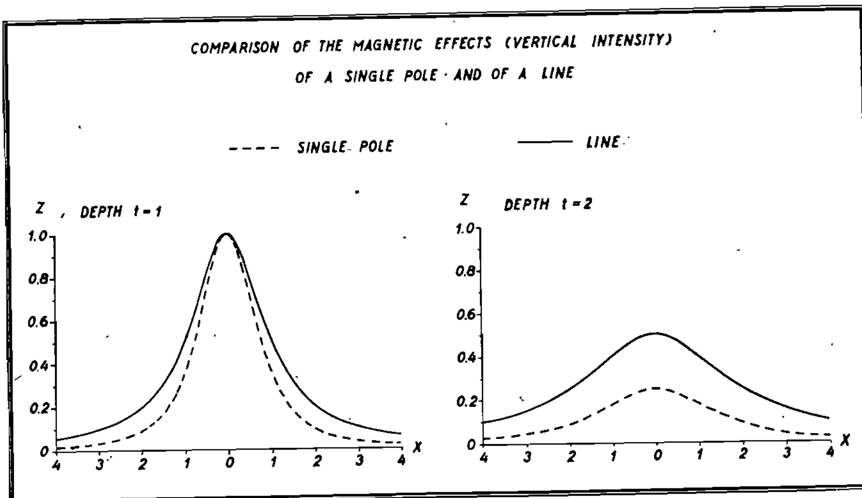

FIG. No. 15—Comparison of the Magnetic Effects (Vertical Intensity) of a Single Pole and of a Line.

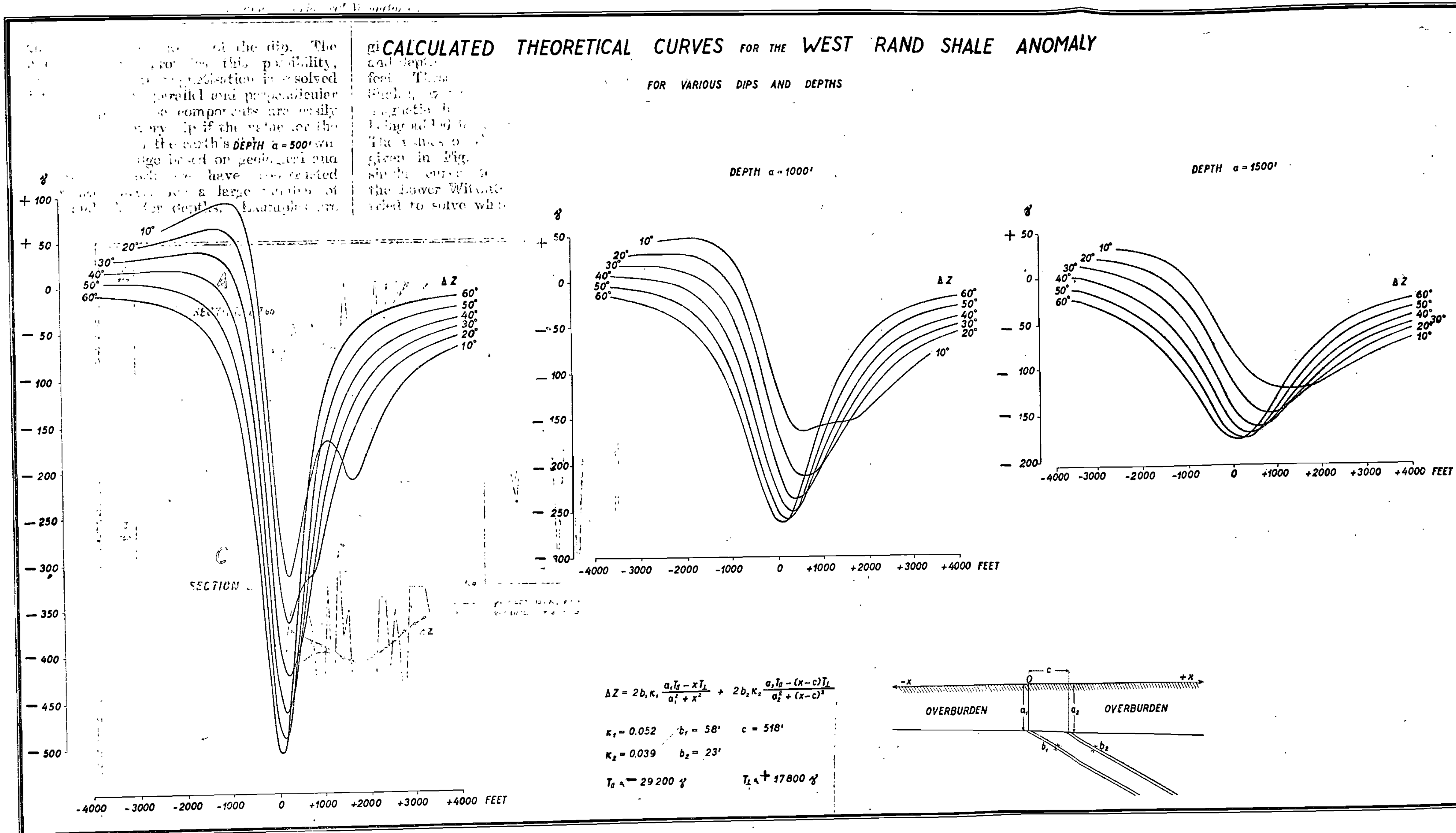

Fig. No. 16 (Plate XI.)—Calculated Theoretical Curves for the West Rand Shale Anomaly for Various Dips and Depths.

to estimate the amount of the dip. The above formula provides this possibility, because the total magnetisation is resolved into components parallel and perpendicular to the dip. These components are easily calculated for every dip if the value for the total intensity of the earth's field is known.

From knowledge based on geological and geophysical work we have constructed theoretical curves for a large number of dips, and also for depths. Examples are given in Fig. No. 16 for dips of 10° to 60° and depths of 500 feet, 1,000 feet and 1,500 feet. These curves are for the West Rand Shales, which in our area contain two magnetic beds; the effects of both beds being added for every point of the traverse. The values of the constants used are also given in Fig. No. 16. By constructing similar curves for every magnetic bed of the Lower Witwatersrand System, we have tried to solve what we may call the main

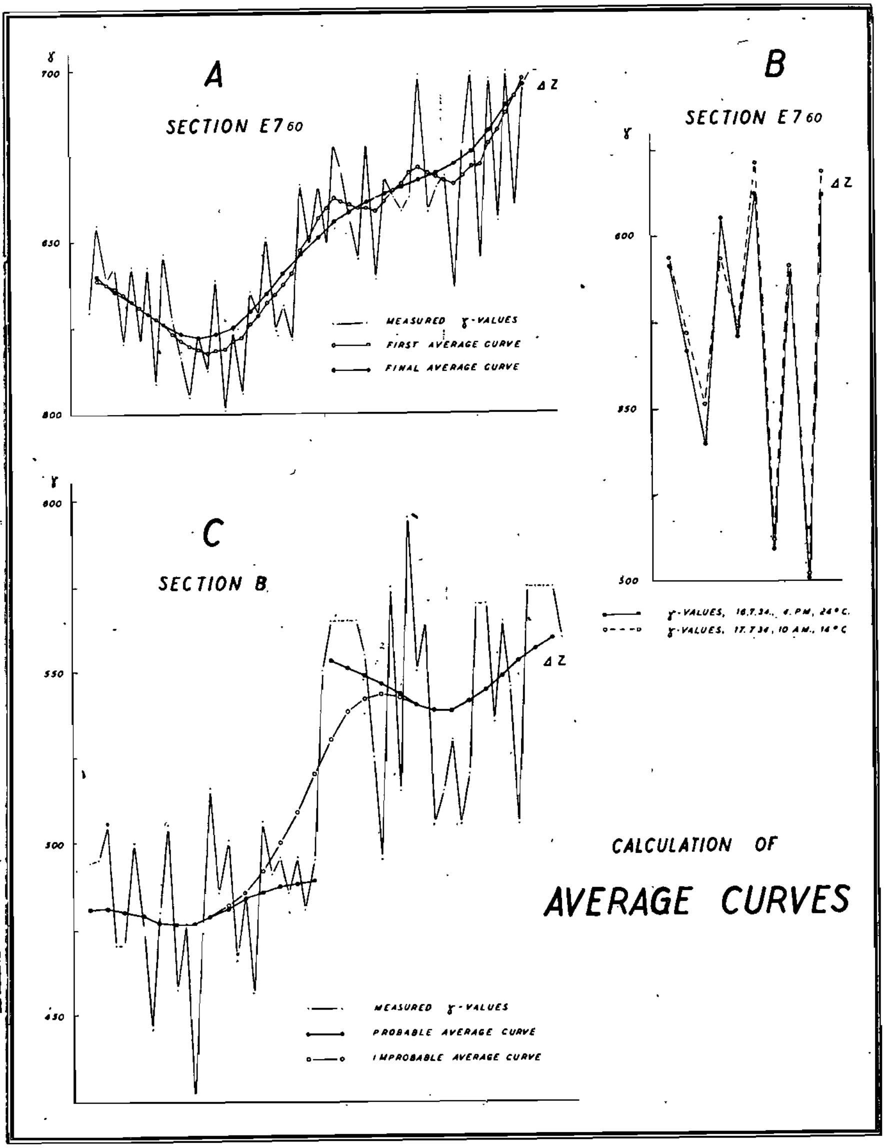

FIG. No. 17—Calculation of Average Curves.

magnetic problem of the Witwatersrand, *i.e.*, to establish from the variation of the vertical magnetic intensity on the surface, as recorded by the magnetic field balance, the true position of these bodies and, if possible, their dip. How far we have been successful in achieving this aim will be shown in a later chapter.

E.—Calculation of Average Curves :

Comparison of theoretical curves with those actually measured is rendered difficult, due to the shape of the latter, which is not at all uniform. In the latter case, values of the vertical intensity on two points only 50 feet apart usually vary from 5 to 25 gamma, while differences up to 100 gamma and more are not infrequent. A typical example can be seen on the next diagram (Fig. No. 17A).

Deep-lying shales or other magnetite-bearing bodies should produce a smooth curve similar to the one shown as the line with full dots in the same diagram, and, therefore, these sudden variations are to be ascribed to other causes, namely :—

(1) Mechanical disturbances in the instrument, caused either by sudden changes in temperature or by small shocks when setting up the instrument, or by the pressure of the wind.
(2) Inaccurate levelling of the instrument.
(3) Inaccurate setting of the compass.
(4) Not keeping the height above the ground equal for all observations.
(5) Small amounts of magnetite unevenly distributed in the soil and sub-soil.
(6) Small and local "magnetic storms," produced by warm and cool currents of air travelling over the earth's surface.

Whatever these causes may be, we found that these variations tended to introduce an error into the curves, especially when a section line could not be completed during a single day but had to be continued the next day or at some later period. If this is unavoidable, it is necessary, for purposes of comparison, to take a series of readings on suitable stations. A typical example is given in Diagram No. 17B.

The full line in Fig. No. 17B connects the values measured at the end of the day's work, while the broken line connects the values measured at the same ten observation points the next morning. Although any or all of the causes mentioned above may have combined to give different readings on each point, yet it seems that the distribution of magnetite in the soil has had by far the most important effect, as, in spite of differences in values on each point, the curves resemble each other very closely. It also seems quite clear that a series of ten repetition stations is sufficient for linking one section to another one.

Provided that these causes are the only ones which produce the unsteadiness of the curves, we are entitled to eliminate them. We have tried out various methods, and we found the most suitable to be a series of formulae which meteorologists employ for similar purposes, and which are :—

(1) $\text{Y average} = \frac{1}{4}\,(Y_{n-1} + 2Y_n + Y_{n+1})$

(2) $\text{Y average} = \frac{1}{9}(Y_{n-2} + 2Y_{n-1} + 3Y_n + 2Y_{n+1} + Y_{n+2})$

(3) $\text{Y average} = \frac{1}{16}(Y_{n-3} + 2Y_{n-2} + 3Y_{n-1} + 4Y_n + 3Y_{n+1} + 2Y_{n+2} + Y_{n+3})$

(4) $\text{Y average} = \frac{1}{25}(Y_{n-4} + 2Y_{n-3} + 3Y_{n-2} + 4Y_{n-1} + 5Y_n + 4Y_{n+1} + 3Y_{n+2} + 2Y_{n+3} + Y_{n+4})$, etc.

In these formulae :—

Y average = the average magnetic intensity at the point n.

Y_n = the measured magnetic intensity on the point n.

Y_{n-1} and Y_{n+1} = the measured values on stations to either side of point n.

The formula one should use depends on the nature of the magnetic bodies to be investigated and on their depth. The greater the number of readings that are used to calculate the mean value "Y average," the smoother the curve becomes, but also the danger increases that magnetic influences from sources distributed along the section line are included in the value of "Y average," thus falsifying it.

In regard to the number of observations it is desirable to take, one is, I think, on the safe side by limiting their number to not more than would correspond to half of the width of the "half-value" of the amplitude which one can find on the theoretical curves.

For example, the theoretical curve for the West Rand Shales, lying at a depth below the surface of a =1,000 feet and dipping 30° southwards produces an amplitude of 238 gamma (see Fig. No. 16); the "half-values," *i.e.*, 119 gamma, are encountered at approximately 900 feet north and 1,400 feet south of the minimum value, the width of the "half-value" being 2,300 feet. One can safely include the readings over a distance of 1,100 feet, which is equal to 22 stations, at intervals of 50 feet in a formula similar to those given above.

We have found the formula No. 4 to be the most suitable for many of our curves, and in such cases where the resulting curve is still too disturbed, we use the same method to calculate a still smoother curve by taking into the calculation every second figure of the first average curve, thus including 25 readings.

The first average curve is shown in dotted lines on diagram No. 17A, and the final curve as a full line on the same diagram.

It is naturally very tedious to calculate average curves unless one uses a calculating machine, and a circular slide rule was designed, as shown in Fig. No. 18, similar to one which was developed by E. A. Ermert and E. Reeh several years ago in the geophysical department of the "Gewerkschaft Elwerath," a German oil-producing company, in connection with their torsion-balance work. With this device one can multiply any figures with the factors wanted in the formula No. 4, namely, 1, 2, 3, 4 and 5; add the products and finally divide the sum by 25, thus giving "Y average" as the final result.

When calculating average curves, discretion is necessary in order to avoid faulty results. In some places, for instance, values of the intensity are measured, which by

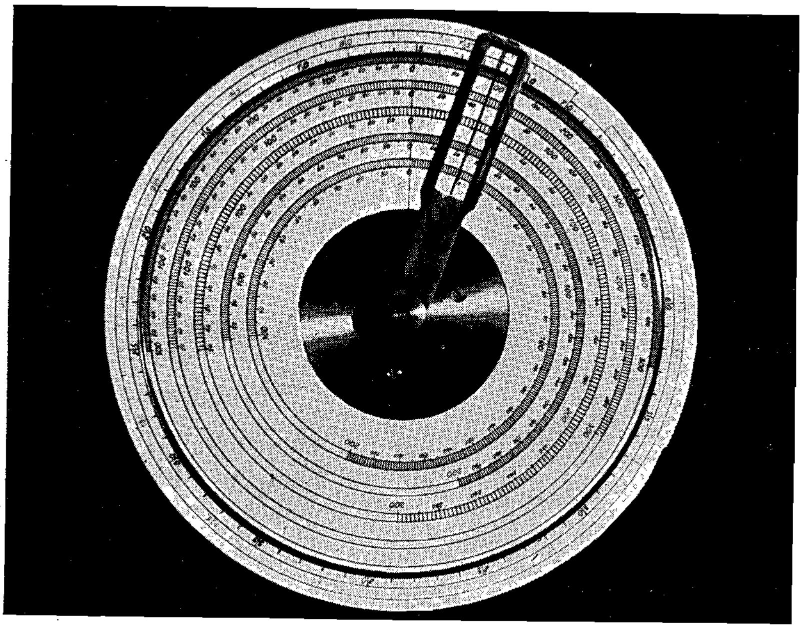

FIG. No. 18—Circular Slide Rule for Calculating Average Values.

their character clearly show that they are abnormal and soley due to some small accumulation of magnetite-bearing material at very shallow depths and close to the instrument, and these values should, therefore, be excluded. Among other cases also arising, are such as shown on diagram No. 17c, in which the correct average curve would be the one shown in heavy lines, with a break between two areas with different values of vertical intensity, whereas the average curve calculated without considering these facts would look like the thin line, giving an entirely wrong impression of the general character of the anomaly. In any case, the average curves should be used only in conjunction with the actually measured ones when interpreting.

F.—A New Method of Interpretation :

The method of interpretation most commonly used we may call an indirect one, as it consists of comparing the observed data with figures calculated from assumed geological conditions. In our special case we compare the curves of the vertical intensity obtained along sections which we endeavour to run as nearly as possible at right angles to the strike of the magnetite-bearing shales with curves which would have been obtained from similar magnetic bodies assuming a certain strike, dip, thickness, susceptibility, length along the strike and thickness of overburden. We have figured out scores of such curves, and have ample material for comparison.

These calculations are not based on mere assumptions, which would lead to grave errors, but they take into account all available data from outcrops and boreholes. There are still, however, sources of errors, mainly due to the fact that the formations and conditions are variable. With the thickness of overburden prevailing on the areas under investigation, however, the volume of magnetite-bearing shales which affects the magnetometer is so large that local abnormalities disappear and good average values result.

The most southerly magnetite-bearing shales, which in this area give very definite anomalies, are the West Rand Shales, and they constitute our most valuable "marker." Unfortunately, their horizontal distance from the Main Reef is more than 10,000 feet, and we have endeavoured to make use of the two magnetite-bearing shale horizons which lie between the West Rand Shales and the Main Reef, namely, the so-called Government Reef Shales and the Jeppestown Shales. Their influence on the magnetometer is, however, much less pronounced, and in many cases, especially with very heavy overburden, their position cannot be precisely determined, although their presence and approximate position can be established.

By comparing the actual observed curve together with the final average curve derived from it with the theoretical curves, we are able to arrive at an interpretation, as shown in Fig. No. 19. The section given as an example is our Number E 7, 60, measured in July and August of 1934, the interpretations having been made shortly afterwards. On diagram No. 19 (I), the final average curve derived from the observed curve (omitted) is shown as a dotted line, and the theoretical curve for West Rand Shales for an assumed dip of 30° to the south, a strike approximately west-east, and a depth of the sub-outcrop of 1,400 feet is shown as a full line. The assumed geological conditions are shown in the lower part of the diagram. It can be seen at once that the minima in both curves correspond, but that otherwise, especially towards the south, the curves are not similar, showing that either the theoretical curve is faulty, or that there are other influences which make themselves felt.

In the course of a series of calculations, which were quite tedious because this was the first section treated in this manner, we found that at a certain distance south of the West Rand Shale Anomaly, but north of the one attributed to the Government Reef Shales, there appears an anomaly, the cause of which is not yet known, as no geological evidence of a magnetite-bearing stratum has so far been found near this horizon. As the same magnetic anomaly appears on a great number of sections, we think that it cannot be due merely to a local effect. We have named it the Z-anomaly. If we combine the theoretical curve for this anomaly to that of West Rand Shales, we obtain the curve shown on the next diagram, No. 19 (II), again plotted against the measured curve. The similarity in the shape of the minimum in both curves is now more apparent. The next step is to add the theoretical curve for the Government Reef Shale Anomaly, as the result of which we

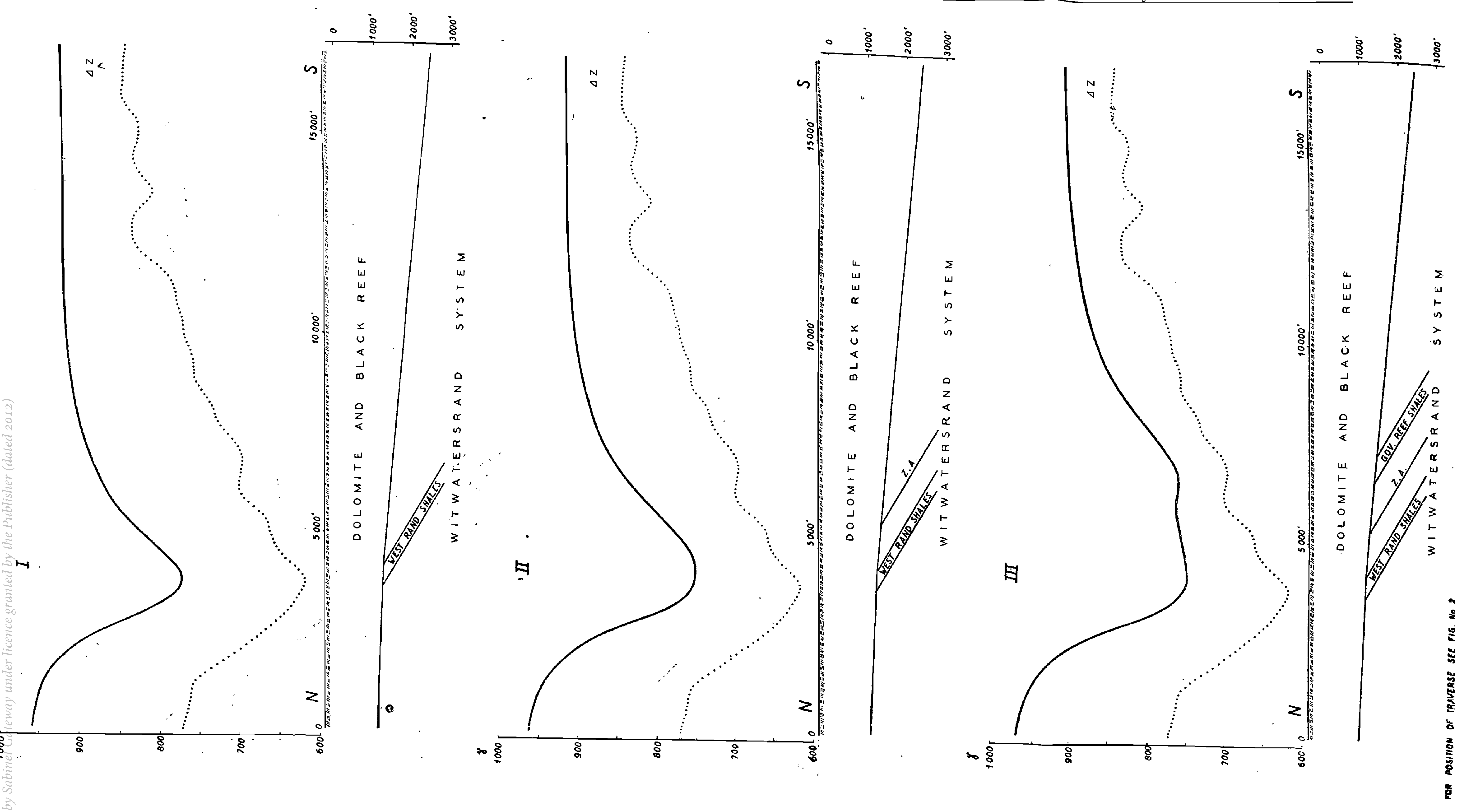

FIG. No. 19 (Plate XII.)—Interpretation for the Magnetometric Traverse E. 7. 60 by Comparison with a Combination of Calculated Curves.

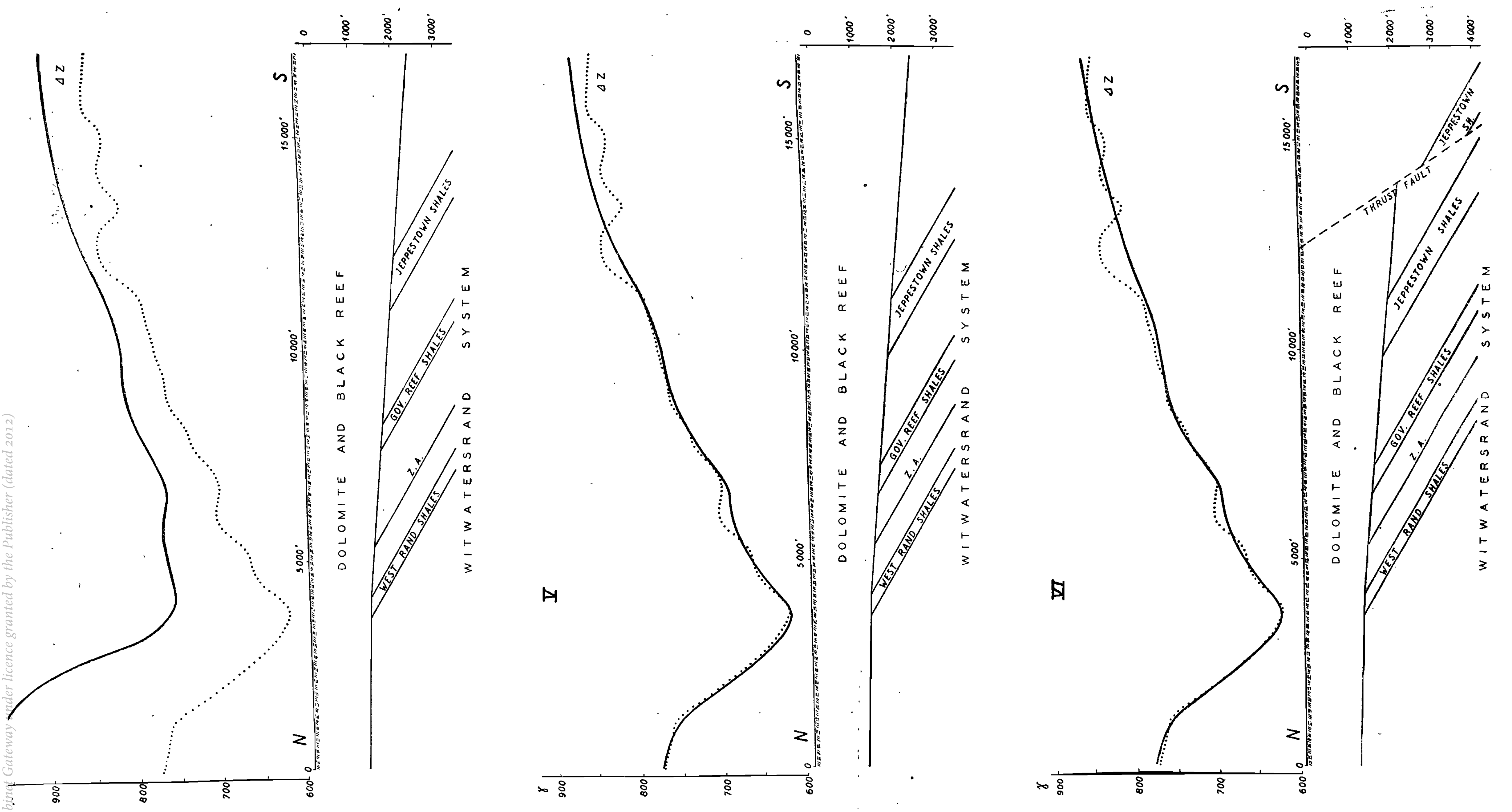

FIG. No. 19a (Plate XIII.)—Interpretation for the Magnetomeric Traverse E 760 by a comparison with a Combination of Calculated Curves.

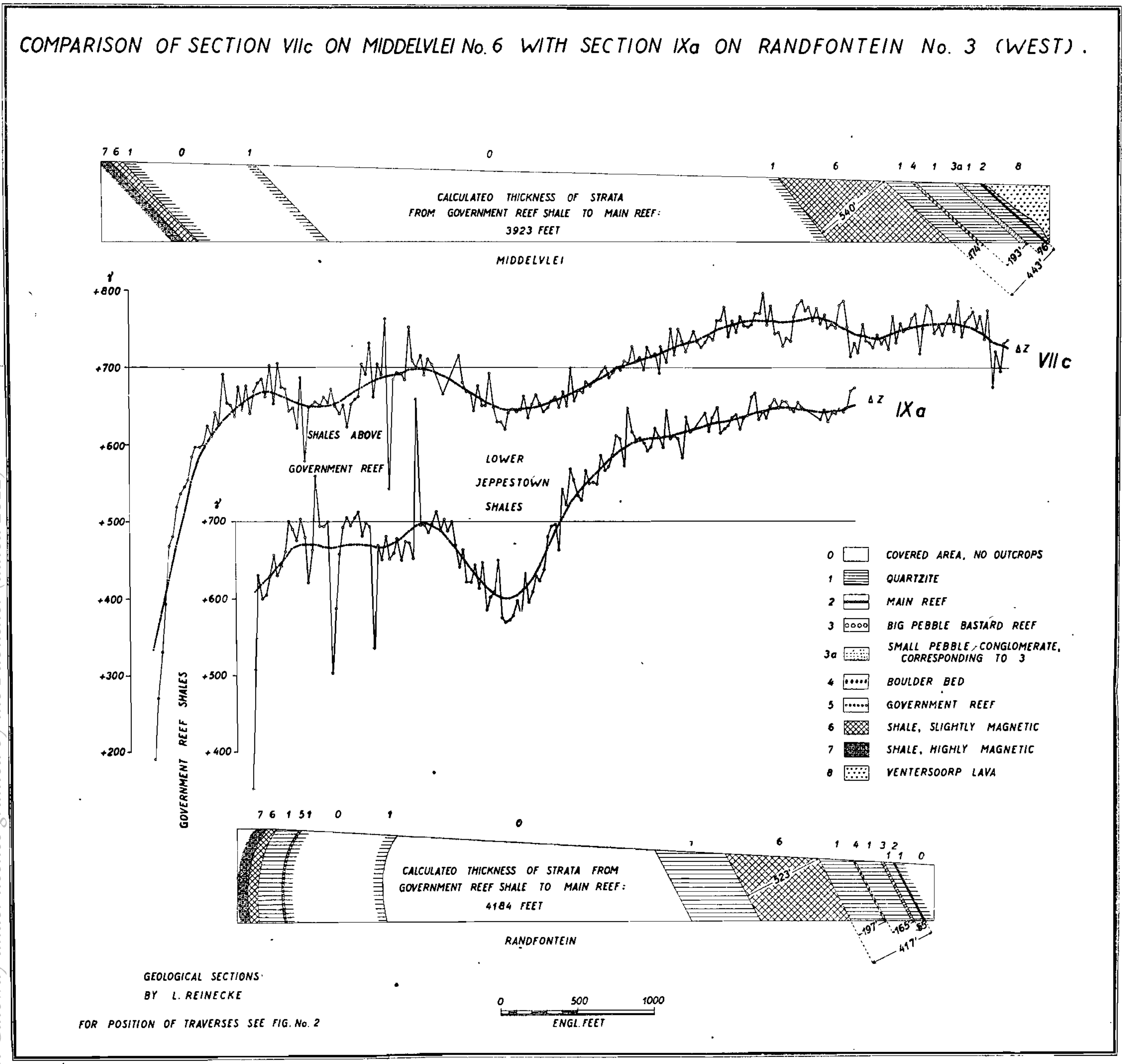

Fig. No. 20 (Plate XIV.)—Comparison of Section VIIc on Middelvlei No. 6 with Section IXa on Randfontein No. 3.

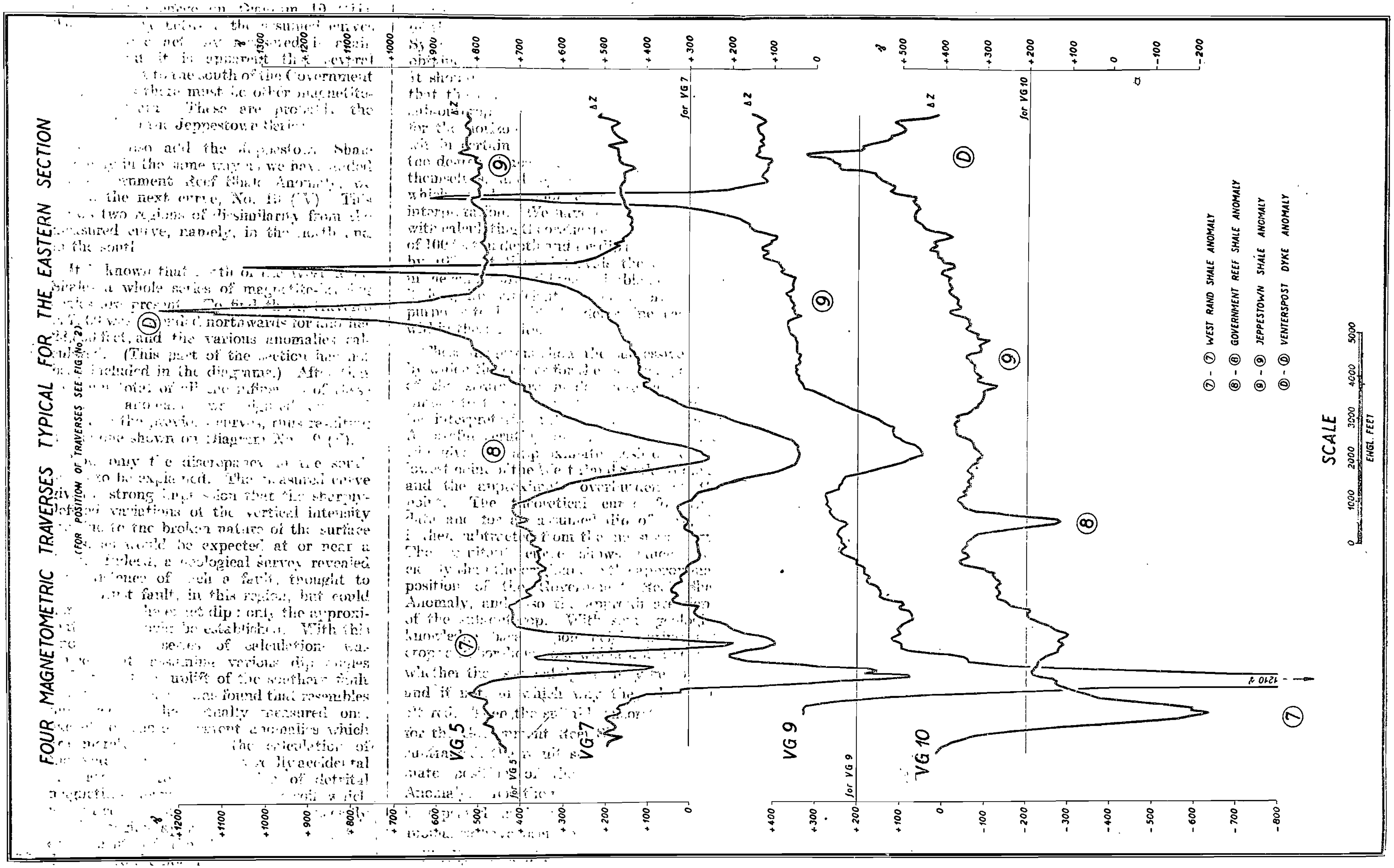

FIG. No. 21 (Plate XV.) — Four Magnetometric Traverses typical for the Eastern Section.

obtained the curve on Diagram 19 (III). The similarity between the assumed curves and the one actually measured is again greater, but it is apparent that several thousand feet to the south of the Government Reef Shales there must be other magnetite-bearing strata. These are probably the shale beds in the Jeppestown Series.

If we also add the Jeppestown Shale Anomaly in the same way as we have added the Government Reef Shale Anomaly, we obtain the next curve, No. 19 (IV). This shows two regions of dissimilarity from the measured curve, namely, in the north and in the south.

It is known that north of the West Rand Shales a whole series of magnetite-bearing shales are present. To find them, traverse E 7, 60 was extended northwards for another 23,000 feet, and the various anomalies calculated. (This part of the section has not been included in the diagrams.) After that the sum total of all the influences of these northern anomalies was figured out and added to the previous curves, thus resulting in the one shown on Diagram No. 19 (V).

Now only the discrepancy in the south needs to be explained. The measured curve gives a strong impression that the sharply-defined variations of the vertical intensity are due to the broken nature of the surface rocks, as would be expected at or near a fault. Indeed, a geological survey revealed the existence of such a fault, thought to be a thrust fault, in this region, but could not disclose the exact dip ; only the approximate uplift could be established. With this knowledge a series of calculations was carried out, assuming various dip angles and amounts of uplift of the southern fault block, until a curve was found that resembles more closely the actually measured one, except for those apparent anomalies which are merely caused by the calculation of the average curves, which are really accidental and are due to accumulation of detrital magnetite-bearing material in the soil, which is caused by surface agencies, especially as this region approaches the base of the escarpment of the Pretoria Series with drainage to the north (see Fig. No. 19 (VI)).

Similar reasons may be responsible for the sharp bend in the curve just south of the position of the West Rand Shales, although this has not been proved.

An approximation of the depth and dip of the contact between the Witwatersrand System and the overlying rocks can be obtained by this method of interpretation. It should be mentioned, in this connection, that the figures given for the depth of the sub-outcrop, for the dip of the strata and for the horizontal position are only correct within certain limits, which are defined by the degree of accuracy of the measurements themselves, and by the time and labour which can be economically devoted to the interpretation. We have had to be satisfied with calculating theoretical curves at intervals of 100 feet in depth and for dip angles varying by 10°. At these intervals the differences in the curves are still recognisable ; moreover, it is quite sufficient for most prospecting purposes to be able to determine the data within these limits.

These diagrams show the successive steps by which the curves for the assumed position of the strata are made more and more similar to the measured curve. In practice the interpretation takes the opposite course. A careful scrutiny of the measured curve will give the approximate position of the lowest point of the West Rand Shale Anomaly and the approximate overburden at this point. The theoretical curve for these data and for an assumed dip of, say, 30° is then subtracted from the measured curve. The resultant curve shows much more clearly than the original one the approximate position of the Government Reef Shale Anomaly, and also the approximate depth of the sub-outcrop. With some geological knowledge based upon neighbouring outcrops and boreholes, one will be able to decide whether the assumed figures may be correct, and if not, in which way they should be altered. Then the suitable theoretical curve for the Government Reef Shale Anomaly is subtracted, the result showing the approximate position of the Jeppestown Shale Anomaly. Here the process referred to above is repeated until all known or assumed anomalies have been found and subtracted.

Finally, assuming that no error has occurred, a straight line should be obtained representing the vertical intensity of the earth's magnetic field, which would be found if disturbing bodies were not present.

III.—Geological Deductions and Further Prospecting by Drilling.

A.—Geological Deductions from the Magnetic Survey in the Eastern Section:

The geology of the eastern section was made the subject of an intensive and critical study by Dr. Reinecke long before the formation of West Witwatersrand Areas, Limited. He arrived at the conclusion that the reefs in the Middelvlei Inlier and the reefs intersected in the old boreholes Nos. 2, 3, 4, 5, 7 and 9 belong to the Main Reef Series. As mentioned in the paragraph I.A in the beginning of this paper, this identification has been a subject of controversy for a long time. The details on which this correlation is based are given in Fig. No. 20, where two geological sections are compared.

The upper portion in this figure represents a section on Middelvlei No. 6 from the shale below Government Reef to the reef on Middelvlei, and the lower part shows a section from the shale below Government Reef to West Reef (Main Reef), near No. 7 Shaft, Randfontein.

Unfortunately, the major portion of both sections is covered. Magnetometric traverses were surveyed in very great detail, both on Middelvlei and at Randfontein, covering the same ground along which the two geological sections were taken, and both magnetometric and geological sections are shown on Fig. No. 20. The close similarity of these two magnetic profiles is evident, and Dr. Reinecke, in his first report on this area, stated that, "to give so similar results, magnetite-bearing shales of about the same character as regards the quantity and distribution of their magnetite content must occur in about the same positions in the two sections. This is to my mind a very strong indication that the covered portion of the sections resemble each other as closely as the upper 1,200 feet of exposures, and that the two series of rocks are in fact identical. The reefs on the Middelvlei Inlier are, therefore, in the Main Reef Series," he concludes.

From Middelvlei No. 6 the magnetic survey proceeded further towards the southwest, outlining the sub-outcrops of West Rand Shales, Government Reef Shales and Jeppestown Beds by means of the anomalies, as is shown on the plan in Fig. No. 2 as sub-outcrop lines, Nos. (7), (8) and (9). From these anomalies the sub-outcrop position of the Main Reef was calculated.

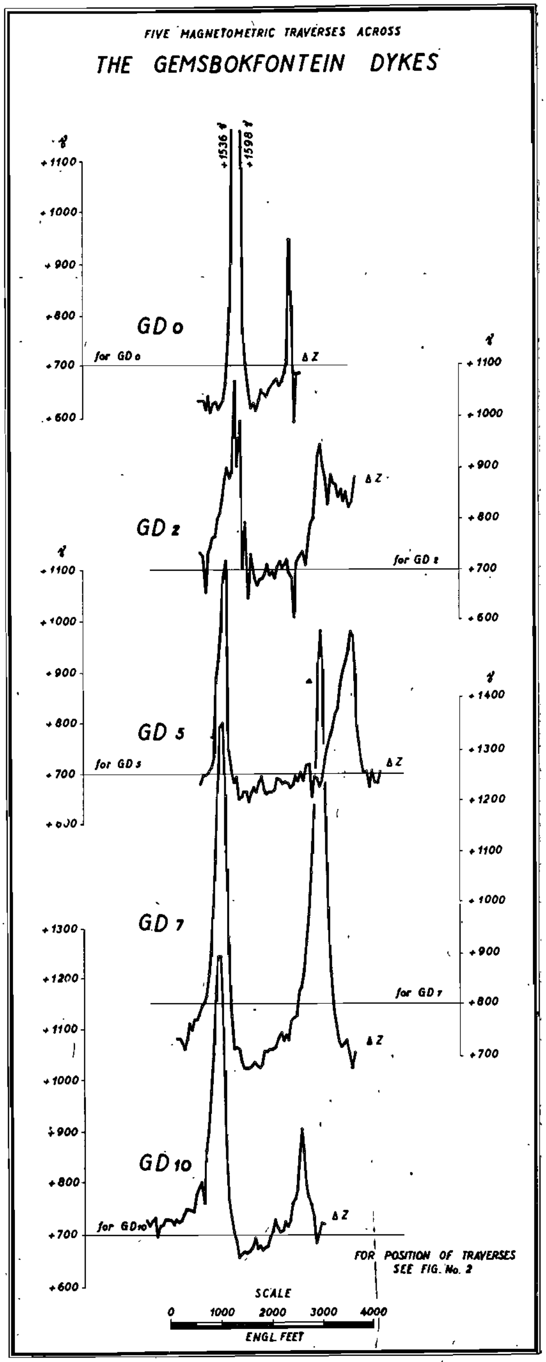

Fig. No. 22—Five Magnetometric Traverses across the Gemsbokfontein Dykes.

Some typical results of the magnetic survey in this area are shown in Fig. No. 21. Traverses VG 5, 7, 9 and 10 are 2,000 feet apart. The Jeppestown Shale Anomaly is easily recognised only in traverse VG 10. On the other three traverses, the strong opposite anomaly caused by the Venterspost Dyke is super-imposed. From the shape of the West Rand Shale Anomaly, a dip of the strata towards the south-east must be deduced.

Furthermore, the magnetic survey outlined the two Gemsbokfontein Dykes, of which some typical magnetic sections, covering 11,000 feet of strike, are shown in Fig. No. 22. The more easterly one of these two

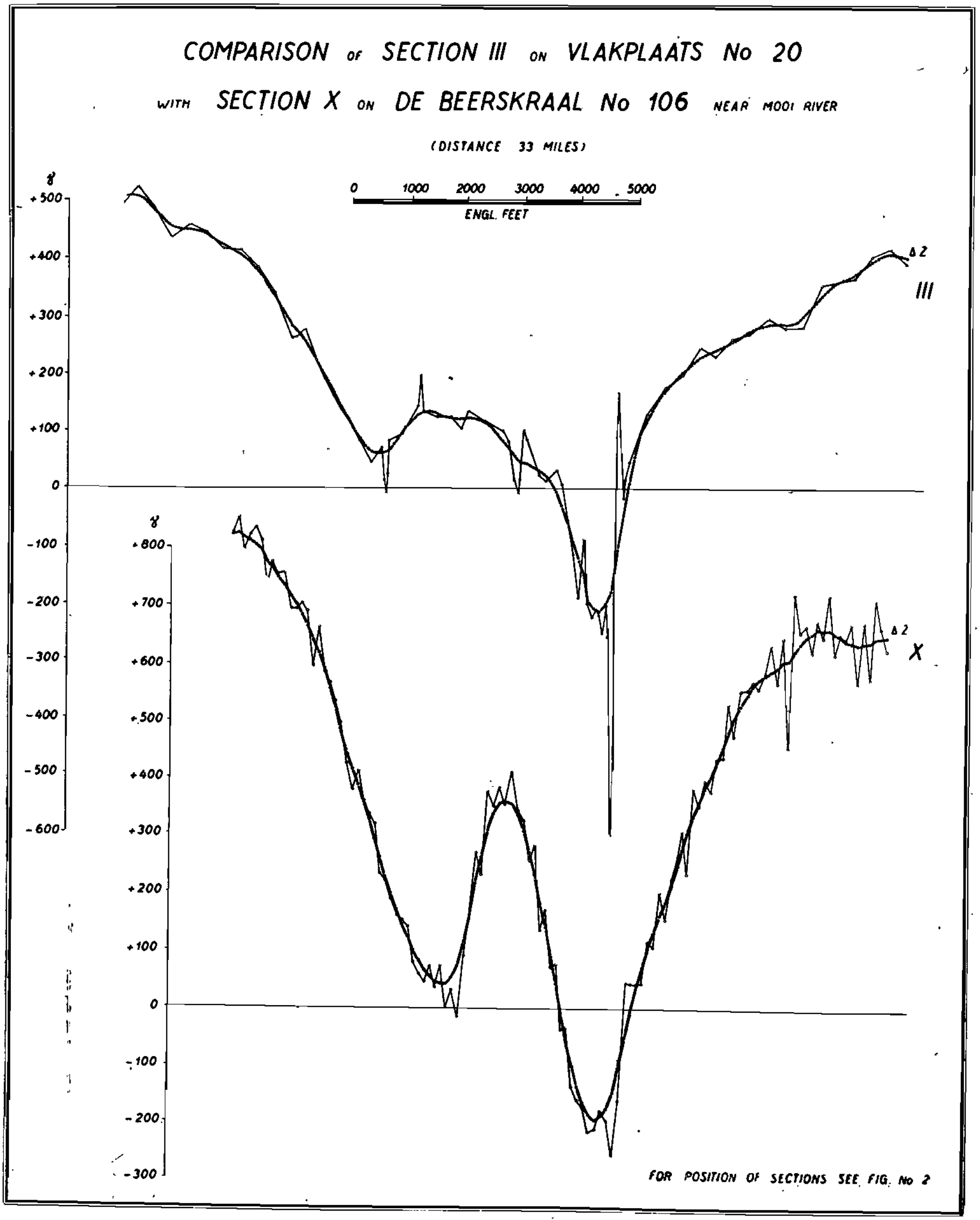

FIG. No. 23—Comparison of Section III on Vlakplaats No. 20 with Section X on De Beerskraal No. 106, near Mooi River.

dykes coincides with the great West Rand Fault, which runs approximately north-south through the centre of Middelvlei.

Finally, the detailed magnetic survey determined a series of minor faults, the more important of which are shown on the plan in Fig. No. 2.

B.—Geological Deductions from the Magnetic Survey of the Western Section :

The first traverse magnetically surveyed in the Western Section in March, 1931, was profile No. X, running from the Mooi River Bridge on the Ventersdorp main road towards Welverdiend Station. I confess that it was somewhat risky to go so far afield over a covered area with the nearest Witwatersrand outcrops at a distance of 22 miles. This first section, nevertheless, established the presence of the Lower Witwatersrand System in this neighbourhood. A comparison of Section X with Section III is given in Fig. No. 23, and shows, in spite of the fact that the distance between these two sections amounts to 33 miles, such a remarkable similarity even in small details that I felt justified in correlating the two northern anomalies of Section X with the Water Tower Slates and the Contorted Bed. This soon led to the discovery of a narrow outcrop of Orange Grove quartzites and of underlying granite, as shown on the plan in Fig. No. 2, taken from the geological map of Dr. L. T. Nel (Lit. No. 13).

This was followed by systematic magnetometric traversing, and some typical sections are reproduced in Figs. Nos. 24 and 25. Fig. No. 24 shows four typical magnetic traverses revealing six successive anomalies from the Water Tower Slates up to the Promise Beds. The distance between traverse OW1 in the west and OB2 in the east is about 10 miles. Fig. No. 25 shows six typical traverses covering about the same length of strike, disclosing the succession of the next three anomalies, namely, the West Rand Shales, the Government Reef Shales and the Jeppestown Beds. From the shape of the curves, a southerly dip of the strata has to be deduced.

If one compares these graphs with those for the Eastern Section given in Fig. No. 21, it is evident from the different amplitudes of the anomalies that the dolomite cover in the Western Section must be nearly twice as thick as in the Eastern Section.

The sub-outcrops of the nine principal magnetic shale horizons of the Lower Witwatersrand System are shown in Fig. No. 2, which enabled the sub-outcrop position of the Main Reef to be calculated.

In the far west, the four uppermost sub-outcrops are sharply bent from the east-westerly strike towards the south, a feature which seems to be in accordance with the small outcrops of granite and Orange Grove quartzites west of the Mooi River, as mapped by Dr. L. T. Nel (Lit. No. 13).

In the Western Section the sub-outcrop of the West Rand Shales was followed eastwards beneath the dolomite cover, and was tied to actual outcrops on the farm Elandsfontein No. 494. The actual connection of the anomaly No. (7) to the outcrops of West Rand Shales north-east of Bank Station was, in the early stages of the survey, an important check for the correct interpretation of all the anomaly lines in the Western Section.

A major fault or system of faults, with a horizontal displacement of over 20,000 feet, has been made the basis for sub-dividing West Witwatersrand Areas into an eastern and into a western section (see Plan No. 2).

The magnetic survey also outlined three dykes, as shown in Fig. No. 2, namely, the Turffontein Dyke, the Oberholzer Dyke and the Wonderfontein Dyke. The latter two were traced magnetometrically towards the north, and both dykes were found to coincide for 3·5 and 6 miles respectively with the major fault mentioned above. This feature enabled the fault to be connected with the great fault 1·5 miles west of Rustenburg, and we, therefore, called it the "Bank-Rustenburg Fault."

Another fault, the Welverdiend fault, of less importance, was magnetically determined about 3 miles east of Welverdiend Station. This fault strikes north-south with a horizontal displacement, which varies from 5,100 feet in the north to only 300 feet in the south.

Other minor faults mapped by the magnetic survey are shown in Fig. No. 2.

A magnetometric reconnaissance survey carried out during 1931 in areas west of the Mooi River, between Klerksdorp and Ventersdorp, gave the following indications :—

(1) The general strike of the anomalies changes sharply from an east-westerly into a north-east-south-westerly direction.

(2) It is, therefore, probable that the course of the Mooi River coincides with a major fault.
(3) The increased number and variety of anomalies seems to indicate that the area west of Mooi River is of a somewhat disturbed nature.

C.—Method of Calculating Borehole Sites:

A very detailed description of our method of calculating borehole sites is given in a paper by the late Dr. L. Reinecke, written shortly before his illness, entitled "Magnetometric Prospecting on the Witwatersrand," which was presented early in 1935 at the geophysical meeting of the American Institute of Mining and Metallurgical Engineers in New York (Lit. No. 14).

This paper contains four figures explaining these methods as applied to the location of Borehole No. E 4, and I have included in Fig. No. 26 a similar section in regard to Borehole No. E 3 in the Western Section. The main factors on which such calculation is based are:—

(1) Topographic contour lines of the surface.
(2) Thickness of younger formations overlying the Witwatersrand System and slope of the contact between these formations and the Witwatersrand System.
(3) Position of anomaly lines on the surface.
(4) True thickness of Witwatersrand Beds lying between magnetite-bearing shales causing magnetic anomalies, and between the highest of these magnetite-bearing beds and the Main Reef.
(5) Dip of the Witwatersrand Beds.

The contour lines of the surface were taken from our topographic survey.

Regarding the Dolomite and Black Reef cover, some data was available from the old Borehole No. 10 on Doornkloof No. 155 and the "Twyfelvlakte" Borehole. Borehole No. 10 indicated that the maximum thickness of the Dolomite and Black Reef Series is about 3,300 feet when the entire section is represented. The Twyfelvlakte Borehole, just south of the West Rand Shale Anomaly, revealed a thickness of Dolomite and Black Reef of 1,250 feet. From these data we constructed the profile shown on Fig. No. 26, giving us a figure of 5°40′ for the slope of of the contact between the base of the Dolomite and Black Reef Series and the Witwatersrand System.

The positions of the anomaly lines on the surface were taken from the magnetic traverse OB2, which is shown on Fig. No. 24. This traverse shows clearly a duplication of the Contorted Bed Anomaly, which is accounted for in the geological section (Fig. No. 26) by a minor fault.

It is assumed that the sub-outcrops of beds causing the anomalies lie vertically below the minimum of the anomalies, although the theoretical curves in Fig. No. 16 show that the positions of the anomalies of the beds which give rise to them are actually some distance down the dip from the sub-outcrops, especially in cases of flatter dips. The reason for this assumption is illustrated in Fig. No. 19. Comparing graphs Nos. IV and V of this figure, it can be seen that the addition of the effects of the Promise Beds Anomaly has shifted the deepest point (minimum) of the West Rand Shale Anomaly some distance up the dip into a position vertically above the sub-outcrop.

The true thicknesses of the Witwatersrand Beds lying between the various magnetic anomalies and between the most southerly anomaly and the Main Reef were taken from Dr. Reinecke's average geological section, given in Fig. No. 4.

In applying these thicknesses to our geological section in Fig. No. 26, the resulting dips of strata, shown in broken lines, are fairly consistent between 38° and 43°, except for the two most northerly anomalies.

The available information regarding the dip of the Witwatersrand Beds for our case of calculating the position for the Borehole No. E 3 was the following:—

A comparison of the shape of the West Rand Shale Anomaly with our theoretical curves suggests a dip nearer to 30° than to 40°.

The Twyfelvlakte Borehole was cleaned out and carefully re-surveyed for deflection. From this survey a dip of the Witwatersrand Beds of 31° 17′ 15″ was established.

Further south, the neighbouring Borehole No. E 4 had established a dip of the Witwatersrand Beds of 25°.

Application of these flattening dips to our section for Borehole No. E 3 made necessary a decrease of 28 per cent. in true thicknesses. This is shown in Fig. No. 26, as well as the resulting calculated position of the Main Reef. How this calculation compares with actual borehole results is shown by the following figures:—

	Calculated Depth (ft.).	Actual Depth (ft.).	Difference (ft.).
Bottom of Black Reef	2,620	2,589	−31
Main Reef	2,880	3,224	+364
Top of Jeppestown Series	3,320	3,726	+426

After four boreholes in the Western Section had been completed, and had shown somewhat uniform results, the method of calculating further new borehole sites could be simplified.

The distances between the well-defined West Rand Shale Anomaly and the actual sub-outcrops of Main Reef as disclosed by these four boreholes are :—

For the Section through—

Borehole	No. E 2	12,540 feet.
,,	No. E 3	11,180 ,,
,,	No. E 4	12,680 ,,
,,	No. E 10	13,400 ,,

These distances, plus an addition of 2,000 feet between the sub-outcrop of the Main Reef and the borehole as safety margin, are used for the selection of new borehole sites.

D.—Borehole Results :

Following on the geophysical survey, a comprehensive programme of further exploration by drilling started, and is still in progress.

The most important results obtained so far by boreholes are shown in Fig. No. 27.

WESTERN SECTION.

In the Western Section, five boreholes, Nos. E 10, C.M. 1, E 4, E 3 and E 2 have been completed, and four boreholes are still in progress, namely, Nos. E 2A, E 3A, E 5 and E 7.

Borehole No. E 10 on Turffontein 90, passed from Dolomite and Black Reef Series into Witwatersrand Quartzites at a depth of 2,331 feet (calculated 2,700 feet). A fault occurred at 2,427 feet, occasioning re-duplication of the lower Dolomite and Black Reef Series, so that the borehole re-entered the Witwatersrand Quartzites at 2,671 feet (calculated 2,700 feet). This horizon proved to belong to the central portion of the Jeppestown Series. The sub-outcrop of the Main Reef is estimated to be about 2,900 feet south of the hole.

The selection of this borehole site was based mainly on two magnetometric traverses which clearly indicated that the area was considerably disturbed. On account of this faulting, a misinterpretation of anomalies was made, as the final check, namely, the location of the Jeppestown Shale Anomaly, which gives the smallest magnetic reaction, was not possible, on account of the proximity of the railway line in this vicinity.

Borehole C.M. 1 lies between Boreholes Nos. E 5 and E 7, on a portion of the farm Blyvooruitzicht No. 71, the option over which is held by the New Witwatersrand Gold Exploration Company, Limited (see Fig. No. 1).

The selection of this borehole site was based on results of a magnetometric survey and on similar principles of calculation as described above.

The borehole, being sunk jointly by the New Witwatersrand Gold Exploration Company, Limited, the Central Mining and Investment Corporation, Limited, and Rand Mines, Limited, intersected 4,000 feet of Dolomite and Black Reef, and then a reef in the Upper Witwatersrand Series, at a depth of 4,887 feet, which is to be correlated as Main Reef, the borehole having entered the Upper Jeppestown Shales at a depth of 5,235 feet.

Borehole No. E 4, on Driefontein 118. This borehole had been drilled by Goertz and Company 33 years ago to a depth of 2,638 feet, where it stopped in dolomite without penetrating the Witwatersrand Beds. The recently deepened hole entered the Witwatersrand System at a depth of 2,694 feet (calculated 3,000 feet).

The Main Reef was intersected at a depth of 3,610 feet (calculated 5,350 feet, re-calculated 3,870 feet). The Jeppestown Shales were penetrated from 3,870 feet (calculated 4,400 feet) up to 5,978 feet. From this depth down to the final depth of 6,060 feet the hole passed through Upper Government Reef Series.

Borehole No. E 3, on Driefontein 118. This borehole passed from the Dolomite and Black Reef Series directly into the Witwatersrand System, without encountering Ventersdorp Lavas, at a depth of 2,589 feet (calculated 2,620 feet). The Main Reef was intersected at a borehole depth of 3,244 feet (calculated 2,880 feet). The Jeppestown Shales were penetrated at a depth of 3,726 feet (calculated 3,320 feet).

Borehole No. E 2, on Driefontein 105, at a depth of 2,856 feet (calculated 2,430 feet), passed from the Dolomite and Black Reef Series into 733 feet of Ventersdorp Lavas, the presence of which was not anticipated, as they are not present in neighbouring holes. The borehole then penetrated the Upper Witwatersrand System at a depth of 3,589 feet and at a point below the horizon of the Main Reef, close to the contact of the Jeppestown Shales, which occurred at 2,670 feet (calculated 3,500 feet). The sub-outcrop of the Main Reef is estimated to be 700 feet south of the hole, and failure to intersect it was entirely due to the unexpected occurrence of the Ventersdorp Lavas.

EASTERN SECTION

including Ventersdorp Gold Mining Co., Ltd.

In the Eastern Section, including Venterspost Gold Mining Co., Ltd., five boreholes, Nos. 15, 14, 13, 12 and 11 have been completed, the sites of which were selected on the same principles of calculation as described above, except Borehole No. 11, which was placed on calculations based, not on the results of the magnetometric survey, but on the results of the old Boreholes Nos. 7 and 9.

Borehole No. 15, on Uitval 26, passed from the Dolomite and Black Reef Series into the Witwatersrand Quartzites at a depth of 3,254 feet (calculated 2,600 feet) at a point slightly below the horizon of the Main Reef. At 3,670 feet (calculated 4,100 feet) the hole intersected the Jeppestown Shales.

Borehole No. 14, on the same farm, passed at a depth of 2,669 feet (calculated 2,150 feet) from the Dolomite and Black Reef Series into quartzites of the Upper Witwatersrand System at a point below the Main Reef horizon. At 2,999 feet (calculated 3,920 feet) the Jeppestown Shales were penetrated.

The sub-outcrop of the Main Reef is estimated to be 300 feet south-east of the hole, and both Boreholes Nos. 15 and 14, therefore, failed to intersect the reef by a very small margin. Had it not been for the presence of the Venterspost dyke, outlined by the magnetometric survey, and which it was desired to avoid, both boreholes would have been placed 500 to 1,000 feet further towards the south-east (see Fig. No. 2).

Borehole No. 13, on Libanon 28, passed at a depth of 2,542 feet (calculated 2,170 feet) from the Dolomite into Ventersdorp Lavas, and at 2,946 feet penetrated the Upper Witwatersrand System. Several reefs belonging to the Main Reef Group were intersected between 3,314 feet and 3,645 feet (calculated 3,930 feet). At 4,444 feet (calculated 4,412 feet) the hole passed into the Jeppestown Shales.

Borehole No. 12, on Venterspost 27, entered at a depth of 2,229 feet (calculated 1,900 feet) from Karroo, Dolomite and Black Reef Series into Ventersdorp Lavas, and at 3,018 feet into Upper Witwatersrand System. The Main Reef was intersected at a borehole depth of 4,056 (calculated 3,610 feet). The Jeppestown Shales were penetrated at 4,442 feet (calculated 4,124 feet).

Borehole No. 11, on the same farm, passed at a depth of 1,700 feet from the Dolomite into Ventersdorp Lavas, and at 3,098 feet penetrated the Upper Witwatersrand System. The Main Reef was intersected at 4,125 feet. At a depth of 4,689 feet the hole passed into the Jeppestown Shales.

Besides these five boreholes already completed, seven boreholes are still in progress, namely, Nos. 17, 15A, 14A, 13A, 12A, 2A and 16. The position of Borehole No. 16 is further south-east of the line of all the other boreholes in order to investigate the Kimberley Series.

In order to obtain additional sections in the Upper Witwatersrand System, the old boreholes, Nos. 2, 4, 5, 7, 8 and 9, originally put down by the former Western Rand Estates, Limited, were cleaned out and deflected at a point close to the contact of the Upper Witwatersrand System and the overlying rocks.

The total amount of drilling carried out in both Western and Eastern Sections up to the end of the year 1935 is as follows :—

TOTAL DRILLING, WESTERN SECTION.

Borehole	E 10 ..	4,881 feet	completed.
,,	E 7 ..	2,086 ,,	in progress.
,,	E 5 ..	2,690 ,,	in progress.
,,	E 4 ..	3,428 ,,	completed.
,,	E 3 ..	4,129 ,,	completed.
,,	E 3A	1,131 ,,	in progress.
,,	E 2 ..	5,730 ,,	completed.
,,	E 2A	2,207 ,,	in progress.

Total Western Section, 26,282 feet.

TOTAL DRILLING, EASTERN SECTION,
including Venterspost Gold Mining Co., Ltd.

New Boreholes.

Borehole No.	2A	231 feet	in progress.
,,	11	4,817 ,,	completed.
,,	12	4,498 ,,	completed.
,,	12A	1,372 ,,	in progress.
,,	13	4,527 ,,	completed.
,,	13A	229 ,,	in progress.
,,	14	4,726 ,,	completed.
,,	14A	3,140 ,,	in progress.
,,	15	4,086 ,,	completed.
,,	15A	1,090 ,,	in progress.
,,	16	3,287 ,,	in progress.
,,	17	1,361 ,,	in progress.

Redrilled Boreholes.

Borehole No.	2	2,358 feet	in progress.
,,	4	2,210 ,,	in progress.
,,	5	—	not started yet
,,	7	—	,,
,,	8	2,803 ,, and	
		188 ,,	in progress.
,,	9	1,942 ,,	completed.

Total Eastern Section, including Venterspost G.M. Co., Ltd. .. .. .. 40,923 feet.

Total West Witwatersrand Areas, including Venterspost G.M. Co., Ltd... .. 67,205 ,,

Eight completed boreholes and nine boreholes now being drilled were sited by means of the magnetometric investigations, and the results obtained in the completed holes are a matter of record. In view of these results, it can be stated that the magnetometric method of applied geophysics used in close co-operation with geological investigations has demonstrated the practicability of tracing the Main Reef Series under heavy cover throughout a large area, which is of great potential economic value and where other methods have been unavailing in the past.

E.—Magnetometric Core Tests :

The correlation of the various reefs intersected in the boreholes depends largely on their distances from the upper shale zone of the Jeppestown Series, and in cases where a borehole proves to have been placed beyond the sub-outcrop and, therefore, fails to get reef, the sub-outcrop position of the reef can be closely estimated from the position of some known horizon disclosed in the borehole. It, therefore, becomes important to identify the various shale zones of the Jeppestown Series, of which there are three, for the purpose of using them as index beds, and to assist in this we use a rough method of testing the borehole cores magnetometrically. This method consists of setting up a magnetic field balance, releasing the magnet system and passing the borehole cores slowly just below the swinging magnet system, and as near as possible to it, and reading the deviations from the zero position. By plotting these readings as graphs, an approximate picture of the distribution of the magnetite contents of the various beds is obtained. The results of these magnetometric core tests, carried out on the cores of Boreholes Nos. E 10, E 4, E 3, E 2, 15, 14 and 8 are shown in Fig. No. 28. The two upper shale zones of the Jeppestown Series and the Jeppestown Amygdaloidal Lava usually show very small and narrow magnetite-bearing beds. The highest values are produced by the upper portion of the lower shale zone. The abnormal high values of this lower shale zone in Borehole No. E 10 indicate an increase of magnetite content towards the west, which fact is substantiated by the magnetometric survey of Western Reefs Exploration and Development Co., Ltd., south-west of the area of our investigations. There the Jeppestown Anomaly is usually stronger than the Government Shale Anomaly and even stronger than the West Rand Shale Anomaly.

F.—Acknowledgments :

I wish to express my sincere gratitude to the following gentlemen—

Dr. Hans Merensky, who, in giving me a magnetometer, enabled me to carry out my first experiments.

Mr. G. Carleton Jones, who so quickly realised from the very beginning the great possibilities in such a method of research, and who during all these five

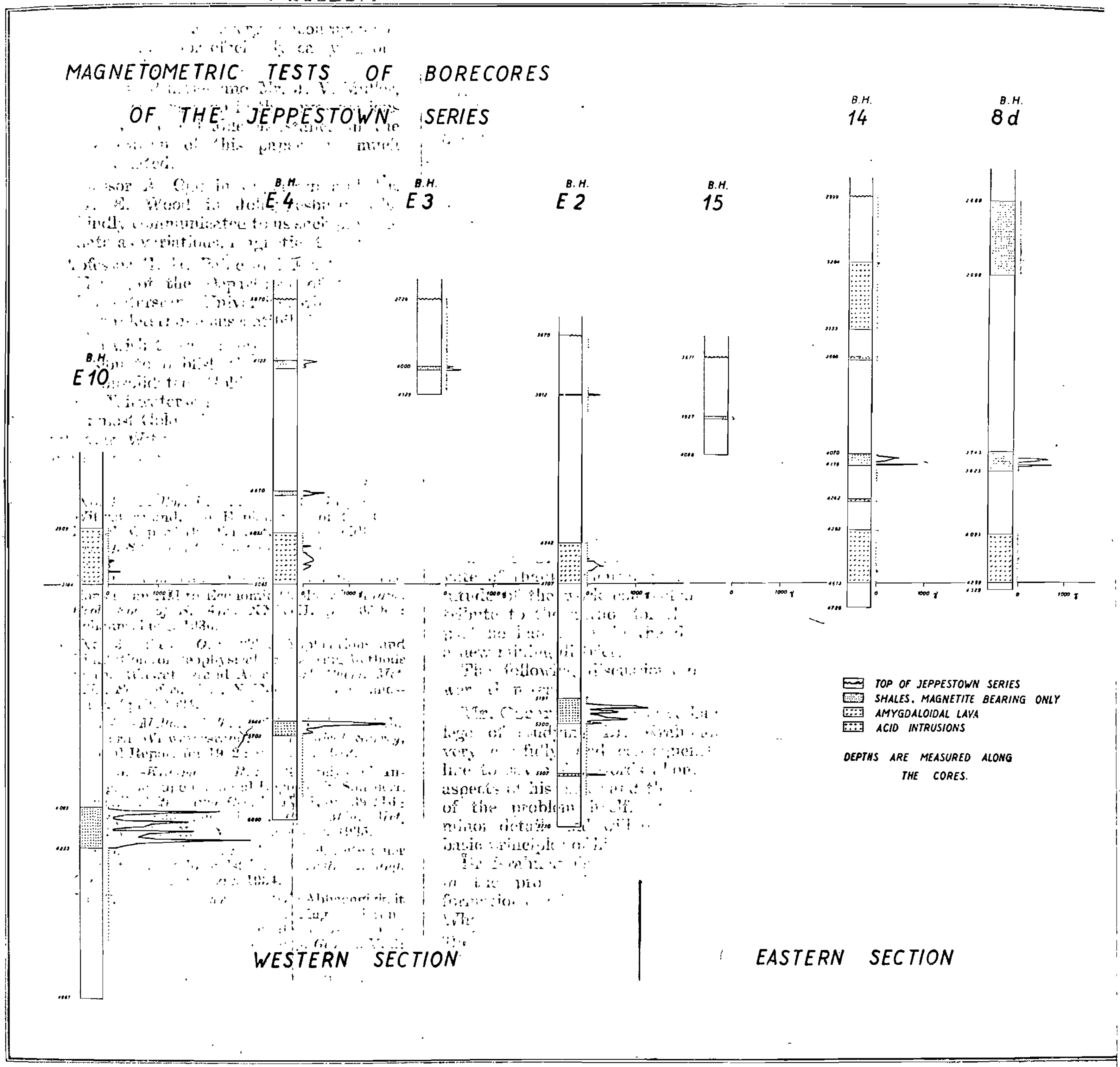

FIG. No. 28 (Plate XX.)—Magnetometric Tests of Bore Cores of the Jeppestown Series.

years gave us every encouragement and facility for efficiently carrying out this work.

Dr. R. A. Pelletier and Mr. J. V. Muller, whose co-operation in the investigations and whose valuable assistance in the preparation of this paper are much appreciated.

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I also wish to record my indebtedness for permission to publish the above details to New Consolidated Gold Fields, Limited; West Witwatersrand Areas, Limited; Venterspost Gold Mining Company, Limited, and New Witwatersrand Gold Exploration Company, Limited.

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Lit. No. 14.—*Reinecke, L., and Krahmann, R.:* "Magnetometric Prospecting on the Witwatersrand." *Amer. Inst. Min. Met. Eng.*, Meeting New York, February, 1935.

Lit. No. 15.—*Stokes, R. S. G.:* "Recent Developments in Mining Practice on the Witwatersrand." *Bull. Inst. Min. Metal.*, No. 374, pp. 16-18; London, November, 1935.

Mr. R. A. H. Flugge-de-Smidt (President Chemical, Metallurgical and Mining Society of South Africa), in proposing a vote of thanks to the author for his paper, described the original experiments and observations carried out by the author on the Witwatersrand rocks, and referred to the great economic value of his work.

Mr. R. S. G. Stokes, in seconding the vote of thanks, mentioned the great magnitude of the work completed, and paid a tribute to the author for the fundamental part he had taken in the development of a new mining district.

The following discussions on the paper were then read :—

Mr. Oscar Weiss : I have had the privilege of studying Dr. Krahmann's paper very carefully, and consequently I would like to say a few words about the various aspects of his paper and the various aspects of the problem itself. I will leave out minor details and will only deal with the basic principles of his work.

Dr. Krahmann's work opened up new ways in the prospecting for the gold-bearing formations of the Witwatersrand area. When he first proved the usefulness of the application of earth-magnetic measurements for the tracing of the magnetic shales of the Lower Witwatersrand System, he laid the foundations of a new intimate co-operation between mining engineer, geologist and geophysicist, a co-operation which has already produced great advantages for the mining industry of this country and which is bound to continue to be the normal routine in mineral prospecting in the Union. Since Dr. Krahmann's results with the magnetometer, all the other important geophysical methods are being used in this country, and they are slowly occupying the place of the magnetic method, owing to the fact that most of the areas are already surveyed with this method. Furthermore, there is no second place found where the conditions are so regular and ideal for the use of the earth-magnetic method than those in the West Rand.

At present Seismic, Gravimetric, Electrical and Earth-magnetic methods are applied in prospecting for gold, base minerals, coal, torbanite and water in the Union.

The basis of the confidence in the application of geophysical methods in this country was established through the work of Dr. Reinecke, the geologist, Mr. Carleton Jones, the mining engineer, and Dr. Krahmann, the geophysical expert. The advantages of this co-ordination of three branches of sciences in mining prospecting can be perhaps better realised if we compare their advantageous position with that of the early pioneers of the extension of the West Rand. The history of the area takes us 30 years back to the work of Kuntz, Zimmermann, Pullinger and others, and Goertz & Co. Had these investigators had means of locating and tracing the Witwatersrand System, their work would have been successfully completed 30 years ago. As it is, it is amazing to see how near they were to the solution. A glance at the map of the location of old boreholes will prove this. It is only fair that we should use this opportunity to acknowledge the merits of their labour.

Having now the use of geophysical methods established in this country, it is our duty to guard their true values.

Dr. Krahmann's results, as far as the tracing of the magnetic shales is concerned, can only command well-merited acknowlegment. There are, however, several theoretical aspects of his paper which are subject to serious criticism. Nor were these problems without practical consequence in the locating of borehole sites and in the progress of the prospecting programme of the New Consolidated Gold Fields in the West Rand. Out of the eight boreholes located by Dr. Krahmann and his associates, four have missed the Main Reef Series. These boreholes were E 10, E 2, No. 15 and No. 14. The expense and delay caused by these results must have been considerable. The reasons of such an outcome of a carefully conducted prospecting programme are of great interest for future operators and for investigators outside this country. It is with this view in mind that the following criticism is presented :—

I cannot agree with what Dr. Krahmann conceives to be the principles of the earth's magnetic field. The following statements are quoted from his paper :—

Page 251. "The magnetite-bearing shales of the Lower Witwatersrand give rise to negative anomalies, which effect is normal for the southern hemisphere."

Page 254. "The earth's magnetic field is negative in the southern hemisphere, such geological conditions as tend to increase this field are represented by negative anomalies. In the northern hemisphere the same conditions would produce a positive anomaly."

The fact is that the positive magnetic pole is on the southern hemisphere, and that under normal conditions magnetic bodies are producing positive magnetic anomalies in the southern hemisphere. Although it is really unnecessary to stress the above well-known facts, we quote the following authorities :—

Imperial Geophysical Experimental Survey, 1931, by Broughton Edge, Professor Laby, D.Sc., F.R.S. (University of Melbourne), Professor Rankine, D.Sc., O.B.E., F.R.S. (Imperial College of Science, London), and others.

Page 177 : "If the rock mass has a greater permeability than its surroundings, the magnetic lines of forces are bent in towards it. The state of affairs for such a body in the southern hemisphere is shown diagramatically in Fig. 123......We thus say that there is a positive anomaly of the vertical intensity above the upper end."

We also quote H. Haalck, "The Magnetic Methods of Applied Geophysics" (in German), Berlin, 1927 :—

Page 18 : "The magnetic north pole is negative (negative pole is the south pole of a magnet), the magnetic south pole is a positive pole."

It would be interesting to know whether Dr. Krahmann's conception was not due to the error of reading magnetometers in the southern hemisphere in the same manner as it is done in the northern hemisphere, namely, in the latter areas the north pole of the magnet dips downwards, so that with increasing magnetic anomalies the north pole dips steeper and steeper, and on the scale of the magnetometer higher and higher readings are read. If this arrangement of the scale reading is continued by using the same instrument in the southern hemisphere, then owing to the fact that here the south pole of the magnet dips steeper and steeper as the susceptibility of the magnetic bodies increases, it will result in obtaining lower and lower readings as the intensity of the magnetic anomalies increases. Such a mistake would produce negative anomalies over magnetic shale beds. It follows that Dr. Krahmann's curves have to be studied upside down. This inconvenience does not affect the conclusions drawn as to the position of the magnetic shale beds, but proves a serious theoretical misconception.

The next part of the criticism concerns the theoretical treatment of the problem of interpretation, especially the determination of the dip and depth of the West Rand shales.

In Fig. 16 of his paper, Dr. Krahmann shows theoretical curves which are based upon the equations of Roessiger and Puzicha, first published in this country by myself. These equations can only be applied for bodies of which magnetisation is homogeneous and is due to induction of the earth's field, *i.e.*, for bodies of which polarisation and permanent magnetism is negligible.

To establish a basis for his computations, Dr. Krahmann attempts to prove that the West Rand Shale has no permanent magnetism. After admitting that the differences between the susceptibility determinations of samples and actually observed curves can be only explained on assuming permanent magnetism (see page 254 of paper), he proceeds by ignoring this fact. We quote from his paper :—

Page 258 : "Pieces of fresh rock out of boreholes which had penetrated the magnetic band of the Jeppestown Shales, disclosed the fact that all core pieces, representing many hundred feet of shales were magnetically soft, *i.e.*, that we have to deal not with permanent magnetism, but with induced magnetism. Besides, wherever we found West Rand Shales under cover, their magnetic effect as regards the direction of the field was the same as observed over Jeppestown Shales, *i.e.*, corresponding to the assumption of induction by the earth's field. We are, therefore, justified in concluding that the West Rand Shales behave magnetically like the Jeppestown Shales, their magnetic effects differing only in intensity."

On page 259, he goes further by saying : "We have seen that the magnetisation of the Lower Witwatersrand Shales in our area is in accordance with the assumption of induction by the earth's magnetic field."

It can be definitely said that the above statements are not borne out by facts. The Water Tower Shales, Contorted Bed and West Rand Shales are polarised and contain very considerable permanent magnetism, their magnetisation is not uniform. These observations were confirmed by investigations in the East Rand, Heidelberg District, West Rand, and on the actual areas where Dr. Krahmann's measurements were carried out. There are, however, further theoretical objections. In the attempted interpretation the effects of magnetic induction are entirely ignored. Besides the factor of demagnetisation, which has to be considered in the theory of the magnetisation of each magnetic body, with the exception of the closed magnetic rings, it has to be remembered that when dealing with the effect of not one single but several closely placed magnetic bodies, the effect of mutual magnetic induction has to be taken into account. This principle was entirely ignored, and this further weakens the basis of the attempted interpretation.

On page 263 of the paper it is stated : "Examples are given in Fig. 16, for dips of 10° to 60°, and depths of 500 ft., 1,000 and 1,500 ft. These curves are for the West Rand Shales, which in our area contain two magnetic beds ; the effects of both beds being added for every point of the traverse." This sort of "addition" is against the correct laws of the theory of magnetism, as it neglects the important and very complicated effects of the mutual induction. For similar reasons Dr. Krahmann's curves of Fig. 19, where he attempts to treat the problem of four magnetic beds, can be questioned.

Leaving the theories alone now, we return to the practical consequences of the magnetic work carried out by Dr. Krahmann.

The above-discussed errors indicate that the theoretical limitations of the method were ignored and its accuracy was over-estimated. It can be seen that in most of the cases where the boreholes missed the Main Reef Series, the failure was due to not allowing a sufficient safety margin in the locating of the borehole sites. The estimated horizontal distance of these boreholes from the actual sub-outcrop of the Main Reef Series is given as follows :—

E 10	..	2,900 feet.
E 2	..	700 feet.
No. 15	..	"slightly below the horizon of the Main Reef."
No. 14	..	300 feet.

I once more emphasise the necessity of the conservative handling of the geophysical methods of prospecting. It is regrettable that, after Dr. Krahmann's valuable results within the true scope of the earth-magnetic method, the over-reaching of the theoretical limits had to be criticised.

It should be finally mentioned that the true results of Dr. Krahmann's work amply justify acknowledgment, and his contribution to what appears to be the most important extension of the gold mining areas of the Witwatersrand remains beyond question.

Mr. J. Allan Woodburn : I have listened with very great pleasure indeed and with a great deal of interest to the description of the many diagrams which Dr. Krahmann has shown us to-night, and to the description of how those diagrams were produced, and the deductions which are to be drawn from them.

Although I have seen some of those diagrams in the past, this is the first time I have heard what one might call the full story of geophysical surveying on the West Rand, and I feel that one will have to wait until those diagrams and the descriptions are printed in the *Journal*, and one has time to compare them rather more carefully than one can merely by listening to what we have heard to-night, before a true appreciation of their value can be obtained. I hope, at some future time, to join in the discussion and to produce some diagrams of practical work on the Far East Rand.

Recently we have developed what I would call an Isogam chart—that is to say, all the anomalies similar to what you have seen represented on the diagrams to-night—we have reduced on the Far East Rand and marked them out by what one might call Isogammatic Lines—that is, curves something like the contours of a very hilly country ; the positive anomalies show up as ridges and hills and the negative ones as valleys.

Theoretically one would imagine that these curves should give one the same interpretation as the joining of the various pinnacles on the different sections, and in many cases, where those pinnacles have been very definite, there has been a very considerable correlation between the Isogam curves and the lines of sub-outcrop, as connected from the sections. Where, however, the sections—that is to say, the anomalies—have been rather weak and not so distinct, the Isogam curves give a somewhat different picture to the lines of sub-outcrop which one might draw by connecting the peaks of the sections.

Another point of great interest—and some of the members of the Chemical, Metallurgical and Mining Society will probably remember our experience—has been that where definite anomalies have shown up in such a way that a line of sub-outcrop could be drawn for a mile, two miles or three miles, and where the curves, the Isogams, correspond and check those same lines very closely, we found we were able to get similar, or almost identical lines by using the ordinary compass, by taking the readings in degrees. That, to me, from a practical point of view, was particularly interesting. Where they have been indefinite, we are still feeling our way, and some of the remarks made to-night may help towards an explanation.

We have found in several boreholes quite a number of magnetic shales. In nearly all cases those magnetic shales have been polarised, and many samples of shales obtained from Nigel and all over Johannesburg, in nearly all cases have been polarised.

In one particular borehole, where the anomalies were rather indefinite, we cut through an igneous rock, it may have been a dyke or a sill, which was almost as highly magnetic as the most highly magnetic shale that we have yet struck. We cut through further magnetic shales in the same borehole, and whether this dyke or sill had an amplifying or modifying effect on the magnetic shales below we have yet to discover. But, as I say, I hope at some future time to contribute probably a copy of this map which will give the results of a great number of anomalies over about 150 square miles on the East Rand.

Dr. Bahnemann: I might point out that, not having had an opportunity beforehand of reading Mr. Weiss's contribution, I am at a disadvantage in not being able to answer some of his questions regarding the method of plotting curves.

That the vertical intensity in this country is considered as being negative, I think, is more a matter of convenience. I can as well produce authorities to show that the normal field of the southern hemisphere is to be treated as being negative. I think I shall perhaps be able to explain this matter better at a later date; but, regarding the question of polarisation and induction on the Rand, I have had the opportunity of doing some work on the Far East Rand as well, and I know that the magnetic conditions on the Far East Rand are very different compared with the magnetic conditions encountered on the Far West Rand.

Mr. Weiss omits some of the statements made in the paper regarding the famous trench. We very well know that most of the pieces there are polarised; but the interesting thing is that the shale came from the surface and not out of a borehole. As a matter of fact, we could not get pieces of West Rand Shale out of a borehole, or shaft. It would be extremely interesting to get some. We have a lot of pieces from the Jeppestown Shales out of boreholes, therefore fresh, and of those pieces, many hundreds of feet were magnetically soft; that means their magnetisation is mostly due to induction by the earth's field. The fact that the shales in the trench are polarised is due to some unknown cause; it may be connected with weathering, lightning, or something else. We have done traverses perpendicular to the strike and parallel to the traverse which covers that trench, and we know well, from geological work, that they were run over ground covered by dolomite to a thickness of 100 to 150 feet. There the shales exhibit a magnetisation which is in accordance with the magnetisation of induction by the earth's field. Therefore, we took it that there must be a cause which has to be made responsible for the polarisation of these shales on the surface; and this cause, which is unknown at present, will be found in the future. On the occasion when the paper of Dr. Reinecke was read before the American Institute of Mining and Metallurgical Engineers, I published a paper covering the work done on one of these very interesting magnetic anomalies on the Far East Rand, interesting regarding not only the intensity but also the direction of magnetisation. In this case I am sure that mechanical forces and heat played a most important part in changing the magnetisation which can be assumed to have been normal before the altering forces were applied to these shales.

All the other things which Mr. Weiss mentioned, I think we can leave to another occasion, for, as I previously mentioned, I have not had an opportunity of reading his remarks beforehand.

The Chairman, before closing the meeting, gave a summary of the main features of the work which had been carried out. He referred to the difficulties which had been encountered, to the great value of the results which had been obtained, and, finally, to the great interest and important part that the late Dr. Reinecke had taken in these investigations.

This concluded the business, and the meeting terminated.

Notices and Abstracts of Articles and Papers.

CHEMISTRY.

Beryllium.—Beryllium (glucinum) occurs in various localities as the beryllium aluminum silicate, 3 $BeO.Al_2O_3.6\ SiO_2$, commonly designated as beryl. In Tasmania and elsewhere, the single silicate Be_2SiO_4 phenacite has been located and may become commercially important. Clear, transparent crystals of beryl, coloured green by a trace of chromium, are the much-prized jewel, emerald, whose history dates back 5,000 years, at least. But the metal beryllium, and the remarkable properties developed when added to copper and other metals, was unknown to the ancients. Recent surmises that the "lost art of hardening copper" might be attributed to the introduction of beryllium by the ancients during the smelting of copper have not been supported in spite of very careful spectroscopic analyses of old copper spear heads.

Various methods have been resorted to for the recovery of beryllium from its ores. Fused caustic soda and potash were frequently employed; other reagents include fused sodium silico-fluoride, fluorspar and calcium carbide.

Dr. W. R. Mott in his exhaustive studies on the behaviour of metals and salts in the carbon arc found that "beryllium oxide is apparently more