MAGNETOMETER EXAMINATION OF THE MONTE CRISTO MAGNETITE-ILMENITE DEPOSITS

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I. Introduction

Situated in the San Gabriel Mountains of Southern California is a large body of anorthosite with which is associated a number of bodies of ilmenitic magnetite. During the summer of 1937, the E. I. duPont de Nemours Corporation obtained options on a group of properties thought to contain several such deposits. In connection with the exploration of the aforementioned deposits, the authors were employed as geophysicists to conduct a magnetic examination of the area. The data contained in this report was collected between August 9 and September 4, 1937. Mr. Dawson is, at the present time, continuing the magnetometer investigation and, in the light of the facts to be presented in the following pages, his work is being watched with considerable interest.

The Monte Cristo area is located a few miles north and west of the head of the Tujunga drainage system in the vicinity of latitude 34°21'N, longitude 118°06'W. The area is one characterized, in general, by a fairly thick cover of brush with few large trees. It was thus both necessary and possible to cut trails along which the magnetometer traverses could be run and on which the position of the magnetometer stations could be subsequently determined with a transit. The area is likewise one of considerable relief. Many of the slopes are quite steep and thus serve to lessen to a certain extent the speed with which the magnetometer work can be executed.

From a purely geophysical viewpoint, however, the area is almost ideal for a magnetic investigation. The anomalies are very high and a high degree of sensitivity is, thus, both unnecessary and unwarranted in the area. The very marked character of the anomalies also renders the interpretation of the results somewhat simpler than is generally the case.

The writers are deeply indebted not only to Dr. Joseph L. Gillson, for permission to use the data comprising this paper, but also to Dr. George H. Anderson, who, as superintendent in charge of exploration, gave liberally of both assistance and advice.

II. General Geology

The area in which the magnetite-ilmenite bodies are found has been stated to be part of a large anorthosite body. In places, the anorthosite consists almost entirely of greyish-white andesine. This facies grades locally into a dioritic phase. These facies are apparently related as derivatives from one original magma. Scattered throughout the anorthosite are bodies of magnetite containing, on the average, about thirty percent ilmenite. Closely associated with such magnetite bodies are dike-like aggregates of actinolite which usually contain a varying amount of magnetite. Field and petrographic evidence would tend to indicate that the actinolite and magnetite are gradational. For this reason it is possible that many bodies which appear to be mainly actinolite on the surface may grade into magnetite-ilmenite bodies with depth. It is, however, notably true that very many large actinolite dikes give relatively small anomalies thus indicating that many such dikes do not grade into magnetite or that the magnetite into which they once graded has now been eroded away. That the latter situation may often well be the case is indicated by the fact that, in the places where the largest broad anomalies are to be found, the outcrops of both magnetite and actinolite are not abundant. It would thus seem to be fairly well established that those areas showing an abundance of magnetite in float or in outcrop are the areas that have been the most deeply eroded and are therefore those in which the smallest anomalies (and hence ore-bodies) can be expected.

Considerable discussion has arisen over the question of whether the magnetite-ilmenite bodies are to be regarded as irregular segregates; as dikes segregated from the same magma as the anorthosite, but intruded later; or as of hydrothermal origin. There is very little evidence for or against the concept of hydrothermal origin. The mere fact that other similar deposits have been regarded as magmatic intrusions or segregates is of very little import since there are some very notable deposits of this type which, in recent years with more careful study, have come to be regarded as hydrothermal. Further mineragraphic study and field mapping of the magnetite-ilmenite bodies might establish the validity of this concept. As to whether these bodies are dikes or irregular segregates, there is a variance of opinion where nearly identical deposits have been studied in other portions of the San Gabriels.[1,2] Suffice it to say that, if the bodies are later intrusives (i. e. dikes) many such dikes are very small and discontinuous in this region. There is a great temptation in any area to line up high anomalies on relatively distant traverses and to regard such an alignment as illustrating a definite trend and thus proving a mode of occurrence. Many more traverses are needed in the area here under discussion before it can be stated definitely that such an alignment exists throughout the area.

The form and continuity of the ore bodies is, however, of the utmost importance in estimating the value of the deposit. For, if the deposit consists of a number of irregularly shaped and heterogeneously distributed aggregates, the cost of mining and the difficulty in exploration would increase tremendously. The difficulties in ascertaining the shape and distribution of such bodies from magnetic profiles will be discussed in a subsequent section.

The entire value of the deposit lies in the titanium content of the ilmenite ($FeTiO_3$) associated with the magnetite in Widmanstätten intergrowth. A small amount of hematite is also present in the ore. Since, with the sensitivity used, only the magnetite is sufficiently magnetic to affect appreciably the magnetometer, the basic assumption on which all of the work is being carried out is that the ilmenite content of the magnetite is fairly constant. Experimentation with surficial ores has tended to substantiate the validity of this assumption. Only diamond drilling, which may be undertaken in the future, can ascertain whether this assumption is also valid for the larger and more deeply buried ore bodies.

1 Miller, W. J., Geology of the Western San Gabriel Mountains of California, Univ. of Cal. at Los Angeles Pub. in Math. and Physical Sciences, Vol. 1, pp. 1-114, 1934.

2 Dawson, C. A., Jr., Petrology of the Igneous Complex Near Lang, California, M. S. Thesis, California Institute of Technology, 1937.

Both of these papers deal with the geology of the San Gabriel anorthosite (and related rocks) in far more detail than is here attempted.

III. Adjustment of Instrument

The primary adjustment in magnetometer work consists of determining the scale constant of the instrument; i. e., the number of gamma equivalent to one scale division. It was determined empirically that, in this particular region, the instrument should be adjusted so that one scale division was equal to approximately thirty three gamma. For this calibration, a single coil, 60.8 inches in diameter, was placed around the instrument. A reading was taken and a current of thirty milliamps was then run through the coil and the deflection caused by the current noted. The bottom screw of the mobile magnet system was then raised and lowered until the constant was a desirable value. The equation used to determine the scale constant was:

$$\text{Gamma} = \frac{20\pi I}{r}$$

I= current in milliamps
r = radius of coil in inches

When the instrument was in final adjustment, the above equation with values substituted was as follows:

$$\text{Gamma} = \frac{20 \times 3.14 \times 30}{30.4} = 62.0$$

The 62.0 gamma were marked by a deflection of the instrument of 1.9 scale divisions. The scale constant was thus 32.6 gamma.

It was also considered desirable, from the viewpoint of facilitating interpretations, that both instruments should have the same reading at a given point. To accomplish this, one instrument was set up at a known point and at a known height and the reading taken. The second instrument was then set up at the same point and height and the two side screws of the mobile magnet system were adjusted until the readings on both instruments were the same.

On account of the size of and wide range in readings it was deemed necessary to make only the temperature corrections. The average range of readings was about 500 gamma and the diurnal, latitudinal, and longitudinal corrections would not amount to more than one-tenth that value. The temperature corrections at times, however, exceeded 200 gamma.

To determine the temperature correction, one instrument was placed in an abandoned mine tunnel, where the temperature was constant and the only variations were due to diurnal fluctuations. The other instrument was placed out in the open. Both instruments were read every twenty minutes for four hours. The diurnal readings were then subtracted from the readings taken in the open air and these corrected instrument readings were plotted against temperature. From this graph it was possible to ascertain the number of scale divisions displaced for each degree change in temperature.

The only other adjustment necessary was the calibration of the auxiliary magnets. This calibration was accomplished by bringing a magnet near enough to the instrument to cause a strong positive deflection. Then another auxiliary magnet was placed in a definite position in the magnet holder with the north pole pointing upwards and the decrease in the former reading was noted. This process was continued until the effect of each magnet was ascertained when the magnet holder was adjusted to each of several positions.

IV. Field Procedure

On account of the dense brush prevailing in the area, it was necessary to have trails cut before the magnetometer work was undertaken. Such trails were first cut at right angles to what a brief examination indicated to be the strike of the ore bodies in the particular area. If the traverse consisted entirely or in part of high anomalies, trails were cut both parallel to and at right angles to the original traverse line until the zone of high anomalies was delimited with reasonable accuracy. The number of traverses used to delimit an area of high anomalies depended on the size of the area. On an area which the first few traverses indicated must be very small, little further work was attempted. Where the area appeared to be one of broad, high anomalies, a number of traverses were run until the limits of the area were well known.

It was the general custom to place all stations as close to sixty feet apart as could be ascertained by pacing. Such paced distances are those indicated on the profiles included with this paper. The position of the stations is now being determined more accurately with a transit, but, for the purpose of the scale used for the profiles, the approximate distance is sufficiently accurate. A variance of a few feet could not be indicated on the graphs. On a few reconnaisance traverses, the stations were placed a hundred feet apart and, on a few of the more detailed traverses, the distances were twenty or forty feet.

Both the distance between stations and the magnetic intensity can be determined from the profiles. The abscissa of the profiles is distance in feet - each millimeter being equal to twenty feet. The ordinate of the profiles is magnetic intensity - each millimeter being equal to thirty three gamma.

Since the anomalies observed were, in general, so high and since the variations in readings between each station were often so large, certain of the corrections commonly applied in regions of smaller anomalies were not here used. Since the average range of readings was over five hundred gamma and since neither the longitudinal nor diurnal corrections would exceed much more than one-tenth that value, these two corrections were not used. However, on account of the high temperature observed, the temperature correction at times reached two hundred gamma. The temperature corrections were thus always applied. Temperatures were read to one-tenth of a degree and magnetic intensity was read to one-tenth of a scale division (3.3 gamma).

The map accompanying this paper is included to show only the approximate areal distribution of the anomalies shown accurately on the included profiles. The anomalies were grouped into various divisions as indicated on the map and very small changes from one group of anomalies to another have been omitted. The position of each of the several trails shown on the map is approximate - many of the trails not yet having been surveyed. The position of the trails and the distribution of the anomalies is, however, in all cases, as close as possible to the correct position as is necessary to show, with reasonable accuracy, the general areal pattern of the magnetic anomalies.

V Discussion and Interpretation of Results

In actual field practice, two types of anomalies were recognized; viz., (a) broad highs or lows in which the large anomaly extended over a wide area and increased or decreased gradually, (b) sharp highs or lows where the actual high anomaly was often larger than in the first type, but occupied only a small area and increased or decreased very rapidly.

In an area in which the main purpose of exploration was the discovery of one or more large ore bodies that could be mined as a unit, the presence of small bodies is of little importance. Hence, it was quickly recognized that a small body, unless near the surface, would cause only a small anomaly. If such a small body is very near to or at the surface, it would cause a marked anomaly that would be very high at one point, but would drop off very rapidly on either side of the marked high. Whether such anomalies were marked highs or lows depended only on the topographic position of the magnetometer station in relation to the pole of the ore body. Many such marked, sharp, local highs were located and were generally associated with surficial exposures of ore. At times there were local outcrops in an area of a broad high and these appear on the profiles as peaks far above the general broad high. The magnetic intensity at the highest point of such sharp highs, unlike the broad highs associated with deeper ore bodies, is inversely dependent on the proximity to and height above an outcrop at which the magnetometer reading was taken.

It might be quite possible that a large ore body could be found near the surface and thus cause a continuous area of extreme highs. Actually, however, no such area was found. Instead the broad highs were all marked by gently increasing and decreasing areas of broad anomalies of moderate size (perhaps 900 gamma in contrast to the sharp highs which at times reached 10,000 gamma and often exceeded 6,000 gamma). Such broad highs could be interpreted in several ways - (1) as one large ore body at considerable depth, (2) as an aggregation of a number of small bodies in one localized area at considerable depth, (3) as one moderate sized body at intermediate depth, or (4) as several fairly small bodies scattered over a wide area at intermediate depth. The possibility of points one, two, and three can be determined only by drilling. It seems quite improbable that point four represents the true situation since, if such were the case, an almost ideal spacing of the numerous small dikes at intermediate depth would be needed to create one broad, consistent high.

Extensive exploration in the Monte Cristo area began with traverse JJ-WW-R-J. (See location of trail on map and also see profile on Plate II.) It will be noted that a broad high commences about 1000 feet west of point R and continues to J. The presence of this high suggested the advisability of extending this traverse to the east. Accordingly, traverse J-E-D-KK-LL was completed. This traverse showed a remarkable continuation of the same broad high (on which were superimposed numerous abrupt highs due mainly to surficial ore pockets) with almost all readings above 600 gamma and many above 1500 gamma (Plate II). It will be noted, however, that from the beginning to the end of this zone of high anomalies, the traverse runs along a topographic ridge. It was therefore, thought possible that a large dike of ore might be the cause of the ridge and that the broad zone of high readings might be due only to the fact that the traverse was conducted parallel to the strike of a dike rather than across a large ore body at considerable depth. Accordingly, a number of traverses were run both parallel to and across traverse JJ-LL to determine the exact cause of the high anomalies. Considering first the parallel trails, it will be noted that none shows a broad, consistent high comparable to traverse JJ-LL. Traverse V-Q-VV (Plate VIII) shows numerous local highs. Traverse WW-O (Plate VIII) also shows only local highs whereas traverse Y-UU-SS-N shows almost no abnormally high anomalies (Plate VIII). Moreover, cross traverses V-W (Plate VII), R-S (Plate VI), G-H-J-K (Plate VI), E-F (Plate VI), and C-D (Plate VI) drop off rapidly after leaving the ridge along which traverse JJ-R-J-E-D-KK-LL was run. These latter cross traverses would thus seem to indicate that the ridge from JJ to LL was actually parallel to and directly above a long dike. However, it will be noted that the readings on traverse A-B (Plate II) and XX-KK-YY (Plate IV) drop off very slowly. Subsequent traverses extended northeast of XX, east of LL, radiating out from KK, and south and east of the XX-KK-A-LL area indicate indeed a broad high somewhat circular in form which centers at KK and extends for at least 1000 feet around KK. All the traverses shown on the map around the KK high area are located on ridges and might reasonably be due to cross dikes. However, traverses run northeast and southeast subsequent to the completion of this map go down a steep slope to the east (more than 700 feet in elevation below the top of the ridge) all the while maintaining the same high readings. Moreover, traverses run on high ridges in other parts of the area often showed very low readings (from perhaps +250 to -250 gamma) thus proving that height alone could not cause the high anomalies. The ore body must thus be broad and at considerable depth. How large an ore body and in what form the ore body exists that causes such a broad circular high some 2000 feet in diameter is problematical and will be disclosed ultimately only by diamond drilling. Traverses V-W, R-S, G-H-J-K, E-F, and C-D as well as Z-HH (Plate III) and MM-NN (Plate I) also served to show the absence of any large ore bodies in the area represented by the southern portion of the map. About a mile south of the southern boundary of this map, however, another broad high, considerably smaller than that centering around KK, has recently been located.

A large part of the area north of the trail going from Z to N showed many surface exposures of ore. For this reason, it was thought wise to run traverses through this northern area. These traverses show excellent examples of small, abrupt highs quite distinct from the broad area centering around KK. Traverses TT-UU, RR-SS, and QQ-U (all on Plate V) all show numerous, small, sharp highs most of which are located at or near surface outcrops of ore. These bodies are thus apparently very small and only surficial in character. Cross trails Y-X (Plate VII), and trails CC-DD and EE-FF (both on Plate IX) show the same situation of a number of narrow, surficial ore bodies indicated by sharp, abrupt highs. Traverse AA-TT-BB (Plate VII) might seem to show near its western extremity an indication of another broad high. However, no such high shows on traverse Y-Z (Plate VII), nor on EE-FF, nor on DD-CC. (The latter has, since the completion of the map, been extended 1500 feet to the east and still shows no indication of this high.) It is thus apparent that the high on AA-TT-BB was caused by paralleling, for a distance, a small, narrow dike.

In conclusion, it may be stated that the valuable discoveries represented by the work summarized in this paper are the area of high anomalies centering at KK with a long, narrow high going to the west, and an area, considerably smaller in size, about a mile south of the southern border of the map. The form, size, and tonnage of these ore bodies can be satisfactorily shown only by diamond drilling supplemented by a large amount of more detailed magnetic prospecting.

EXPLANATION OF PROFILES

Horizontal scale - one millimeter equals twenty feet.

Vertical scale - one millimeter equals thirty three gamma.

Letters above the profile correspond to letters on the map.

Base line (zero line) of each profile is inked in brown.

Where anomalies are too large to be shown on the graph, numbers typed at the point at which such excessively large anomalies leave the graph indicate the magnetic intensity, in gamma, of such anomalies.

Plate I

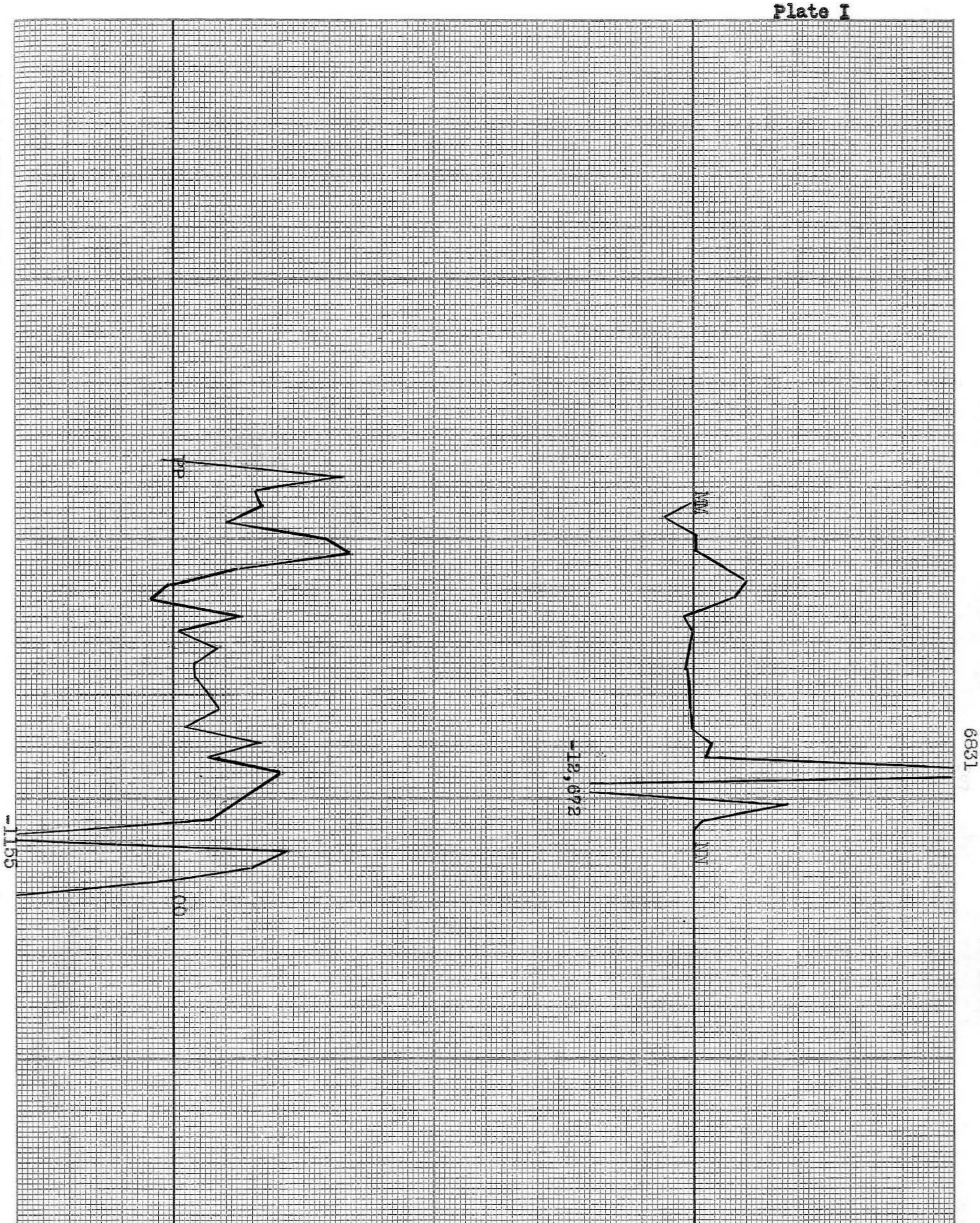
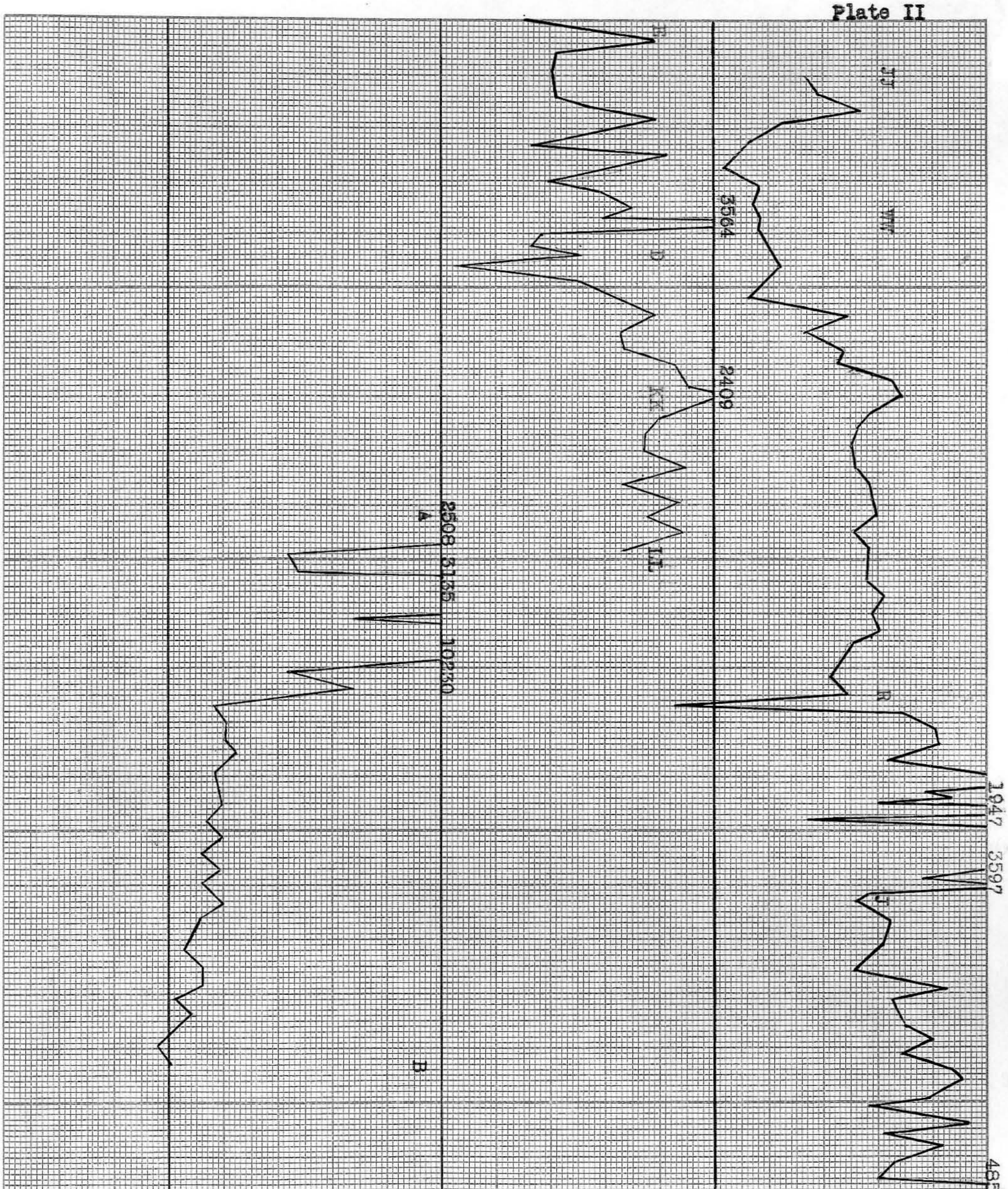
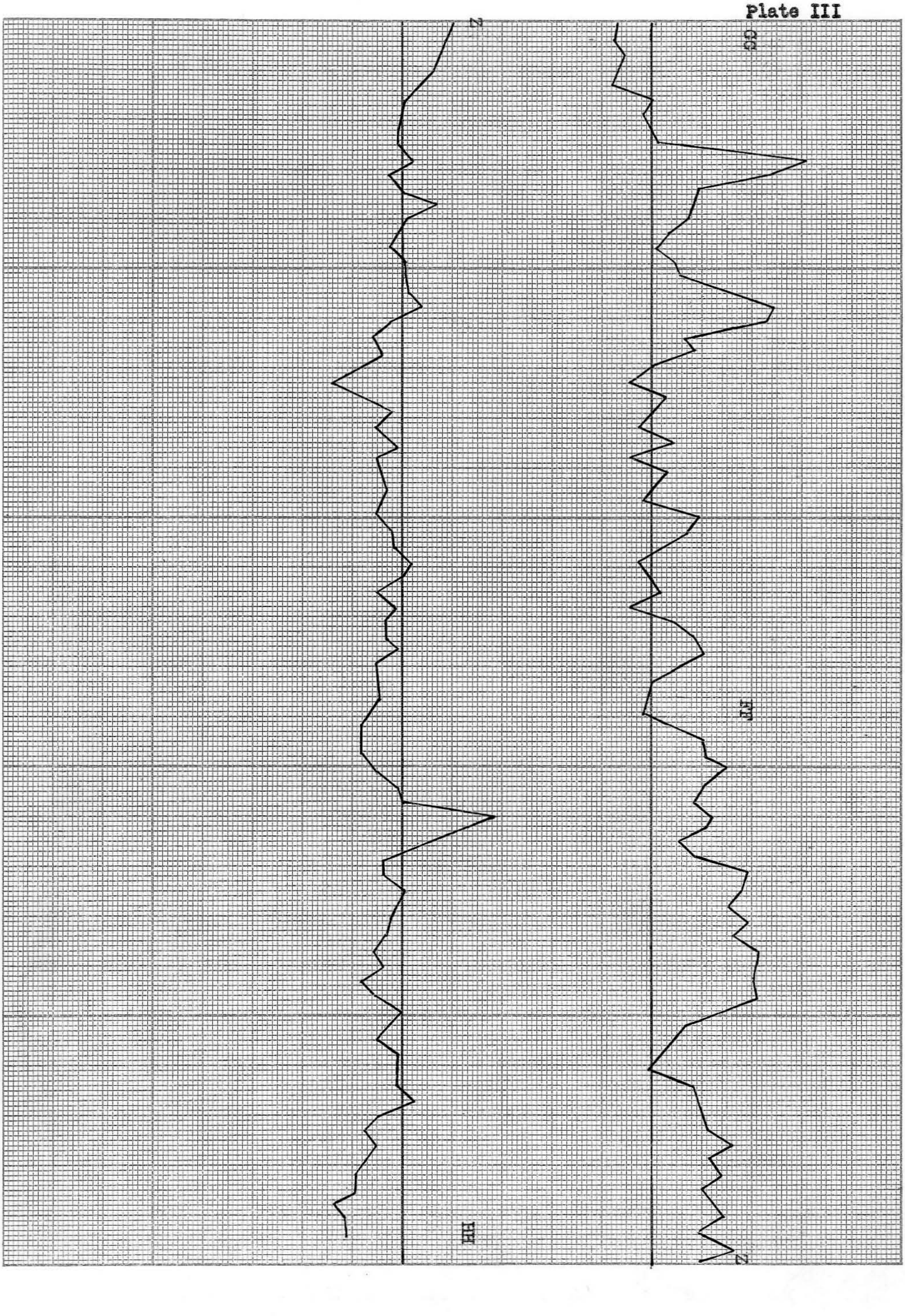


Plate II



JJ
WW
3564
D
2409
KK
LL
2508
A
3135
10230
R
1947
3597
J
B
4851
2475
1749
6270

Plate III



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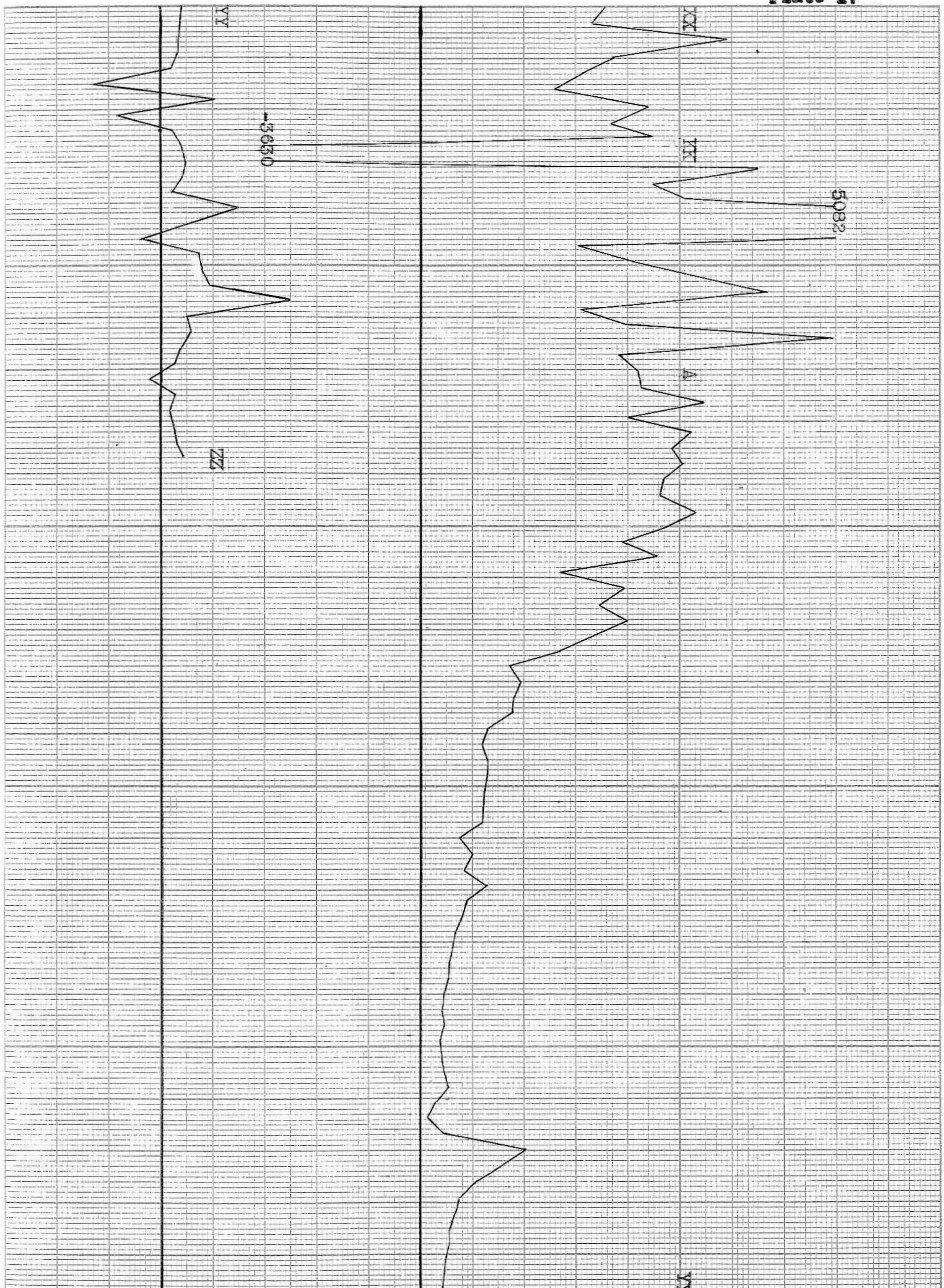

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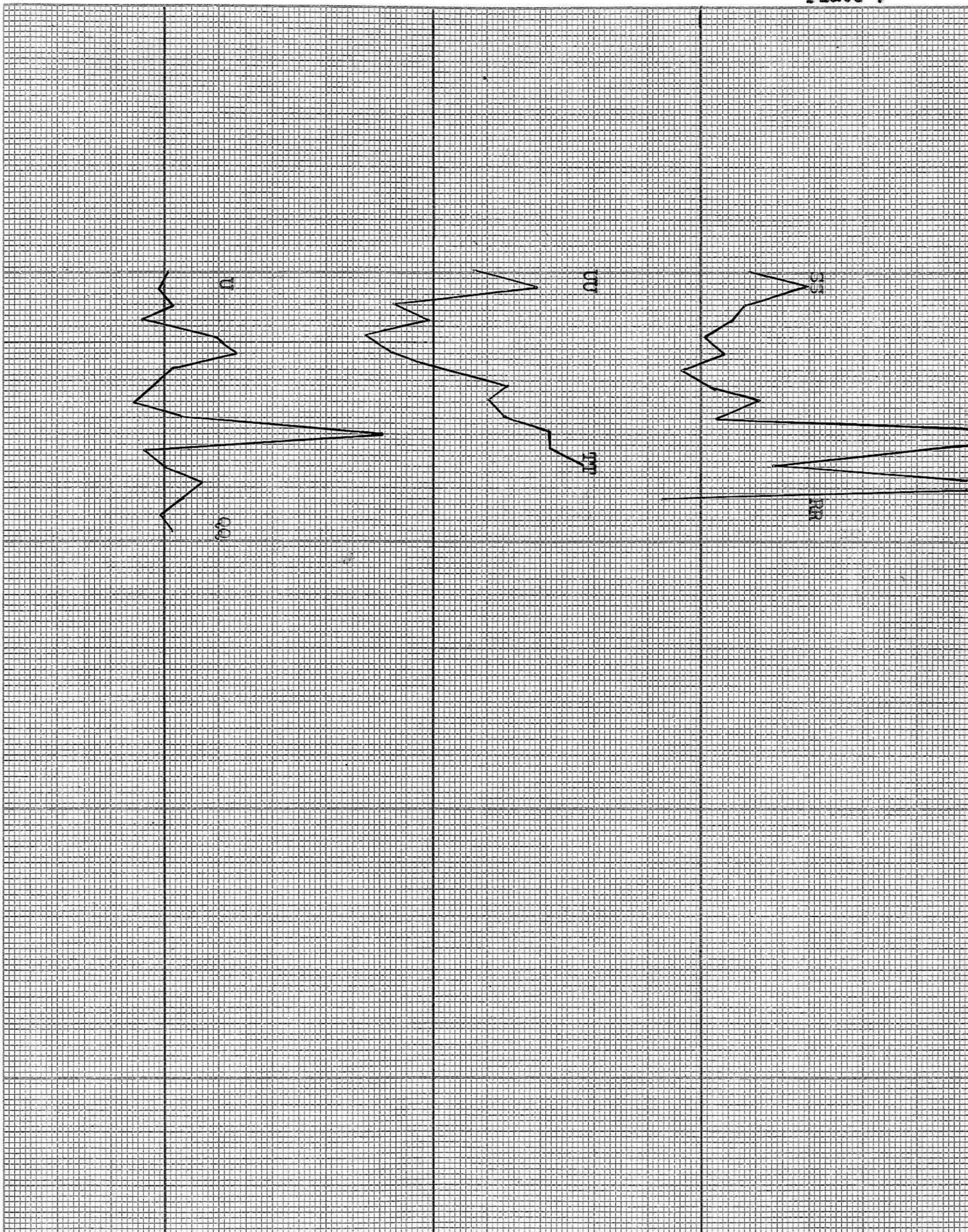
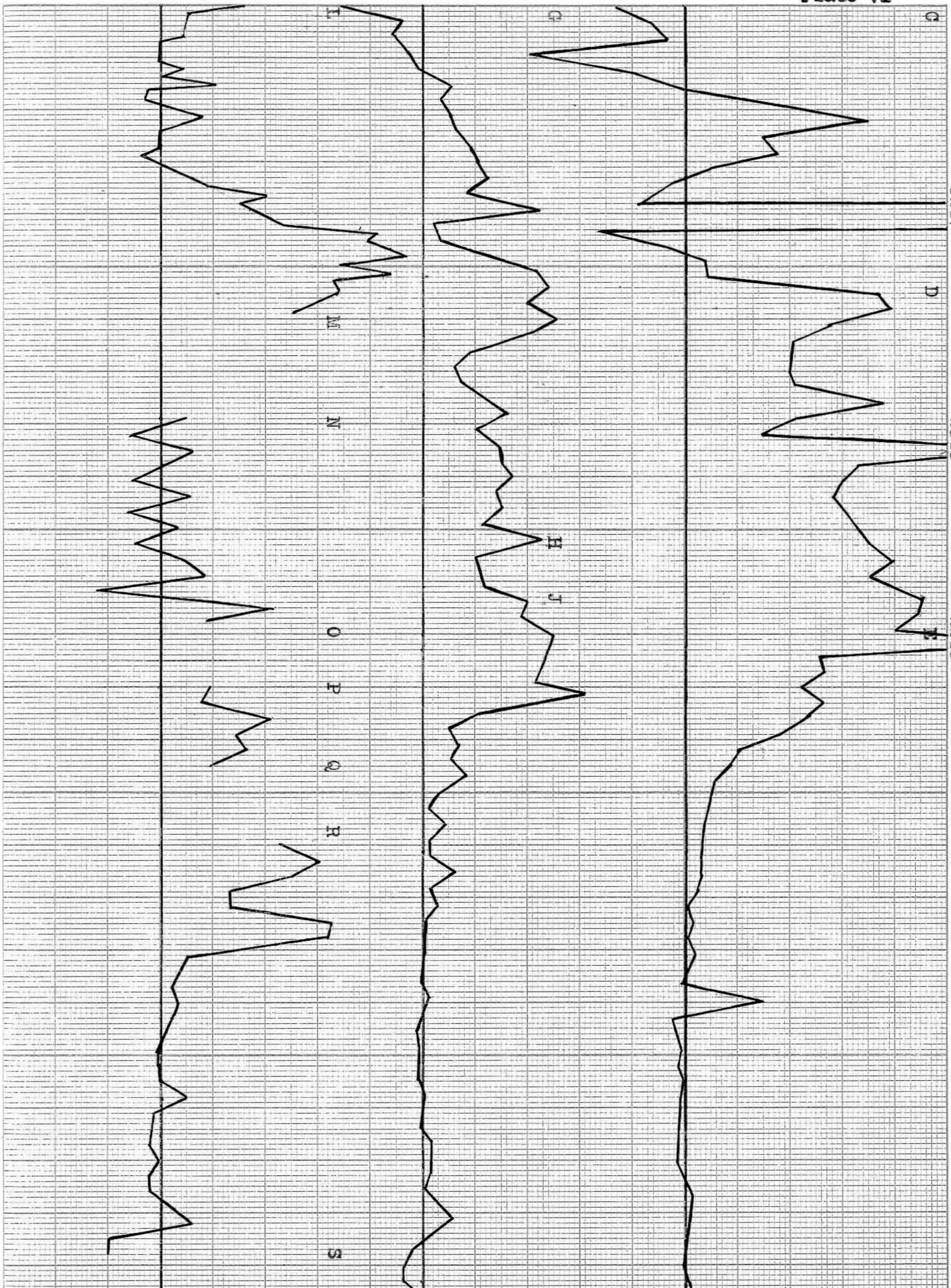


Plate VI



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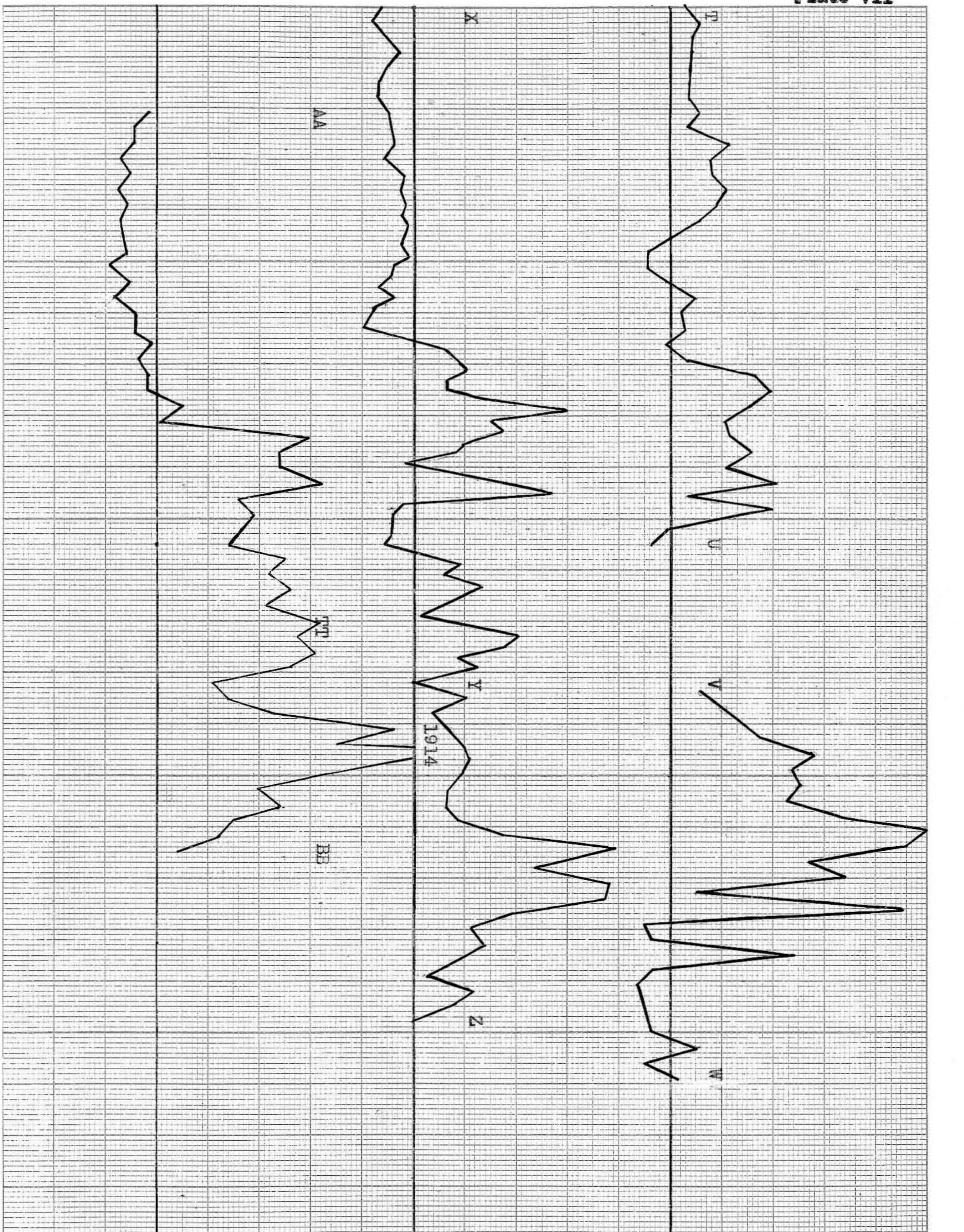

Plate VIII

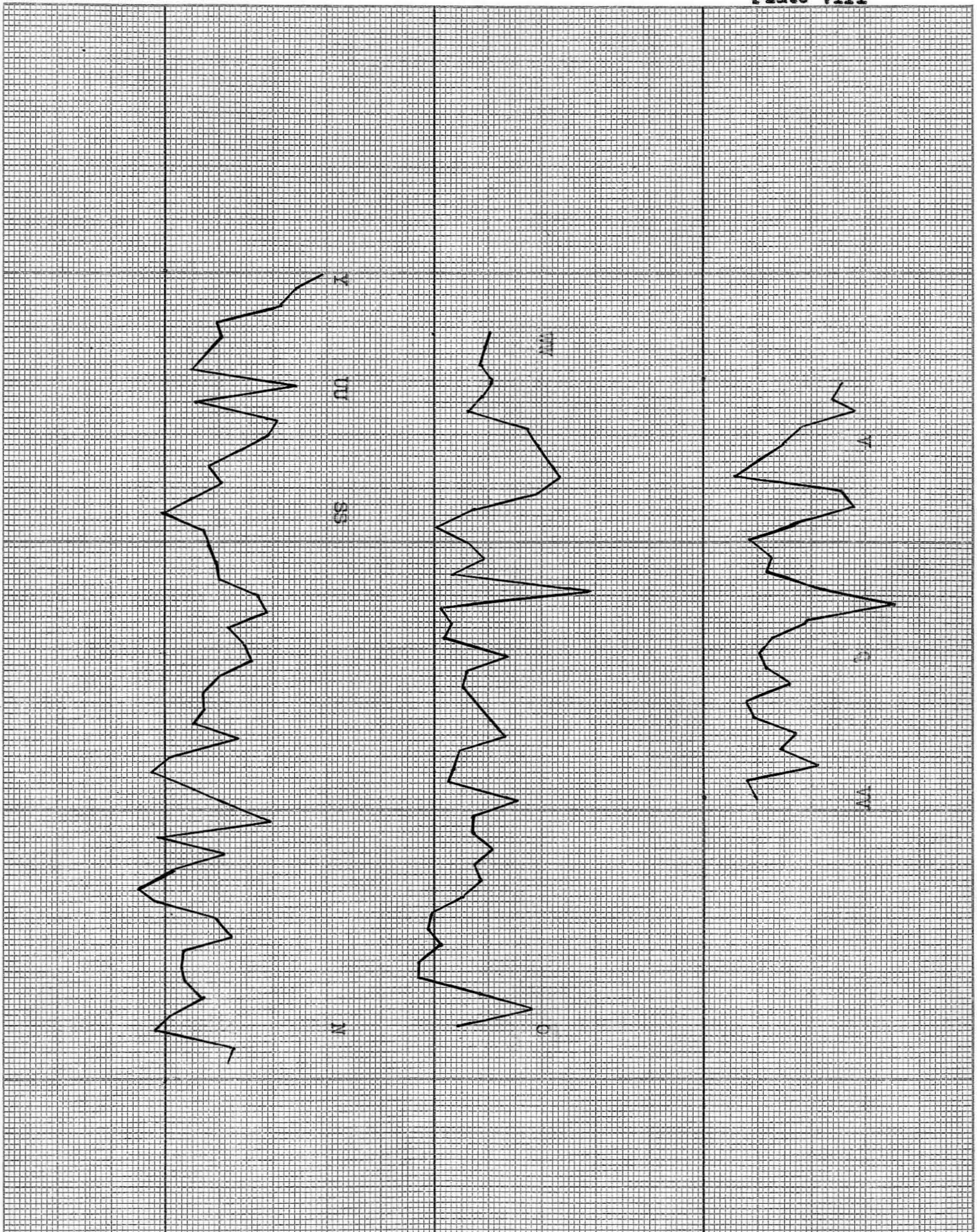

Plate IX