APPENDIX 7-41

MINERALOGY OF CRANDALL CANYON MINE OVERBURDEN

MINERALOGY OF THE CRANDALL CANYON MINE OVERBURDEN, IMPLICATIONS FOR HEALING OF FRACTURES RESULTING FROM RETREAT MINING

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Emery County, Utah

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1.0 X-Ray Diffraction Analysis Results

MINERALOGY OF THE CRANDALL CANYON MINE OVERBURDEN, IMPLICATIONS FOR HEALING OF FRACTURES RESULTING FROM RETREAT MINING

1.0 INTRODUCTION

The mineralogy of Genwal Coal Company Incorporated's Crandall Canyon Mine overburden was investigated to determine if fractures that result from retreat mining will be naturally self-healing. Self-healing fractures are those that close naturally following retreat mining. Fracture-healing principally occurs as a result of (1) clay migration and swelling, (2) mineralization along fracture planes, and/or (3) physical closure of fractures. Fractures that are created following retreat mining may initially allow water to escape from perched aquifers intersected by fracture planes. However, upon fracture-healing, water is no longer permitted to travel along the fracture and escape from the perched aquifer. In comparison to healing of fractures by mineralization, sealing of fractures by clay migration/swelling and physical movement of fracture planes occur relatively fast.

The importance of determining if fracture-healing can occur is significant due to potential affects on perched aquifers of permanently open fractures. The most extreme detrimental effect is draining of laterally continuous aquifers, causing seeps and springs to run dry, thereby disrupting stock animal and wildlife water supplies. The consequences of fracturing into and draining of water from local, laterally discontinuous aquifers are considered to be much less than permanent disruption of regional aquifers, since laterally discontinuous aquifers are generally incapable of supplying the volumes of water to the surface that the regional aquifers can. Seep and spring studies performed by EarthFax Engineering at the request of Genwal Coal Company, and a hydrologic investigation conducted by Lines (1985), indicate the aquifers overlying the Hiawatha Coal seam are perched aquifers with limited lateral extent. Drilling and monitoring well

data in the Genwal Mine area indicate the regional Blackhawk-Starpoint aquifer of Lines (1985) underlies the Hiawatha Coal, and hence will not be affected by fracturing of the overburden during retreat mining.

This report is divided into seven sections, including this introduction. Section 2 contains a summary of the methodology used to determine the presence of factors that suggest fracture-healing will occur. Sections 3 and 4 present findings indicating that fracture-healing can occur by the processes of clay migration/swelling and mineralization, respectively. Section 5 presents a review of a U.S.F.S. study conducted at the SUFCo mine, where the physical closure rates of subsidence fractures are reported. Section 6 summarizes the findings of this investigation, and assess the probability of the occurrence of fracture-healing of the Crandall Canyon Mine overburden. And finally, references are listed in Section 7.

2.0 METHODOLOGY

To identify the specific mineralogy of the Crandall Canyon Mine overburden, x-ray diffraction (XRD) and thin section petrographic analyses were conducted on shale and siltstone obtained from exploratory drill hole cores that encountered the Blackhawk, Castlegate, and Price River Formations. XRD analyses of each sample consisted of the following four tests:

1. Air-dry bulk sample
   Scan range from 10° to 65° 2-Theta
   Speed = 2° 2-Theta/minute,

2. Air-dry clay mineral identification
   Scan range from 2° to 10° 2-Theta
   Speed = 1° 2-Theta/minute,

3. Vapor glycolazation - clay mineral characterization
   Scan range from 2° to 10° 2-Theta
   Speed = 1° 2-Theta/minute, and

4. Quartz standard and repeats of off-scale peaks.

XRD analyses were conducted on 12 samples (6 from the Blackhawk, 3 from the Castlegate, and 3 from the Price River Formation). Mining in the Crandall Canyon Mine takes place in the Hiawatha Coal seam, which lies at the base of the Blackhawk Formation. The Castlegate Formation overlies the Blackhawk, and the Price River Formation overlies the Castlegate. A larger number of samples were collected and analyzed from the Blackhawk than the Castlegate and Price River Formations, since the largest degree of fracture development will occur in the Blackhawk Formation. Mineral amounts were measured by weight percent.

Thin-sections of these 12 samples were prepared and analyzed with a petrographic microscope under both plane- and crossed-polarized light.

Petrographic analyses were conducted to document clay distribution, thereby enabling assessment of clay distribution affects on fracture healing.

To assess the likelihood that mineralization along subsidence fracture planes will occur, the following were analyzed:

1. water chemistry of groundwaters present in the mine overburden,
2. presence of mineral phases that could precipitate along fracture planes and heal fractures, and
3. chemical conditions controlling dissolution and precipitation of these mineral phases.

Water chemistry of mine overburden groundwater was analyzed by investigating laboratory and field analytical results of water samples collected from springs in the area. Spring samples were collected at points of spring issuance. Knowledge of mineral phases present in strata of the mine overburden capable of dissolution and precipitation, were obtained through investigation of mine overburden core samples. Chemical conditions controlling dissolution and precipitation of overburden mineral phases were assessed from a review of current aqueous geochemistry literature.

To determine if, and to what degree, physical movement of fracture planes would result in fracture-healing, a Fish Lake National Forest investigation of tension crack self-healing phenomenon was reviewed.

3.0 POTENTIAL FOR FRACTURE HEALING FROM CLAY MIGRATION

One of the principal means of fracture healing in the Crandall Canyon Mine overburden is via clay migration. Migration of clay minerals along subsidence fractures is generally believed to result in fracture healing at distances greater than 9 mine widths above the mined interval (Crandall Canyon Mine M&RP, Chapter 12). Clay minerals are principally responsible for healing of subsidence fractures. The clay minerals with the greatest capacity for healing fractures are the swelling clays, principally the smectite (bentonite) clays. Smectite clays possess swelling properties due to their high cation-exchange capacities (Bates and Jackson, 1980). This swelling property enables the smectite clays to seal fractures. Smectite is a standard water plugging agent used in groundwater monitoring well completions due to its water sealing property.

XRD analyses of samples collected from the Crandall Canyon Mine overburden reveal the presence of significant quantities of smectitic clays. Table 1 contains a summary of the XRD data, while Appendix 1 contains copies of the raw XRD data. Smectitic clay varieties found include mixed-layer smectite-chlorite and smectite-illite. Pure smectite was found in one Price River Formation sample. Smectitic clay content of the Blackhawk Formation averages 24.3% (range: 3% to 34%). Smectitic clay content of the Castlegate Formation siltstones and shales average 19% (range: 7% to 29%). Price River smectitic clay content averages 14.7% (range: 4% to 29%).

XRD analyses (Table 1) also reveal the presence of additional clay minerals that would aid in fracture-healing, (most noticeably, kaolin and illite). Blackhawk Formation kaolin and illite quantities average 5.5% and 2.1%, respectively. Castlegate Formation kaolin and illite quantities average 5% and 0.6%, respectively. The quantities of Price River kaolin and illite average 5.6%

MINERALOGY OF CRANDALL CANYON MINE OVERBURDEN

MINERALOGY, APPROX. WT.% ☒ (or) RELATIVE ABUNDANCE ☐

SAMPLE NO.	QUARTZ	PLAGIOCLASE	K-FELDSPAR	CALCITE	SIDERITE	DOLOMITE	PYRITE	KAOLIN	MIXED-LAYER CHLORITE-SMECT.	ILLITE	MIXED-LAYER ILLITE-SMECT.	SMECTITE	TALC	BELOW DET. LIMIT	% SMECT. IN MIXED-LAYER
BLACKHAWK FM.															
DH-3 436-436.3	45	TR	2				4	6	3	3	27			10	25
DH-4 64.6-64.9	50	1	4			5	1	6	4	2	27				40
DH-5 809-809.5	26	1	3		2	26	1	6	4	6	25				30
DH-6 645-645.5	42	1	4			11		6	3	2	31				40
DH-7 1470.3-1470.5	37	TR	TR		14	42		4		TR	3				
DH-7 1480-1480.4	27		1		5	32	2	5			19			9	20
CASTLEGATE FM.															
DH-5 553-553.4	56	TR	6				3	5	3		26		TR		30
DH-6 556.5-557	52	1	4		1	1	13	1	4	5	2	16			30
DH-7 766-766.3	72		7		TR		1	1	6	2	TR	5		6	
PRICE RIVER FM.															
DH-5 384.3-384.6	72		6			TR	TR	1	5	3	2	8		3	
DH-6 119.5-119.6	34		6			TR	6	1	8	6	3	9	14	13	
DH-7 600-600.3	48		3		7		31		4		3	4			

MM = PREDOMINANT M = MAJOR m = MINOR Tr = TRACE ? = TENTATIVE IDENTIFICATION

SUMMARY OF X-RAY DIFFRACTION ANALYSIS

UNIVERSITY OF UTAH RESEARCH INSTITUTE , EARTH SCIENCE LABORATORY

LE 1: SUMMARY OF X-RAY DIFFRACTION ANALYSIS

and 2.6%, respectively. Although these clay minerals do not posess the swelling characteristics of smectite, their presence would create a physical barrier to the movement of water within that fracture.

Petrographic microscope analyses of the Crandall Canyon Mine overburden (in addition to the XRD analyses) also reveal the presence of swelling clays. Representative photomicrographs of Blackhawk Formation shales appear in Figures 1 and 2. Figures 3 and 4 contain Castlegate Formation photomicrographs, with Price River Formation photomicrographs appearing in Figures 5 and 6. The white or light grey patches in the plane-polarized light photos (figures 1, 3, and 5) are silt-size quartz grains. Quartz grains are floating in a fine-grained matrix composed of the clay minerals (smectite, mixed-layer chlorite-smectite, mixed-layer illite-smectite, kaolin, and illite). The yellow color is due to the presence of illite. The linear black or dark-brown patches are relatively thick accumulations of these clay minerals. The long thin black linear feature present in the Castlegate Formation pictures (Figures 3 and 4) is a fracture sealed (closed) by compaction of the clay minerals.

The crossed-polarized light microphotographs (Figures 2, 4, and 6) also reveal the presence of the quartz grains. Here the quartz grains appear as white and opaque black patches. The bulk of the samples are composed of a clay mineral matrix, which appears as yellow (illite) and the small dark granular speckles. The swelling clay minerals occur as a well-mixed matrix, supporting the silt-size quartz grains rather than as a cement encircling the quartz grains. As a result, the swelling clays can be easy transported by moving waters along the fracture planes.

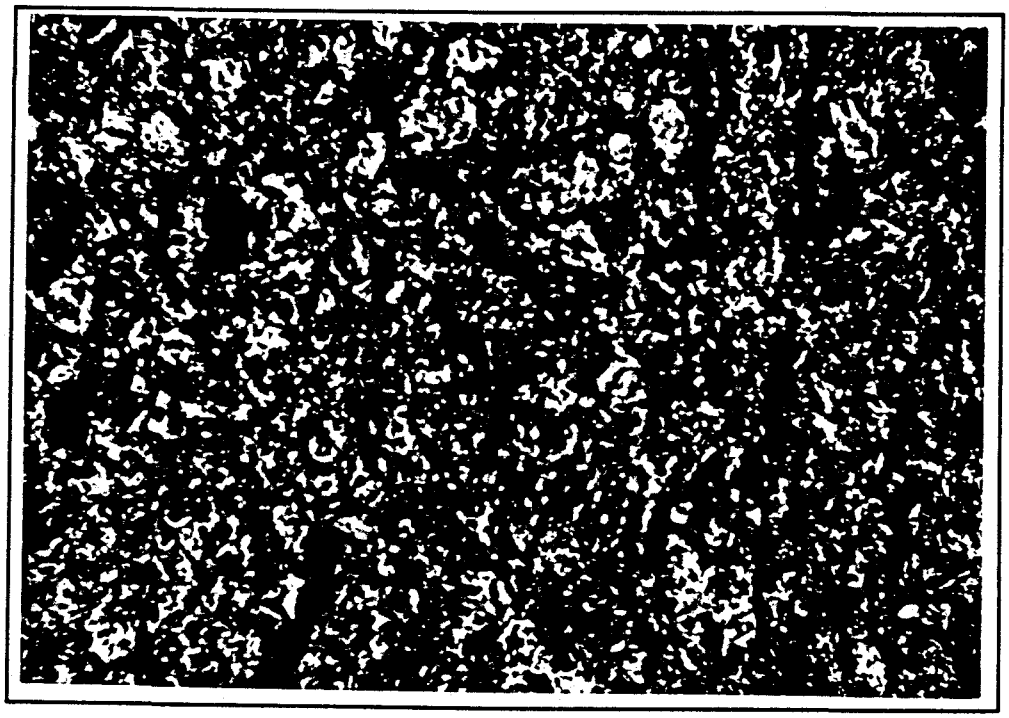

Figure 1 Blackhawk Formation shale photomicrograph. Drill hole #6, depth 645 to 645.5 feet. Plane-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the greenish-grey fine-grained matrix. Dark linear patches are compressed clay minerals. White and black grains are silt-size quartz grains.

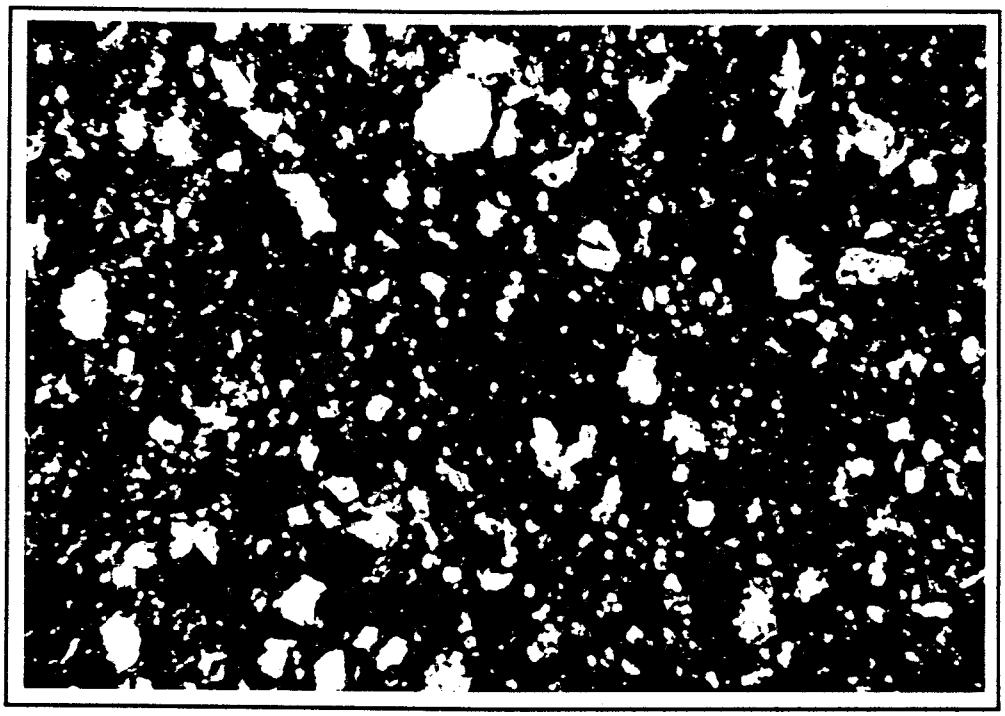

Figure 2 Blackhawk Formation shale photomicrograph. Drill hole #6, depth 645 to 645.5 feet. Crossed-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the yellowish, green, and black fine-grained matrix. Yellow color of clay minerals is due to illite mineral presence. White and black grains are silt-size quartz grains surrounded by clay matrix.

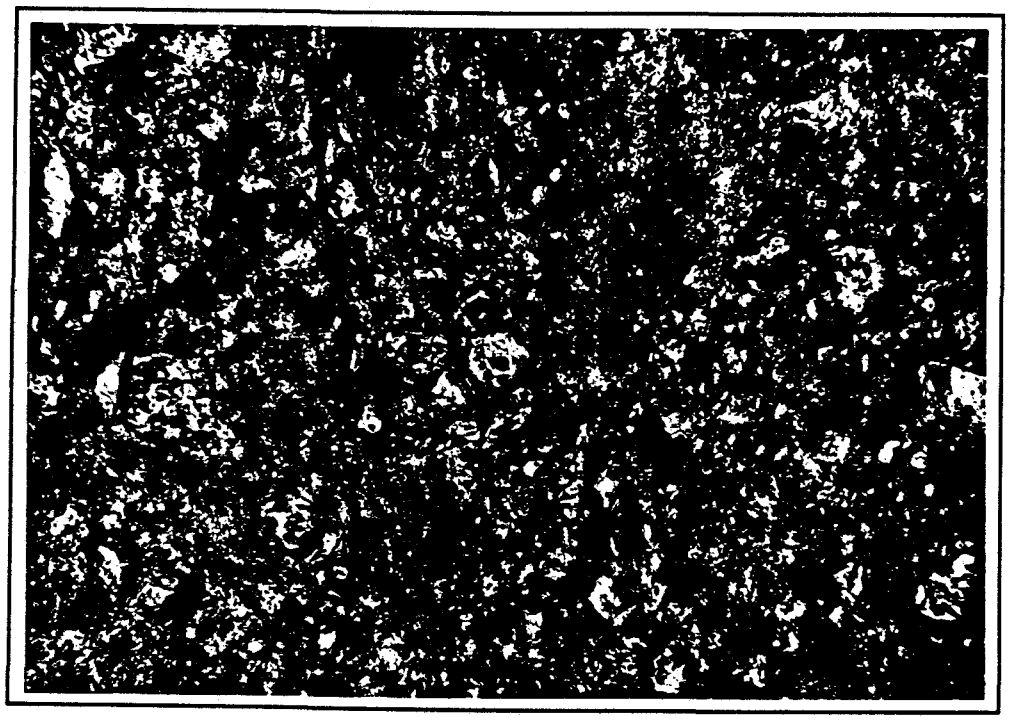

Figure 3 Castlegate Formation shale photomicrograph. Drill hole #6, depth 556.5 to 557 feet. Plane-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the greenish-grey fine-grained matrix. The long thin black linear feature is a fracture sealed with compressed clay minerals. White and black grains are silt-size quartz grains.

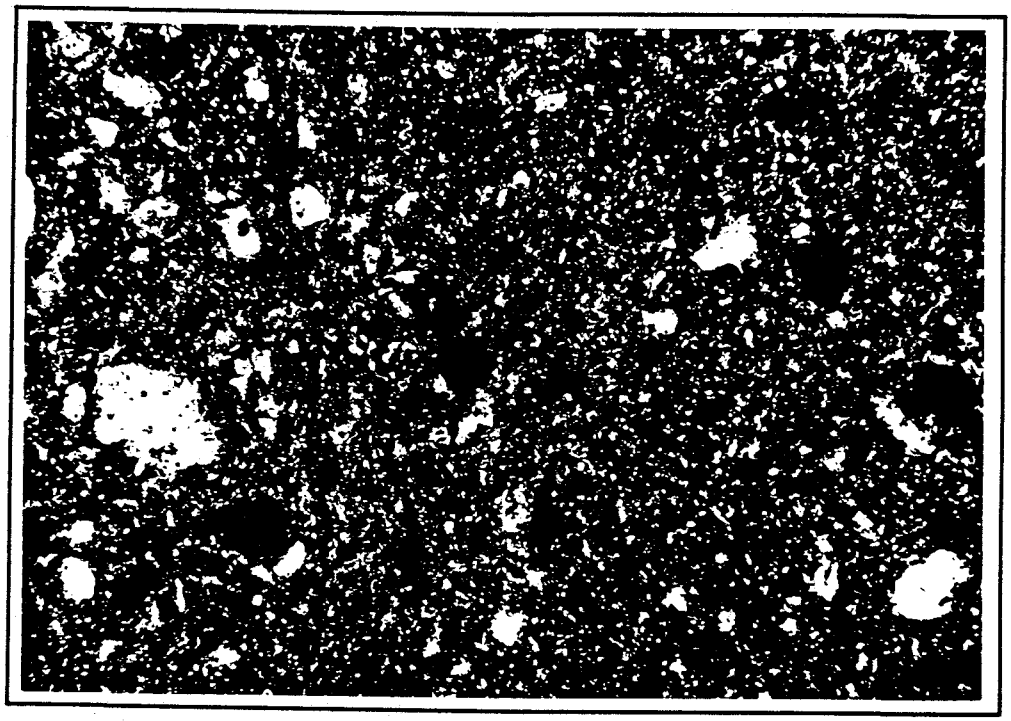

Figure 4 Castlegate Formation shale photomicrograph. Drill hole #6, depth 556.5 to 557 feet. Crossed-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the greenish-yellow fine-grained matrix. The long thin black linear feature is a fracture sealed with compressed clay minerals. White and black grains are silt-size quartz grains.

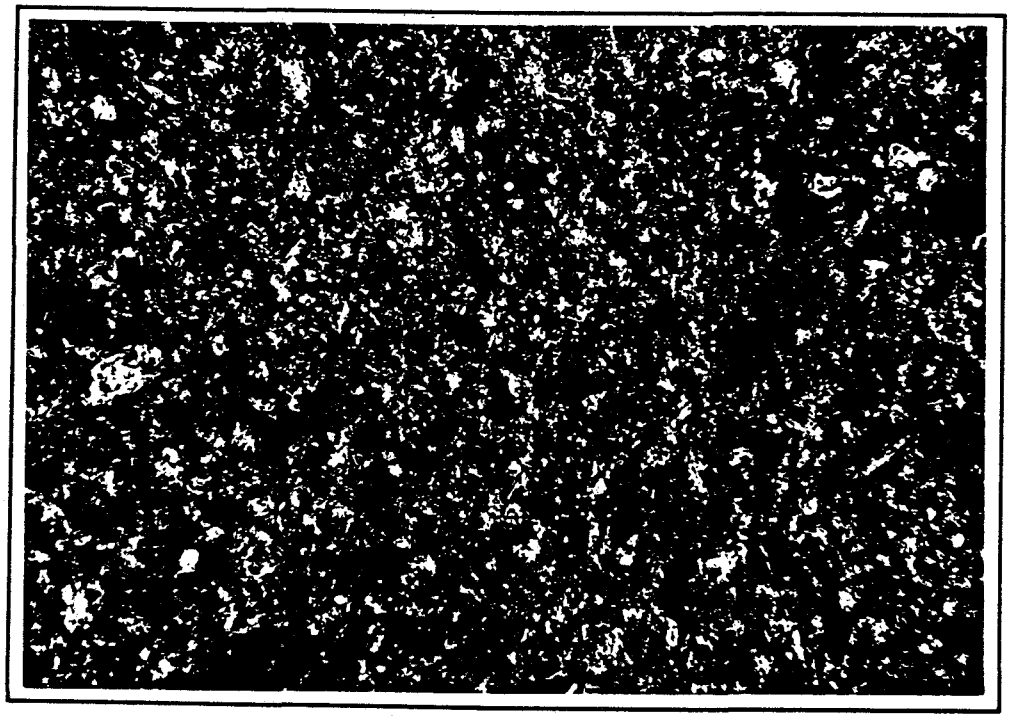

Figure 5 Price River Formation shale photomicrograph. Drill hole #6, depth 119.5 to 119.6 feet. Plane-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (smectite, mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the yellowish-brown fine-grained matrix. White and black grains are pyrite and silt-size quartz grains.

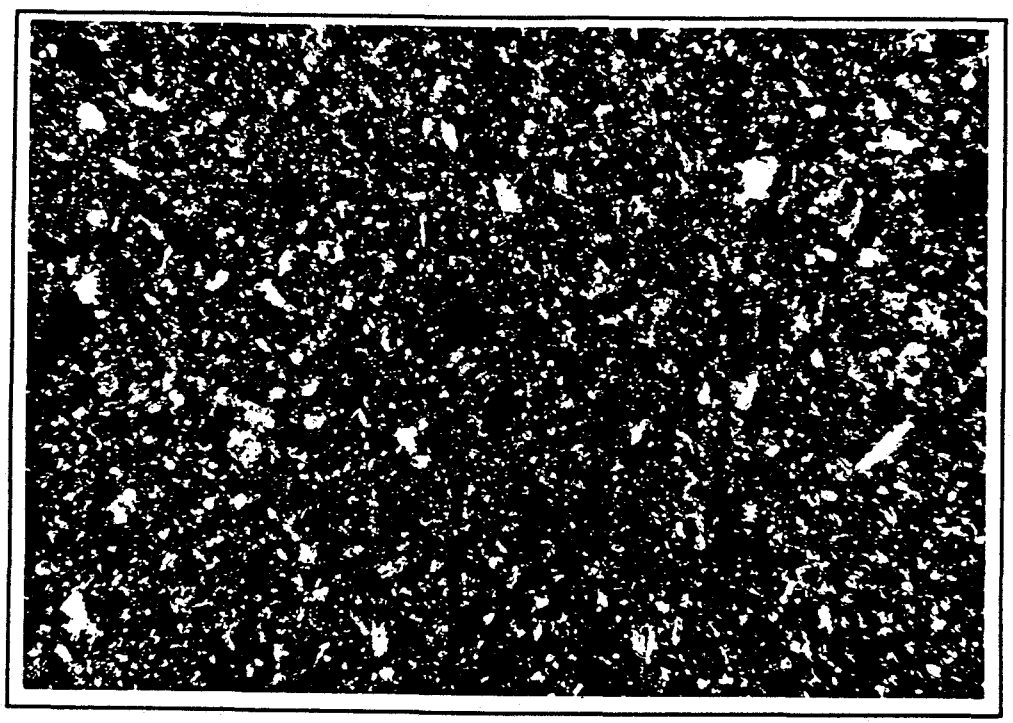

Figure 6 Price River Formation shale photomicrograph. Drill hole #6, depth 119.5 to 119.6 feet. Crossed-polarized light. Magnification: 125x, short axis of photo is 0.8 mm in length. The up-direction is to the right. Clay minerals (smectite, mixed-layer illite-smectite, mixed-layer chlorite-smectite, illite, and kaolin occur as a mixture, and appear as the greenish-yellow fine-grained matrix. White and black grains are pyrite and silt-size quartz grains.

4.0 POTENTIAL FOR FRACTURE HEALING FROM MINERALIZATION

Analyses of groundwater chemistry, the presence of mineral phases that could precipitate along fracture planes, and chemical conditions controlling precipitation of these mineral phases, indicate that mineralization of fracture planes produced by subsidence mining will occur. Although this process will occur slower than fracture healing via clay migration, mineralization will contribute to fracture healing. The primary fracture healing mineral is calcite ($CaCO_3$).

Analyses of cores indicate calcite is the dominant cementing agent present in sandstones that are contained in the overburden of the Crandall Canyon Mine. Calcite is also present in the siltstones and, to a lesser extent, the shales in the overburden (Table 1). This calcite is present as small crystals occluding a portion of the pore network. Water chemistry analyses of overburden waters from 1985 through 1991, indicate pH values range from about 7.5 to about 8.3. The following equilibration equation defines the reaction between dissolved calcite, bicarbonate, and free OH^- (Krauskopf, 1979).

$$Ca^{2+} + HCO_3^- + OH^- = CaCO_3 + H_2O$$

This reaction results in precipitation of calcite. Ph values above 7.0 indicate a preponderance of OH^--ions (Walton, 1970). This abundance of OH^--ions drives the above equation to the right, resulting in precipitation of calcite. The small crystal habit of the calcite cement enables calcite to be readily dissolved, thereby enriching the groundwater with calcite (Krauskopf, 1979). As evidence that calcite is being precipitated in the area, tufa deposits are present at selected spring locations in the Hiawatha Coal seam overburden.

5.0 SELF-HEALING OF TENSION FRACTURES

Retreat mining results in both tension and compression fractures (Dunrud, 1986). Due to the larger size of their openings, tension fractures have the capability of being more disruptive to the overlying hydrologic system than compressional fractures. Compressional fractures are held closed very tightly by compressional forces, and thus do not provide as large a conduit for groundwater flow as tension fractures. Furthermore, compressional fractures are commonly filled with gouge, which results in further sealing of the fracture.

A study performed by the Fish Lake National Forest investigated physical self-healing of subsidence tension fractures in the overburden of Coastal States Energy Corporation's SUFCo #1 Mine in Convulsion Canyon, Utah (DeGraff, 1978). Convulsion Canyon is located approximately 40 miles south-southeast of the Crandall Canyon Mine. Both mines lie in the Wasatch Plateau, mine the Hiawatha coal seam of the Upper Cretaceous Blackhawk Formation, and have similar overburden formations and lithologies. According to DeGraff (1978), measured rates of tension fracture closure ranged from less than 1/32 to more than 1/4 inch per week; with an average self-healing rate of greater than 1/16 inch per week. The amount of fracture closure ranged from 13 to 100 percent. Average tension fracture closure is 56 percent. These data indicate that 56 percent of the maximum width of the tension fractures are self-healing.

6.0 SUMMARY

Analyses of Hiawatha Coal seam overburden lithology, groundwater chemistry, and a tension fracture self-healing study results suggest that fractures resulting from retreat mining at the Genwal Coal Company Crandall Canyon Mine will be self-healing. X-ray diffraction analyses reveal the presence of swelling clays in significant quantities. Mixed-layer smectite-illite and smectite-chlorite, as well as pure smectite, are present. These swelling clay minerals will serve to seal subsidence fractures. Kaolin and illite clay minerals are also present, which will aid in fracture-healing. Additionally, water chemistry of the overburden groundwaters indicate that fractures can be sealed via chemical precipitation of calcite. Field observation records of tufa deposits at seeps and springs verify that calcite precipitation is taking place. In addition, a National Forest Service subsidence fracture study in the region indicates that 56 percent of tension fractures resulting from retreat mining are physically self-healing. This physical self-healing occurs without the aid of any clay migration or mineralization along fracture planes. These three phenomena suggest that fractures resulting from retreat mining at the Crandall Canyon Mine are self-healing, and thus do not pose a serious threat to interruption of perched aquifer water flow.

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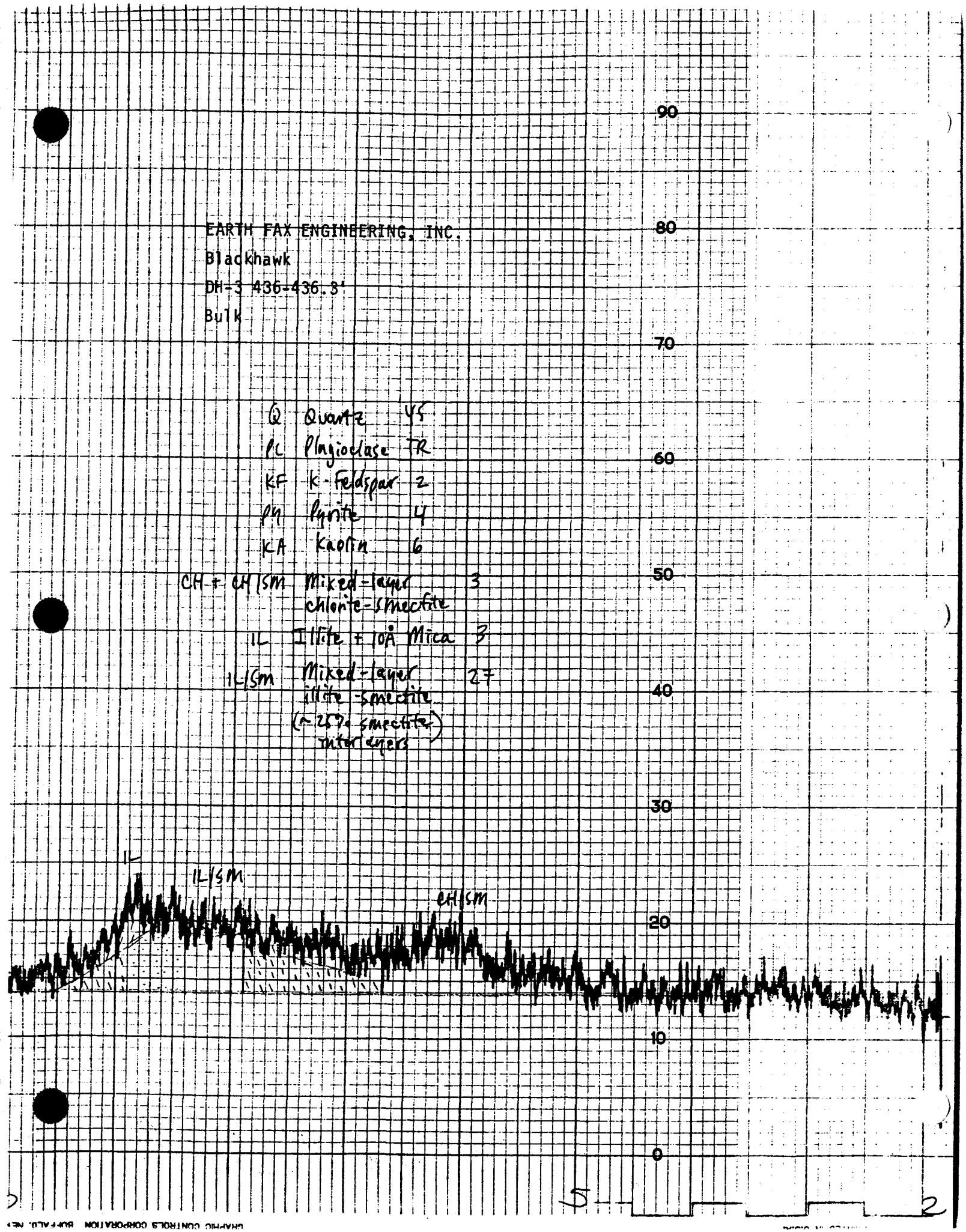
APPENDIX 1

X-RAY DIFFRACTION ANALYSIS RESULTS

EARTH FAX ENGINEERING, INC.
Blackhawk
DH-3 436-436.3'
Bulk

Q	Quartz	VS
PL	Plagioclase	TR
KF	K-Feldspar	2
PY	Pyrite	4
KA	Kaolin	6
CH + CH/SM	Mixed-layer chlorite-smectite	3
IL	Illite + 10Å Mica	3
IL/SM	Mixed-layer illite-smectite (~25% smectite interlayers)	27



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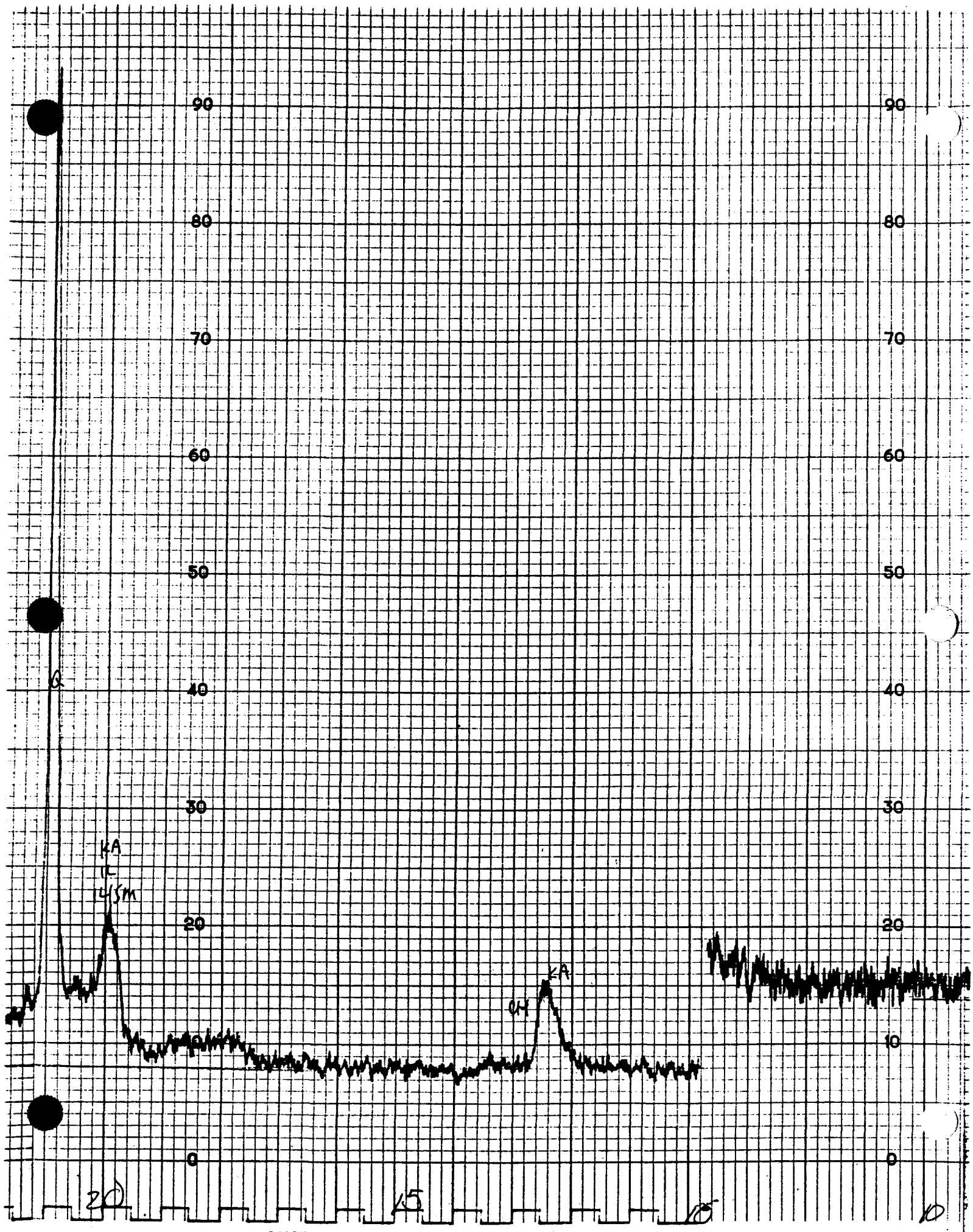
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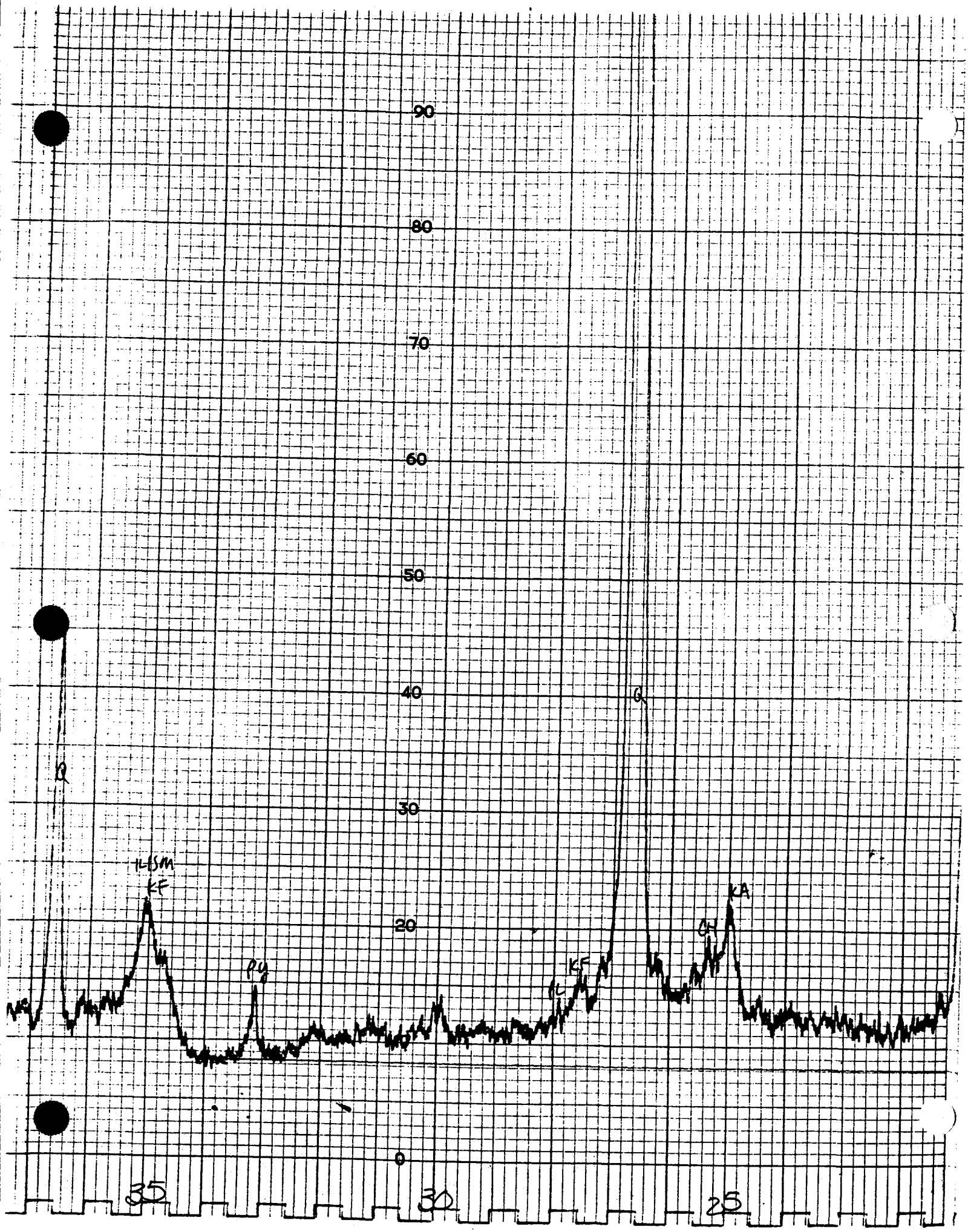

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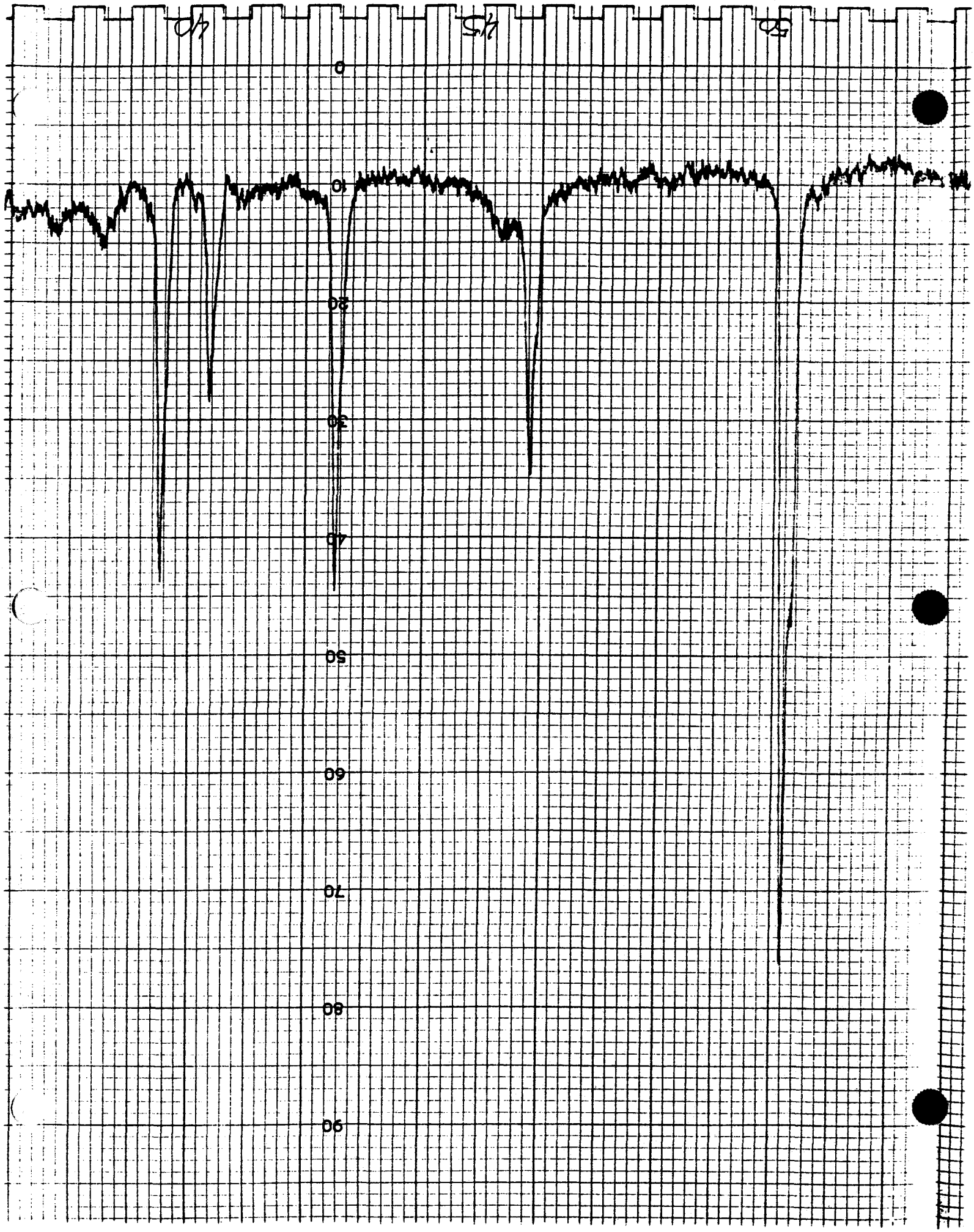

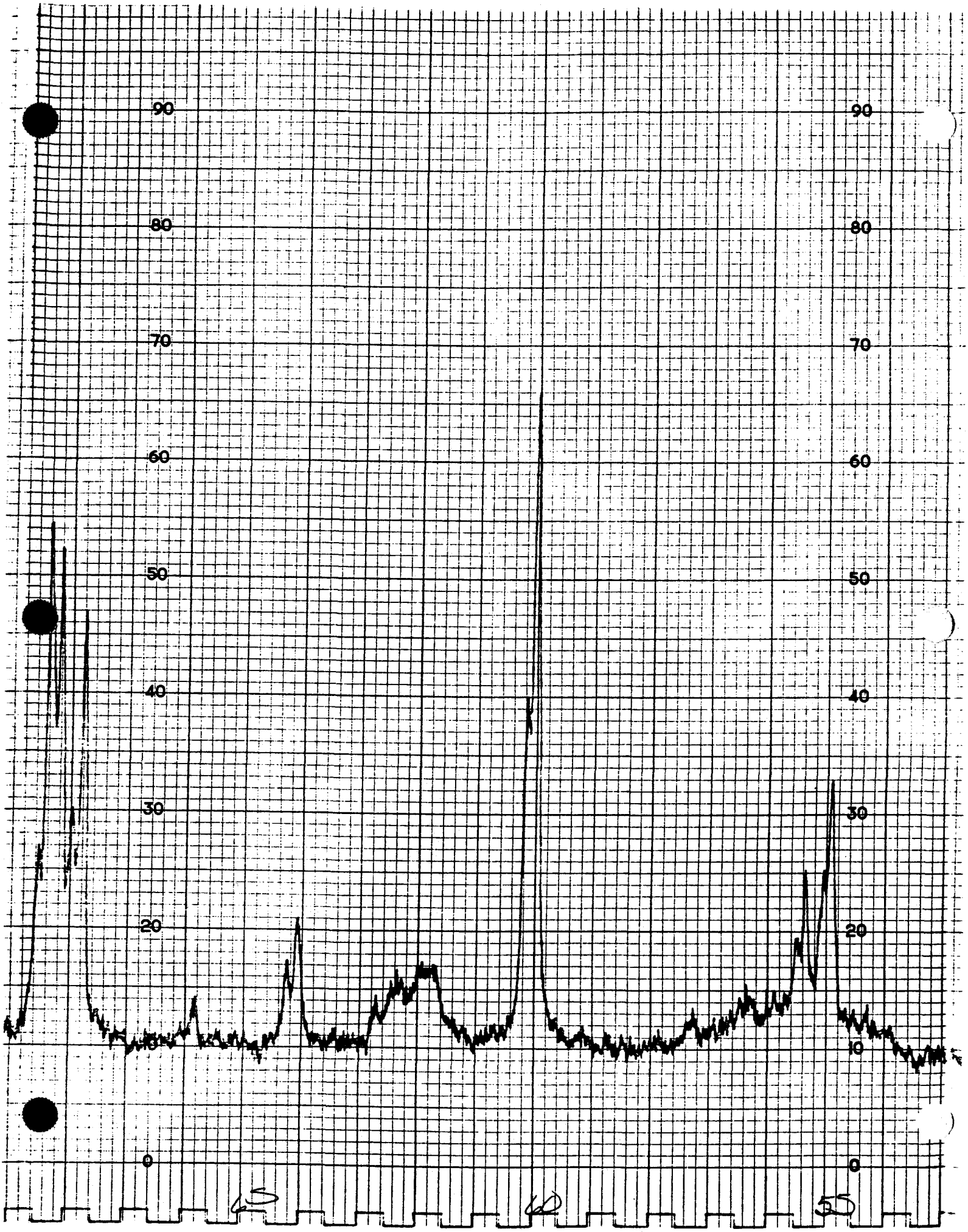

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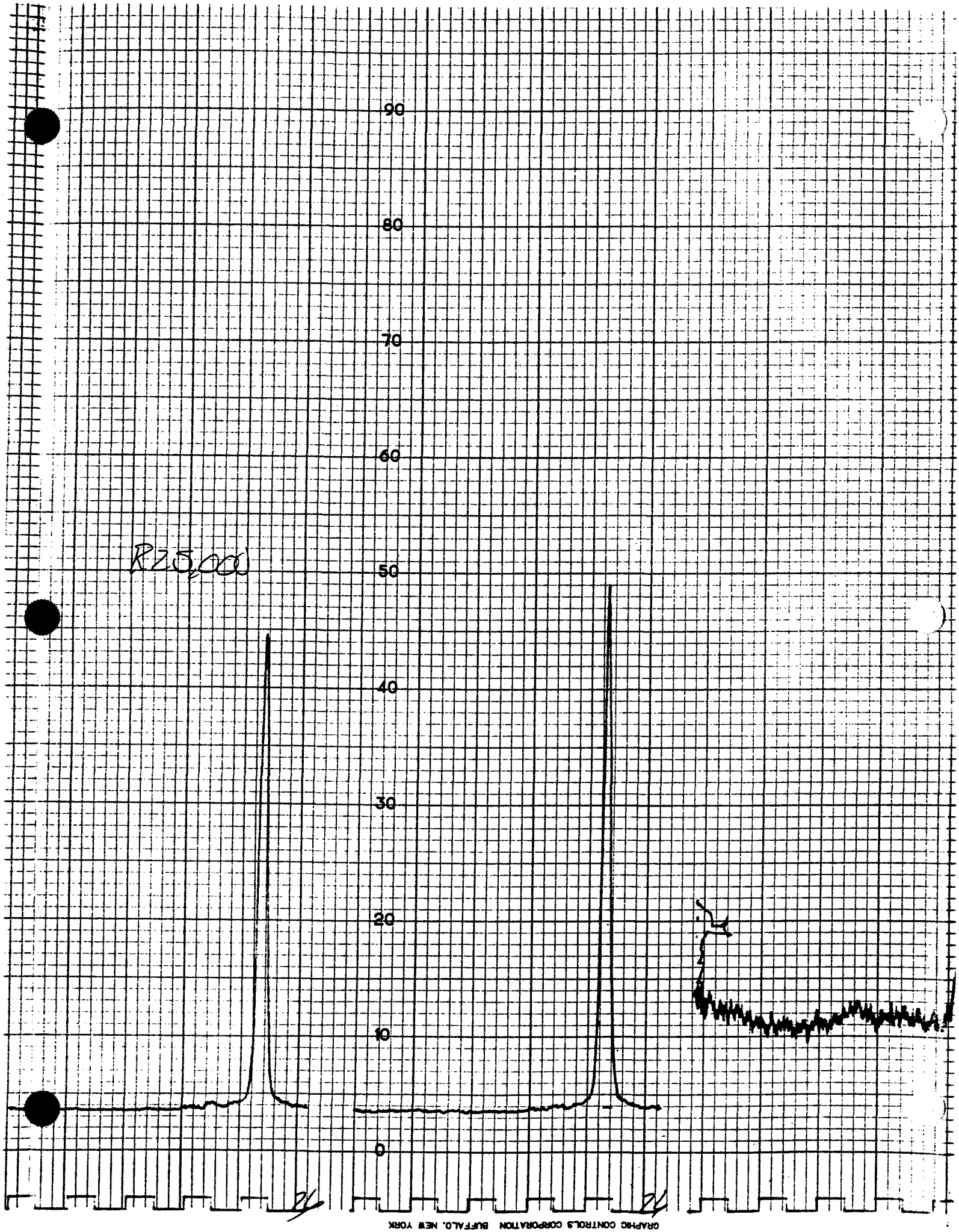

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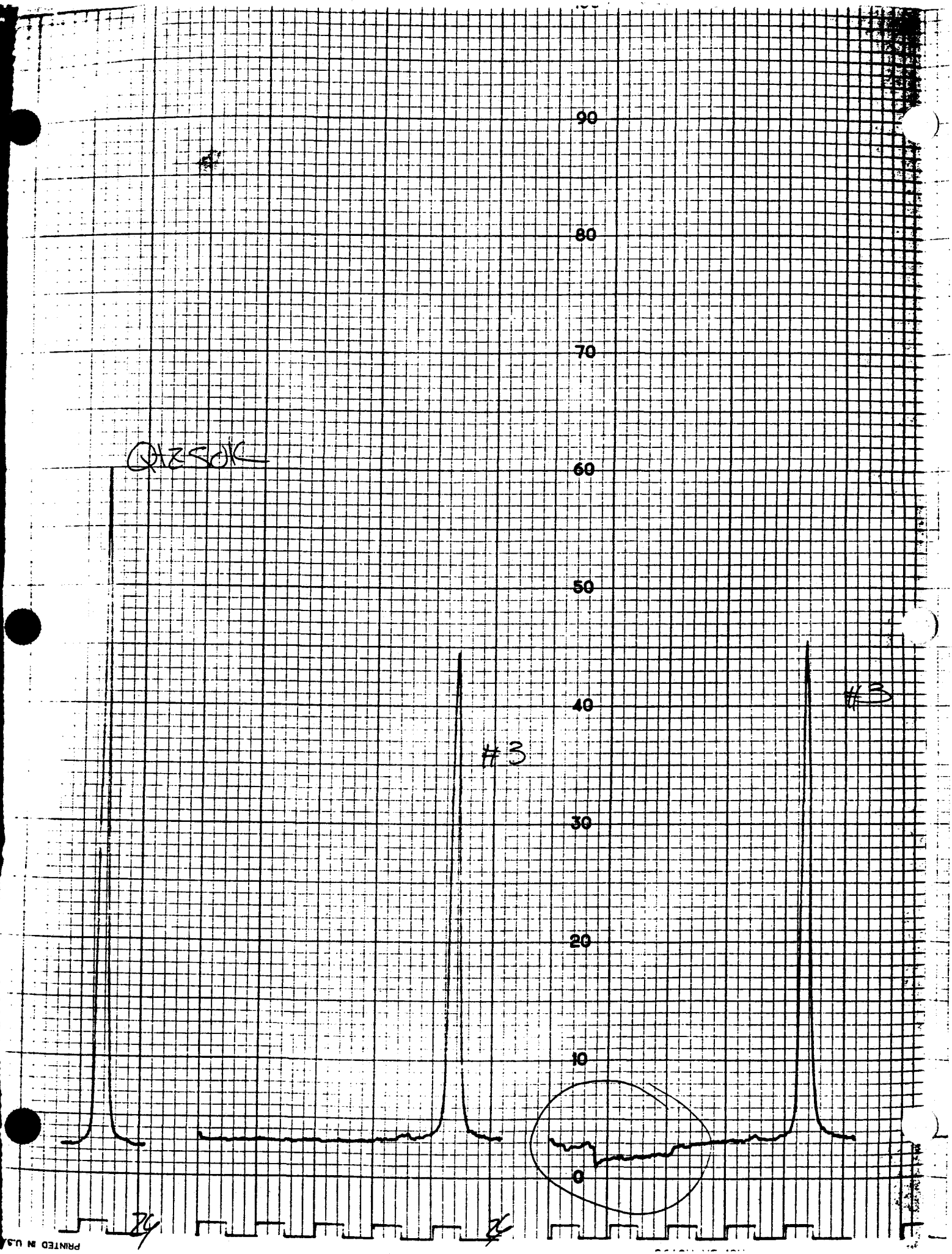
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EARTH FAX ENGINEERING, INC.
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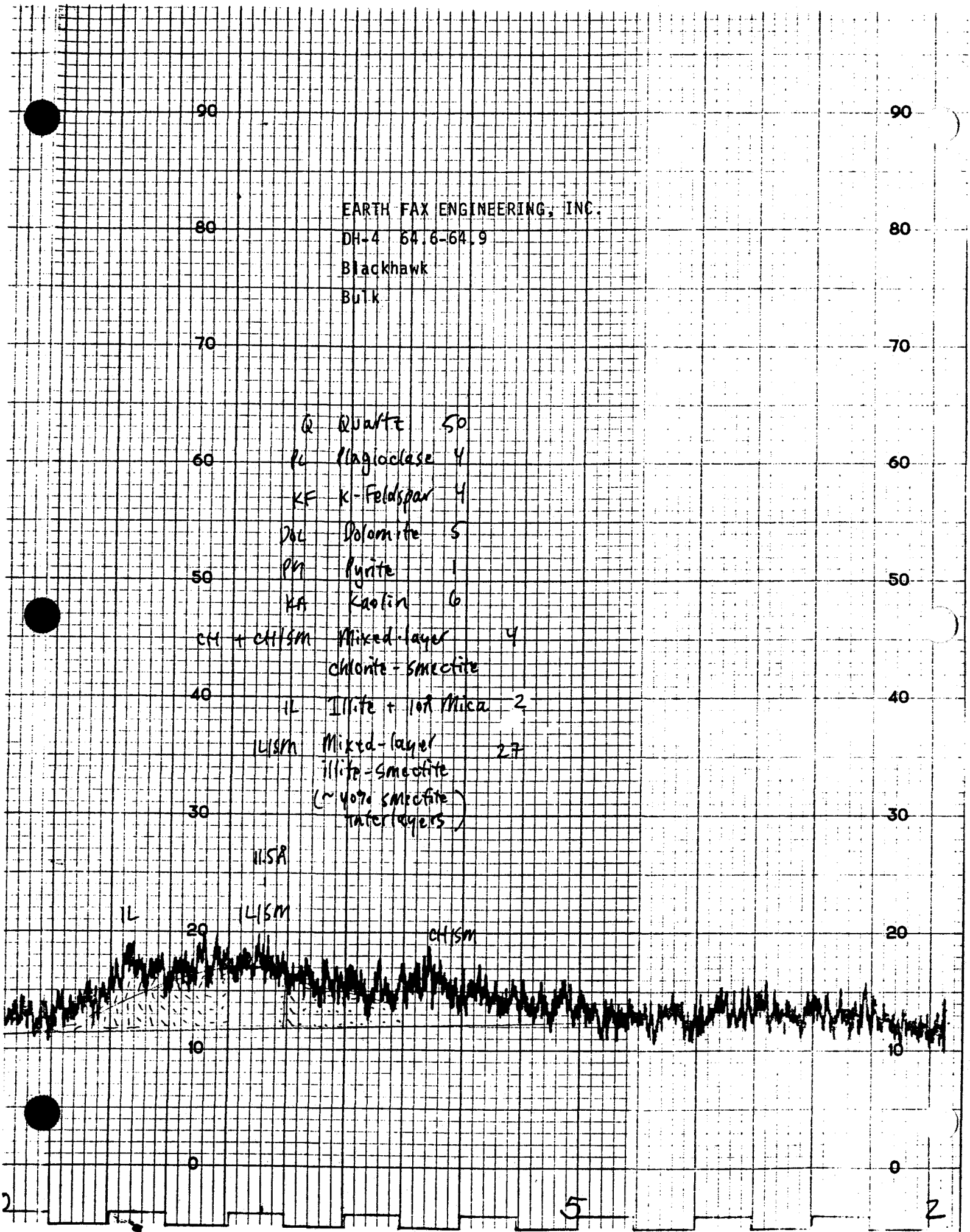
Blackhawk
Bulk

Q	Quartz	50
PL	Plagioclase	4
KF	K-Feldspar	4
DOL	Dolomite	5
PY	Pyrite	1
KA	Kaolin	6
CH + CH/SM	Mixed-layer chlorite-smectite	4
IL	Illite + 10Å Mica	2
IL/SM	Mixed-layer illite-smectite (~40% smectite interlayers)	27



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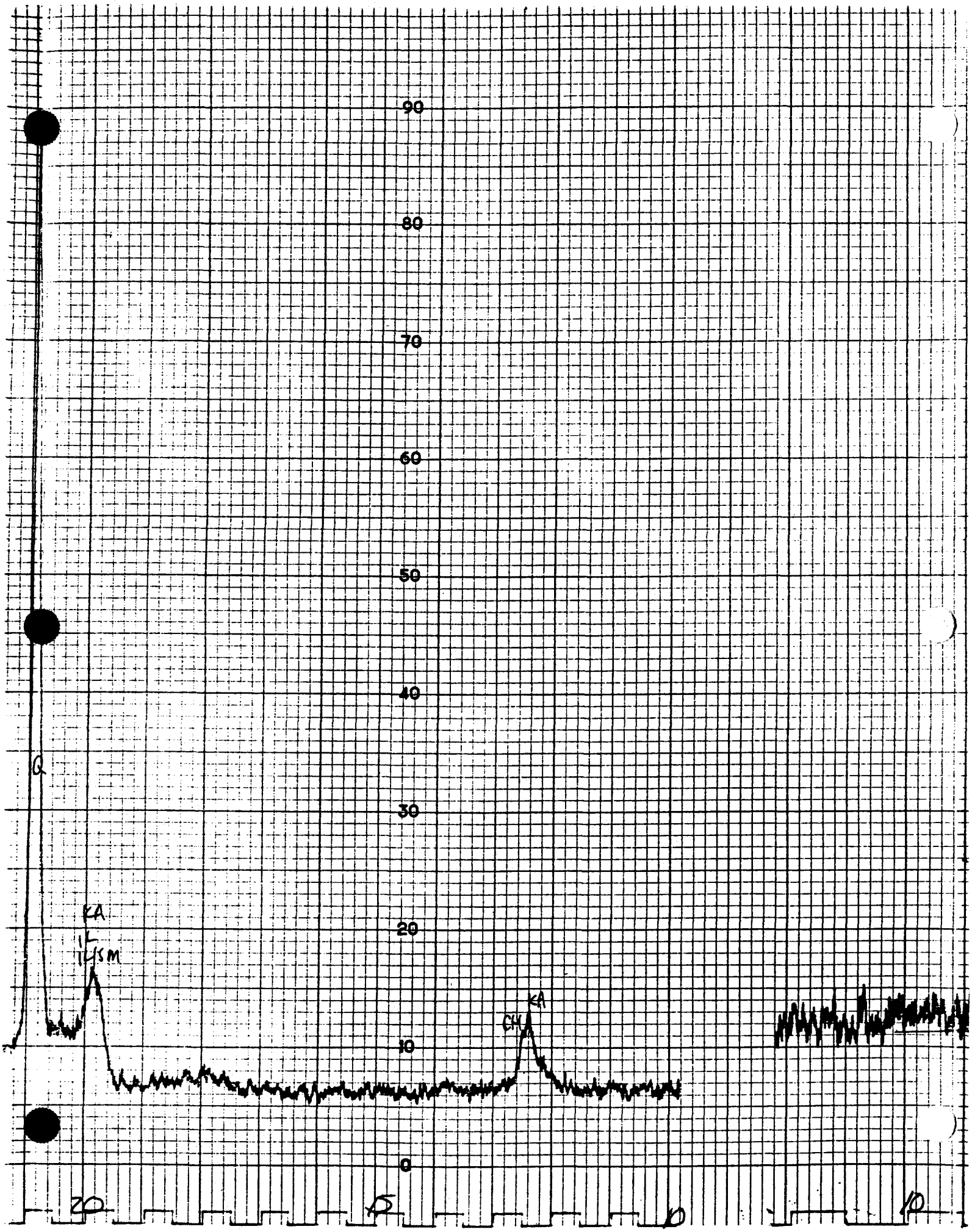

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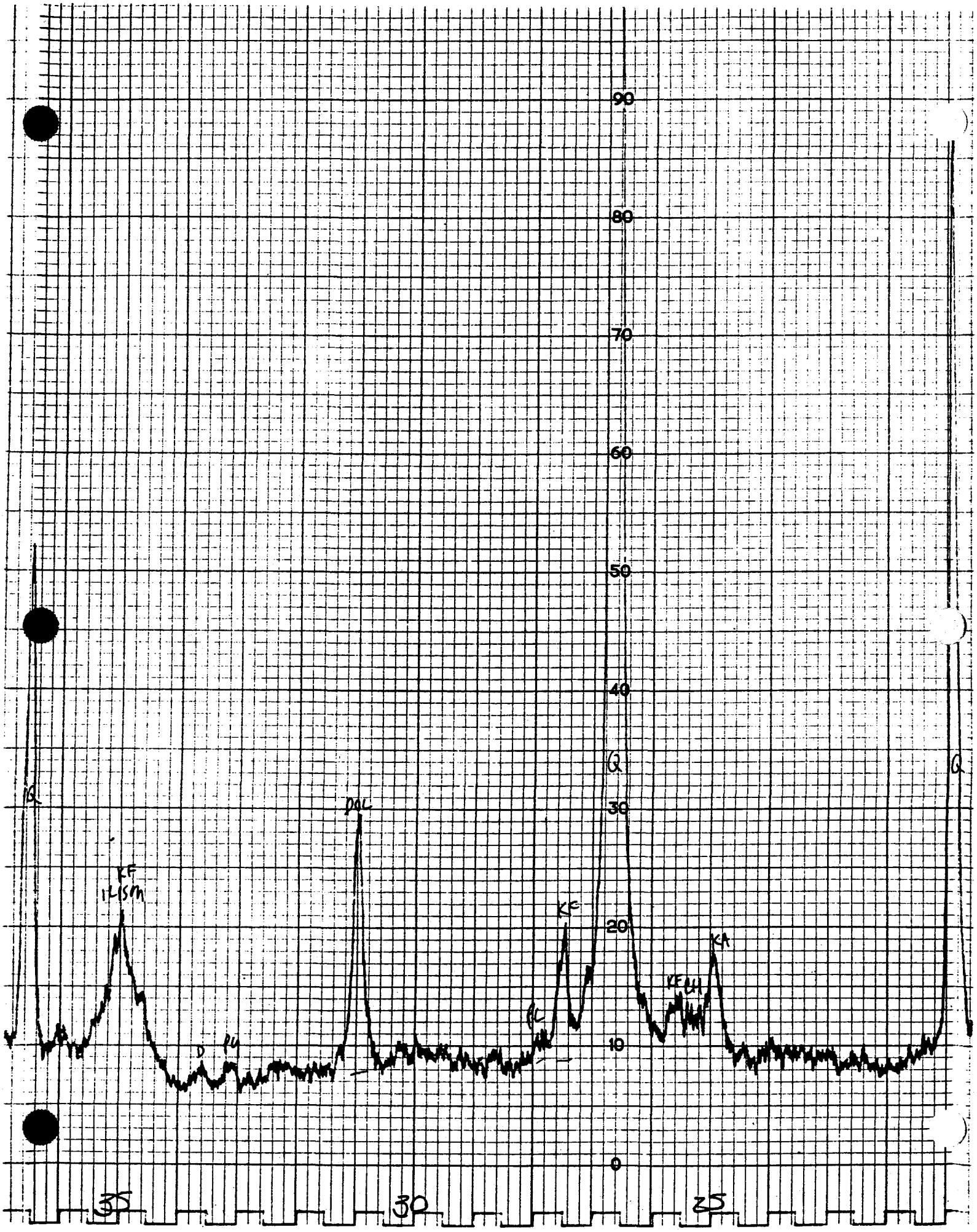

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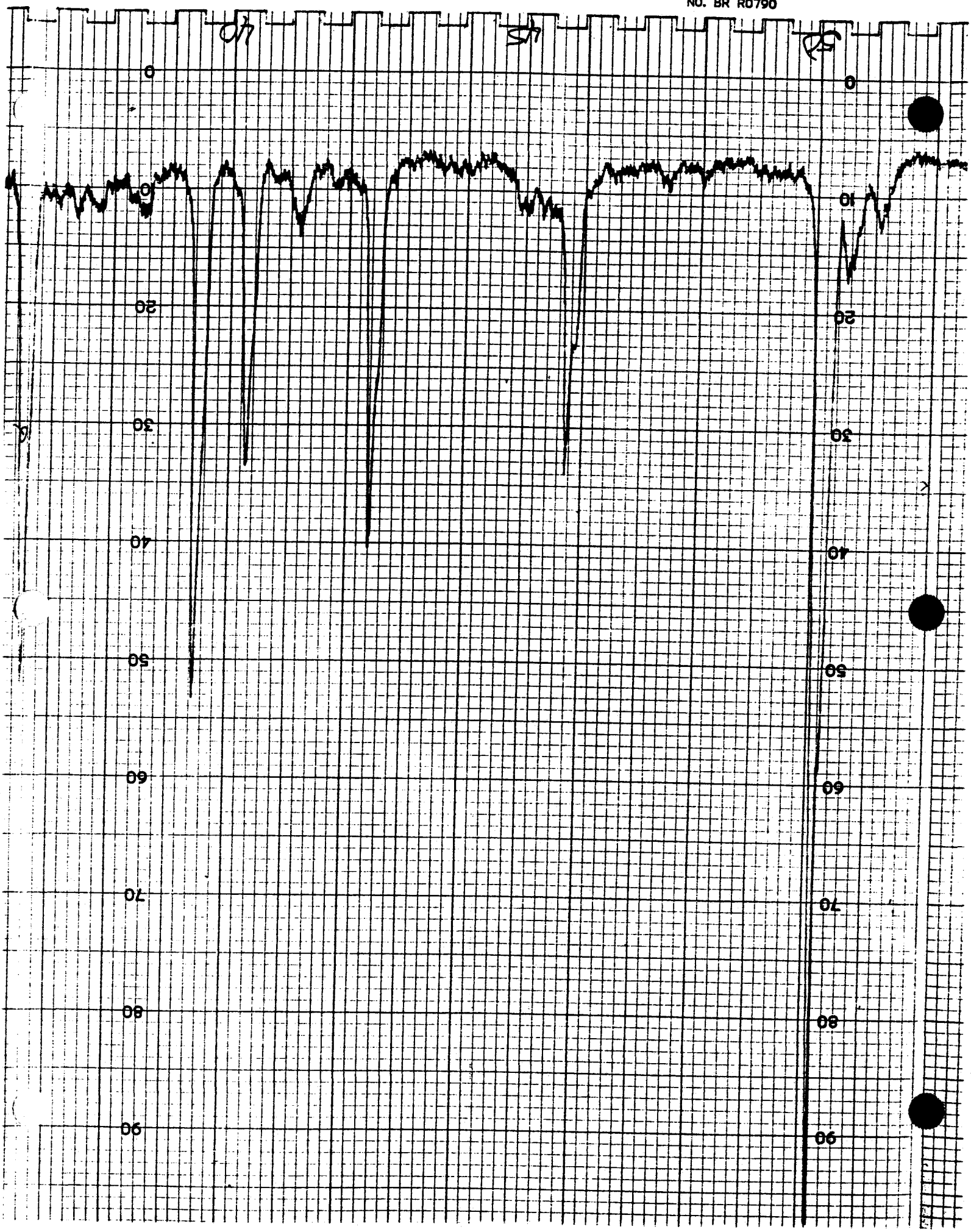
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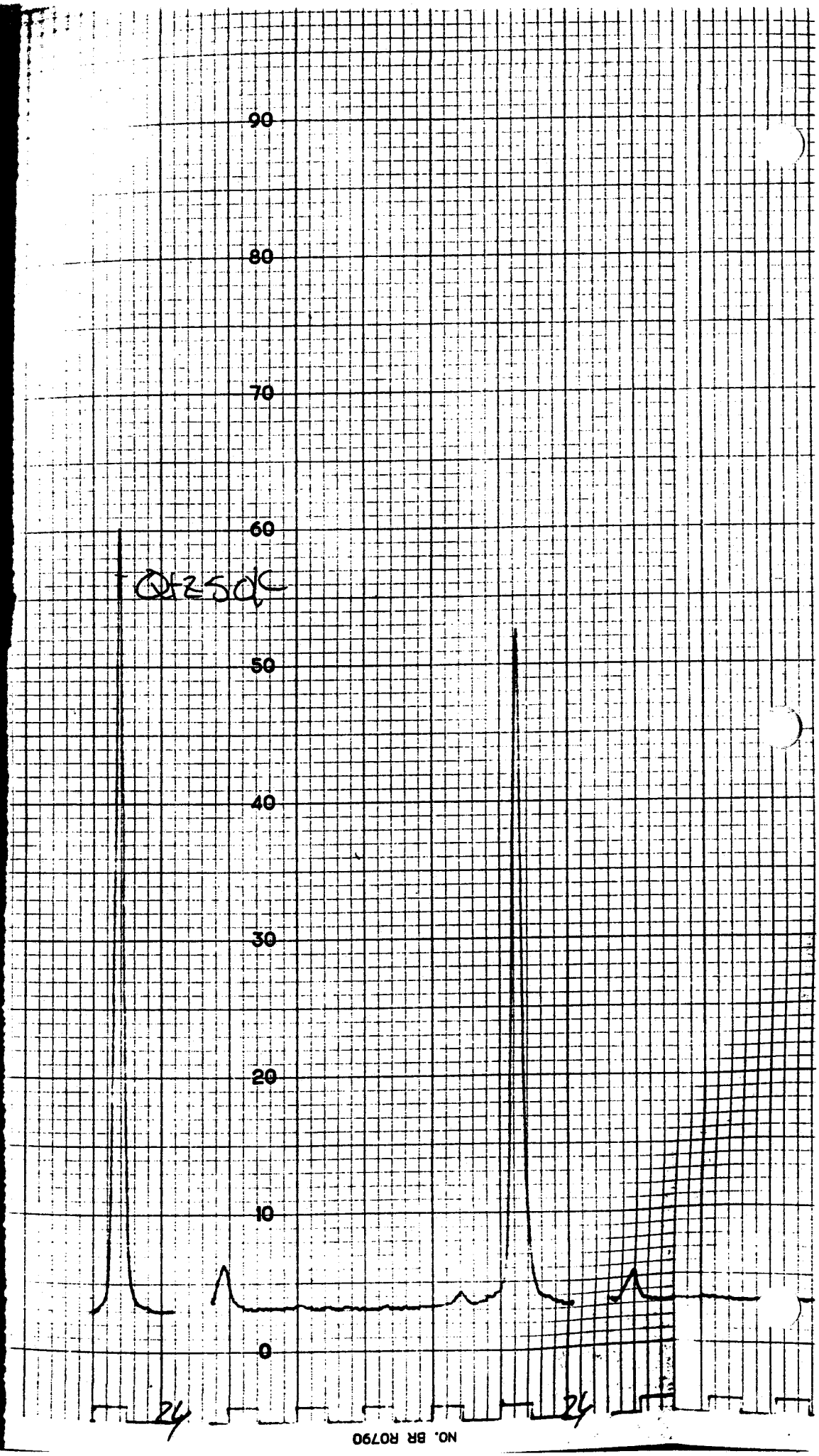
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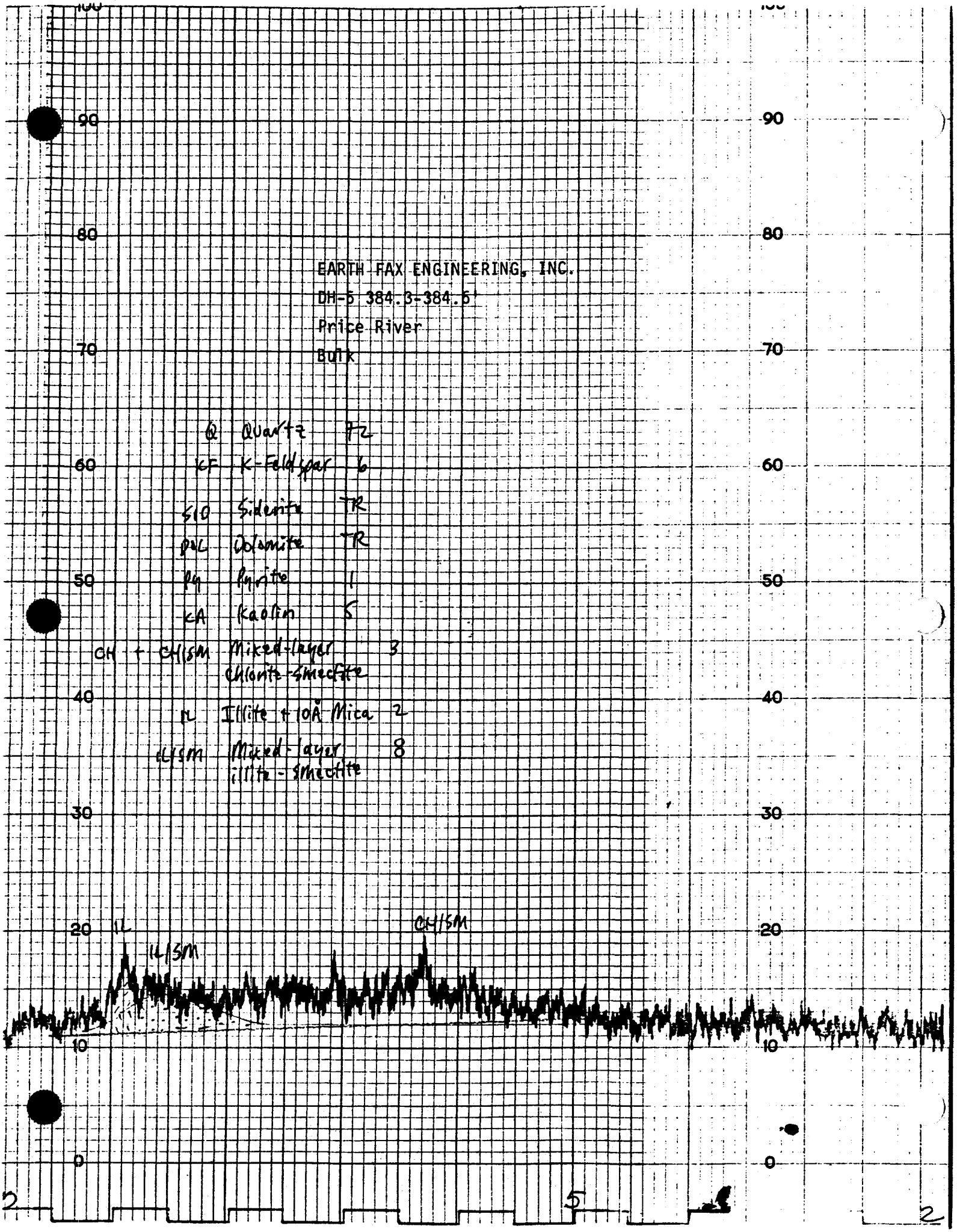
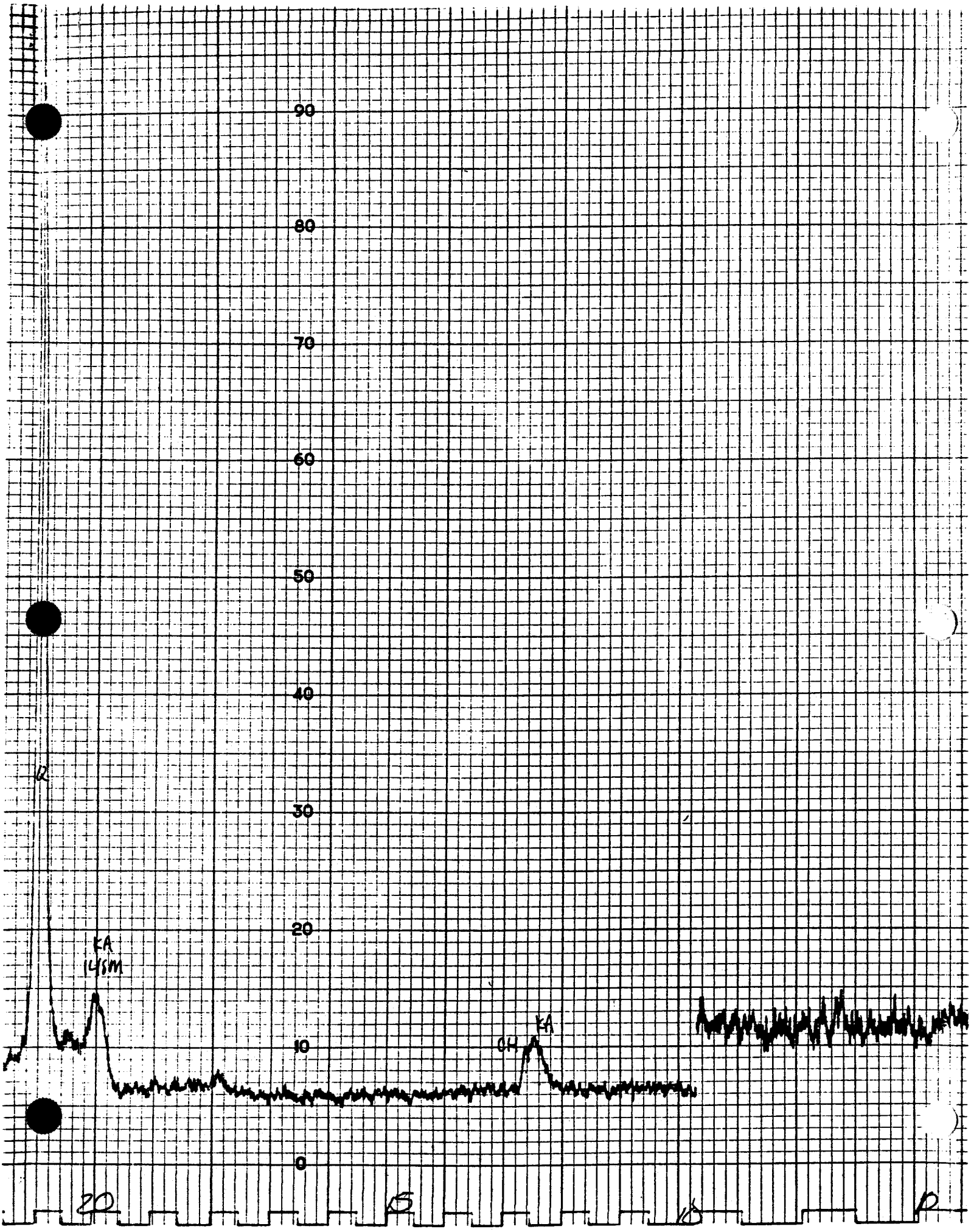
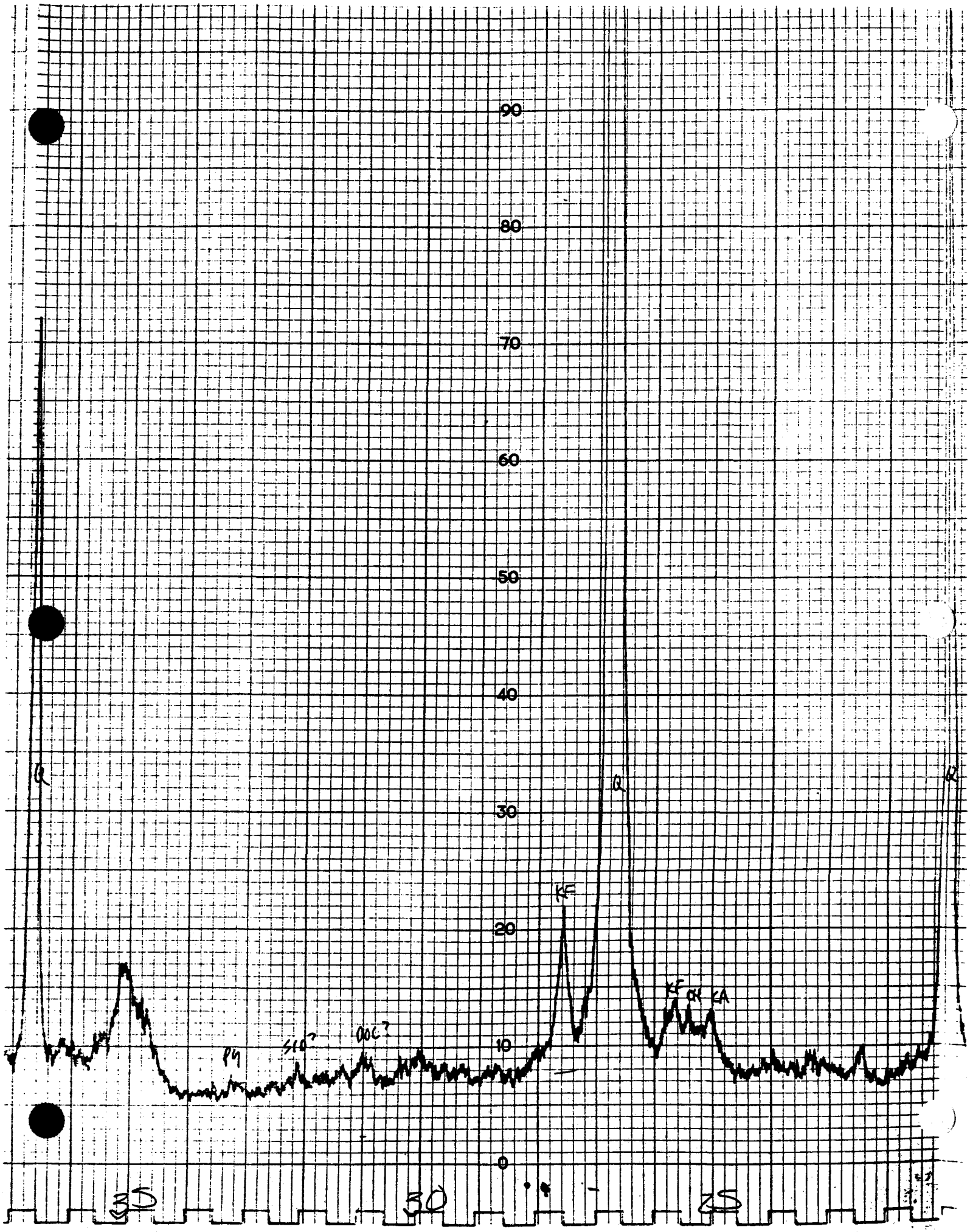
DH-5 384.3-384.5'
Price River
Bulk

Q	Quartz	72
KF	K-Feldspar	6
SID	Siderite	TR
DOL	Dolomite	TR
PY	Pyrite	1
KA	Kaolin	5
CH + CH/SM	Mixed-layer chlorite-smectite	3
IL	Illite + 10Å Mica	2
IL/SM	Mixed-layer illite-smectite	8





NO. BR R0790



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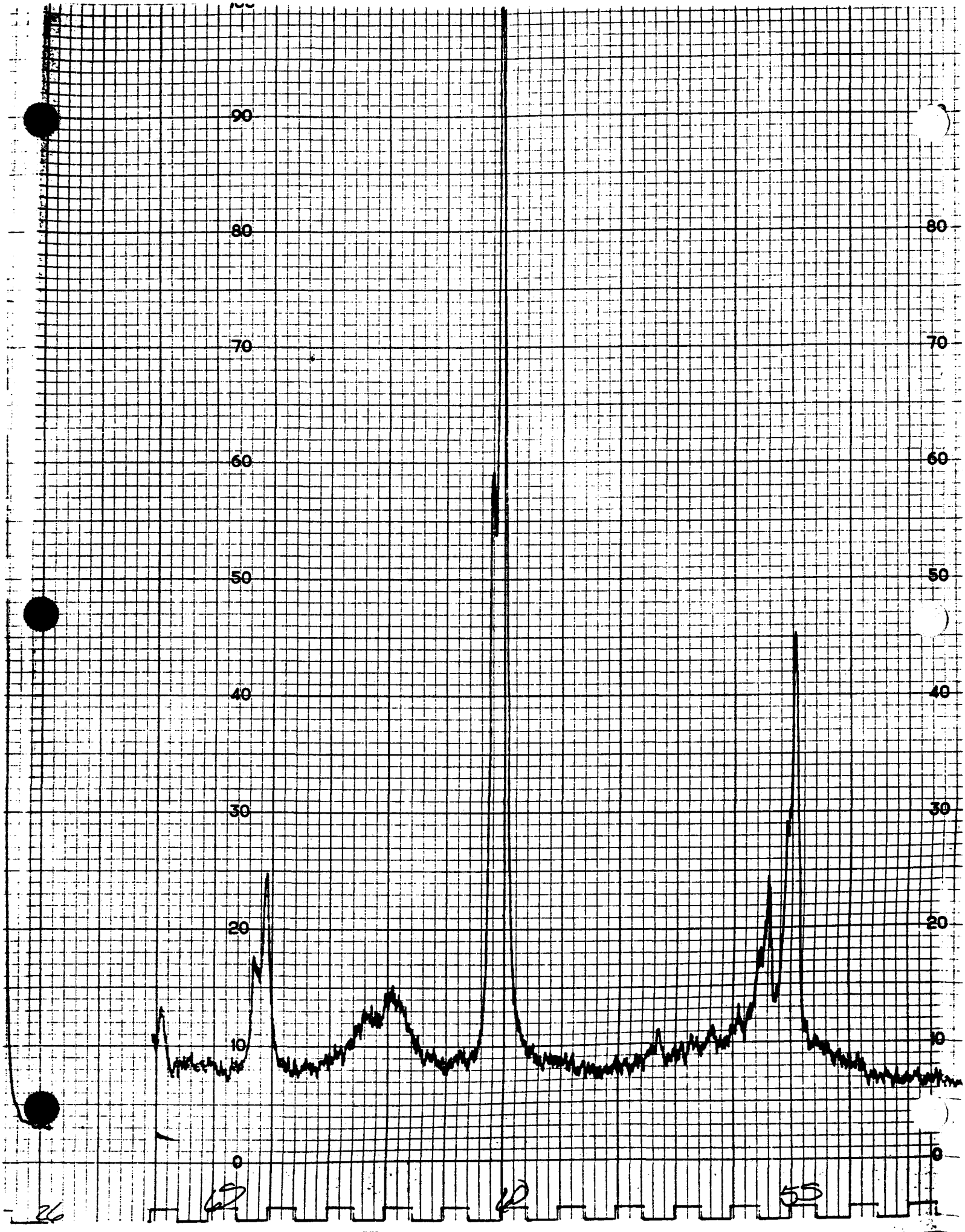
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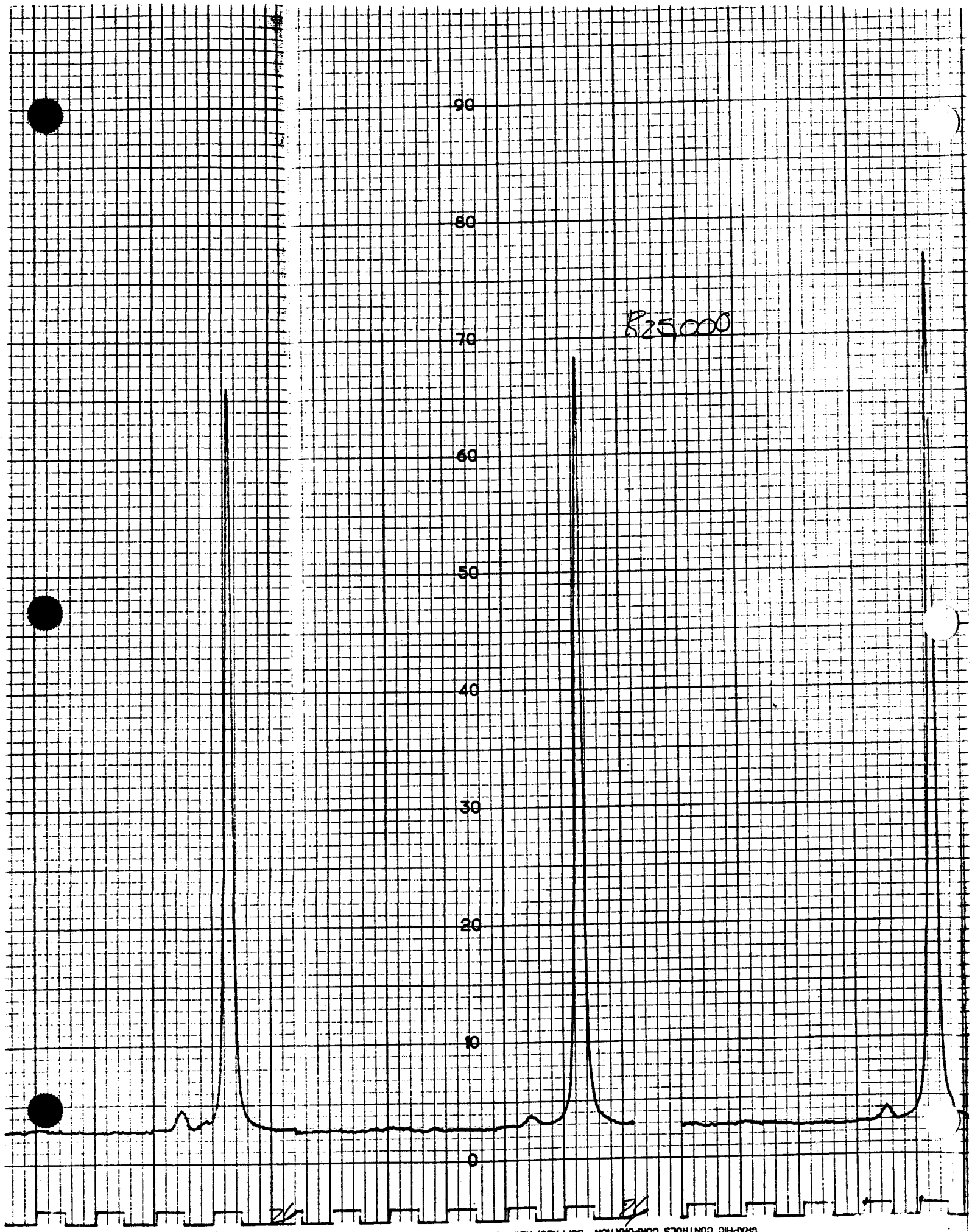
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GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

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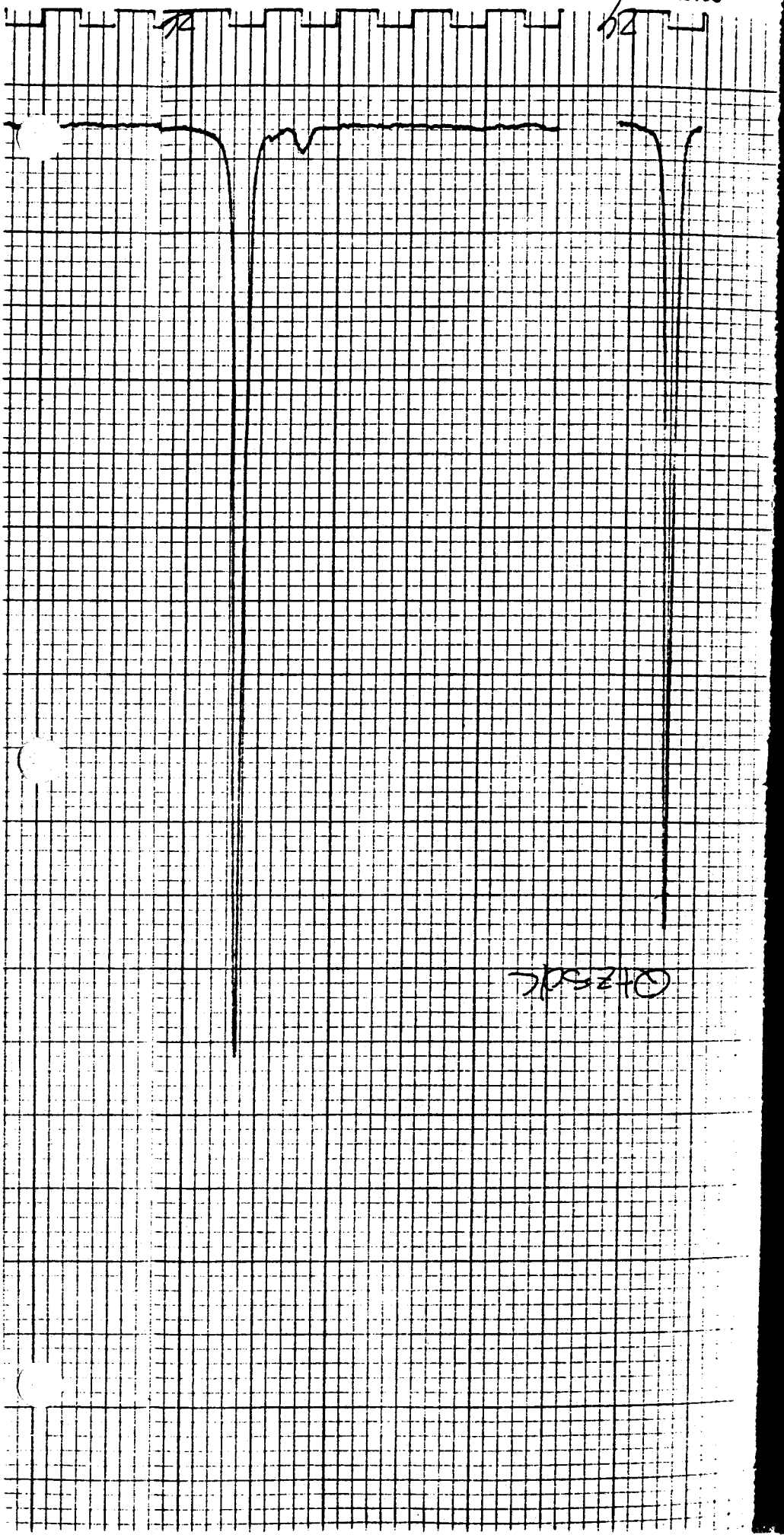
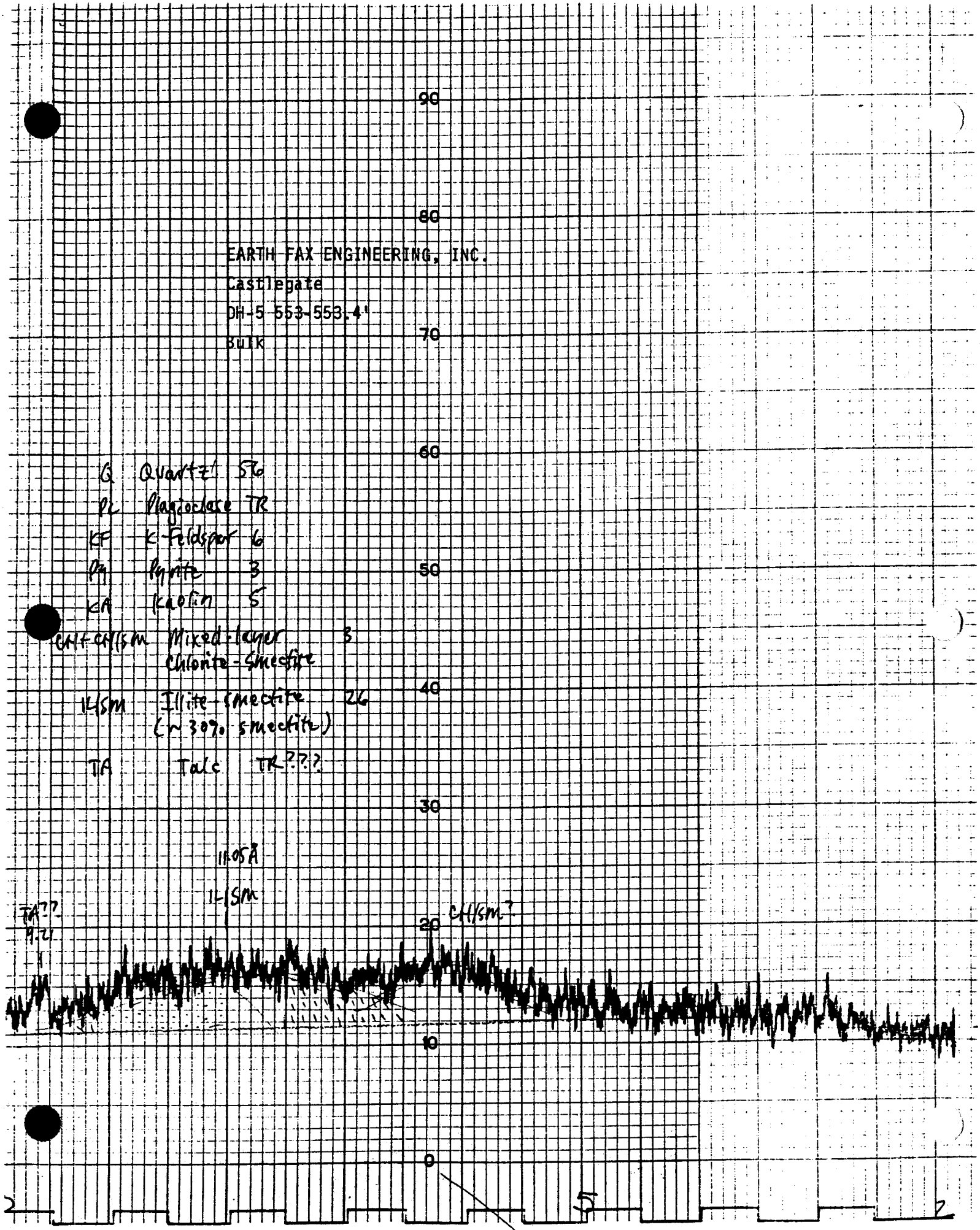


EARTH FAX ENGINEERING, INC.
Castlegate
DH-5 553-553.4'
Bulk

Q	Quartz	56
PL	Plagioclase	TR
KF	K-Feldspar	6
Py	Pyrite	3
KA	Kaolin	5
CH+CH/SM	Mixed-layer Chlorite-Smectite	3
I/SM	Illite-Smectite (~30% smectite)	26
TA	Talc	TR ???



GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

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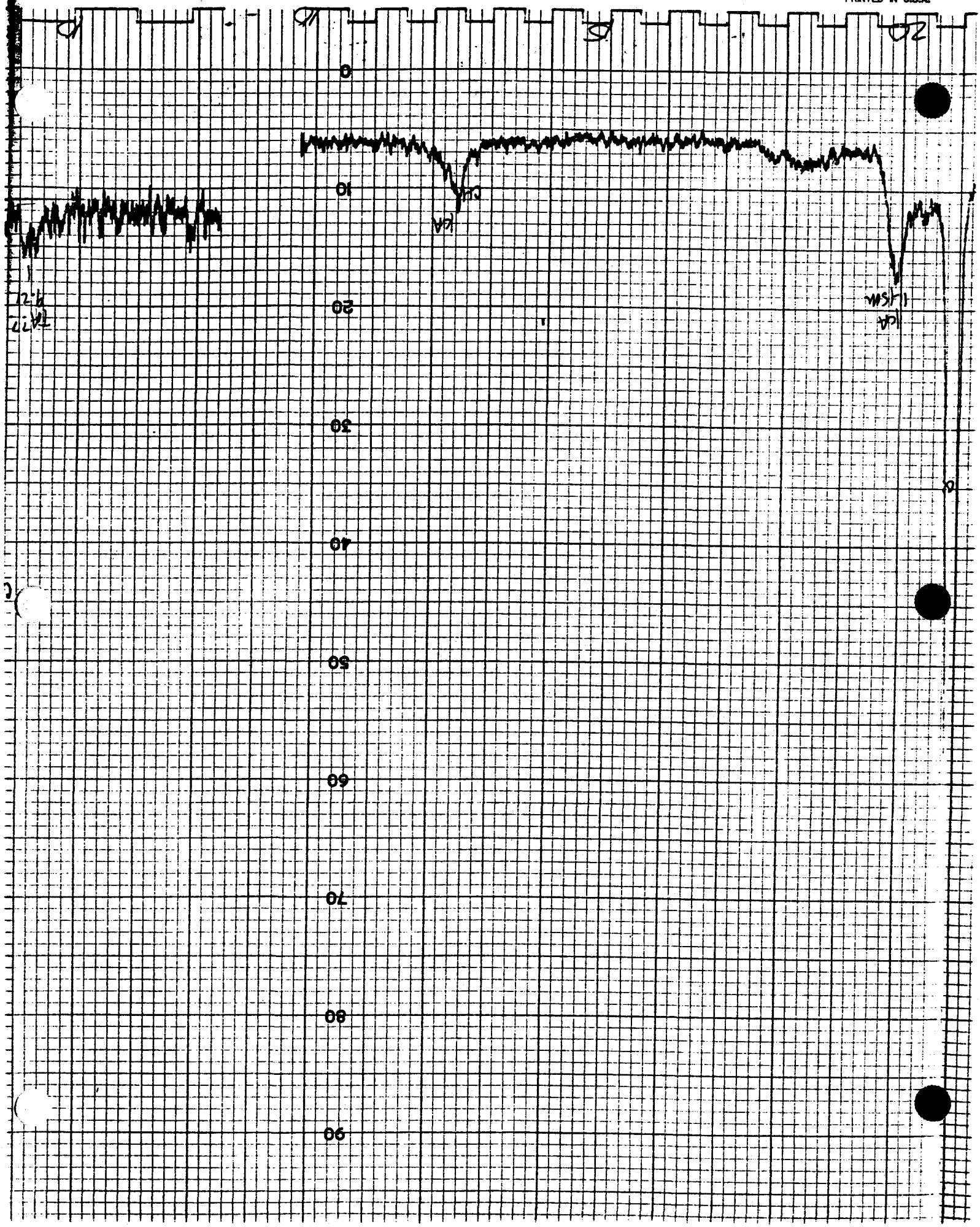
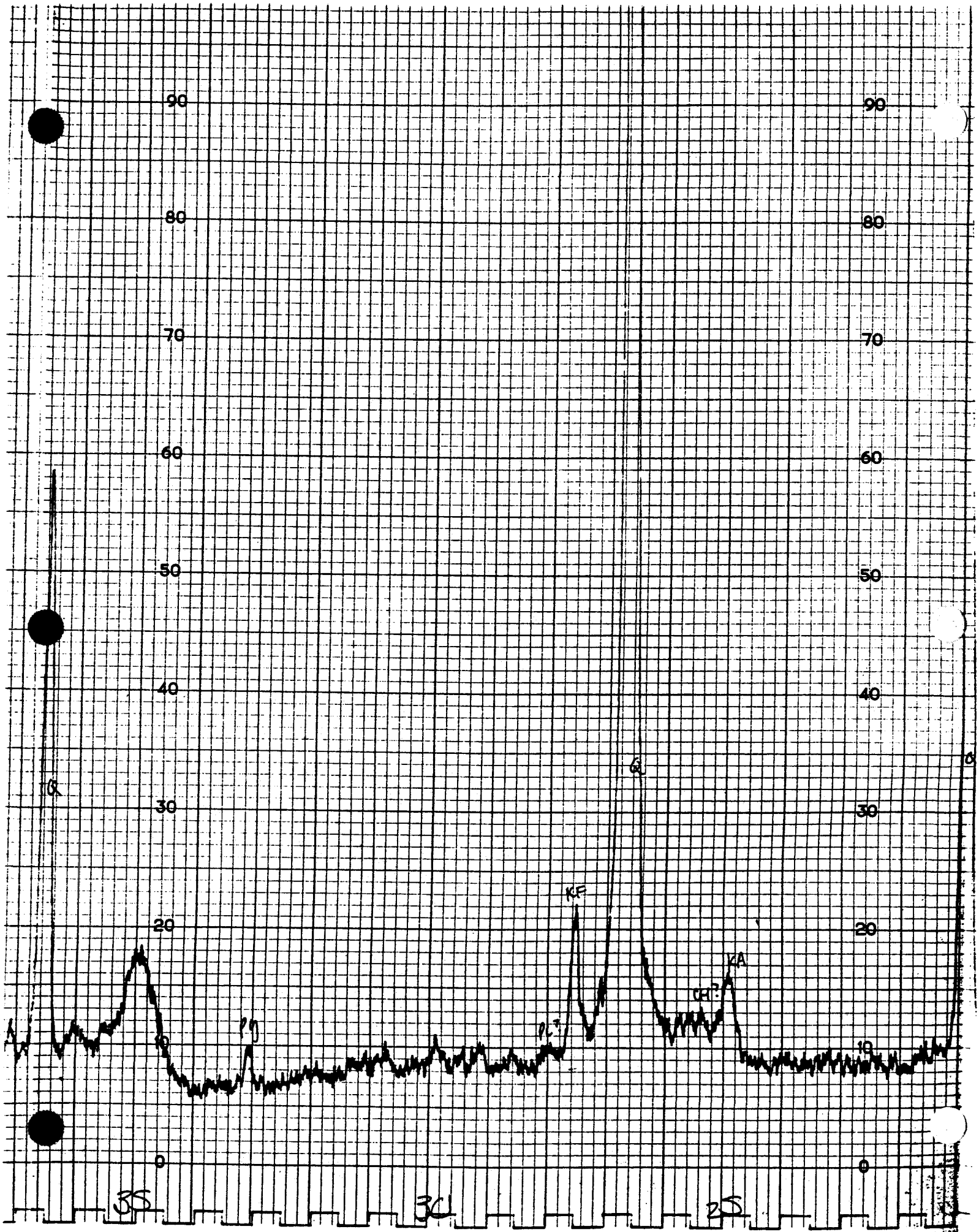
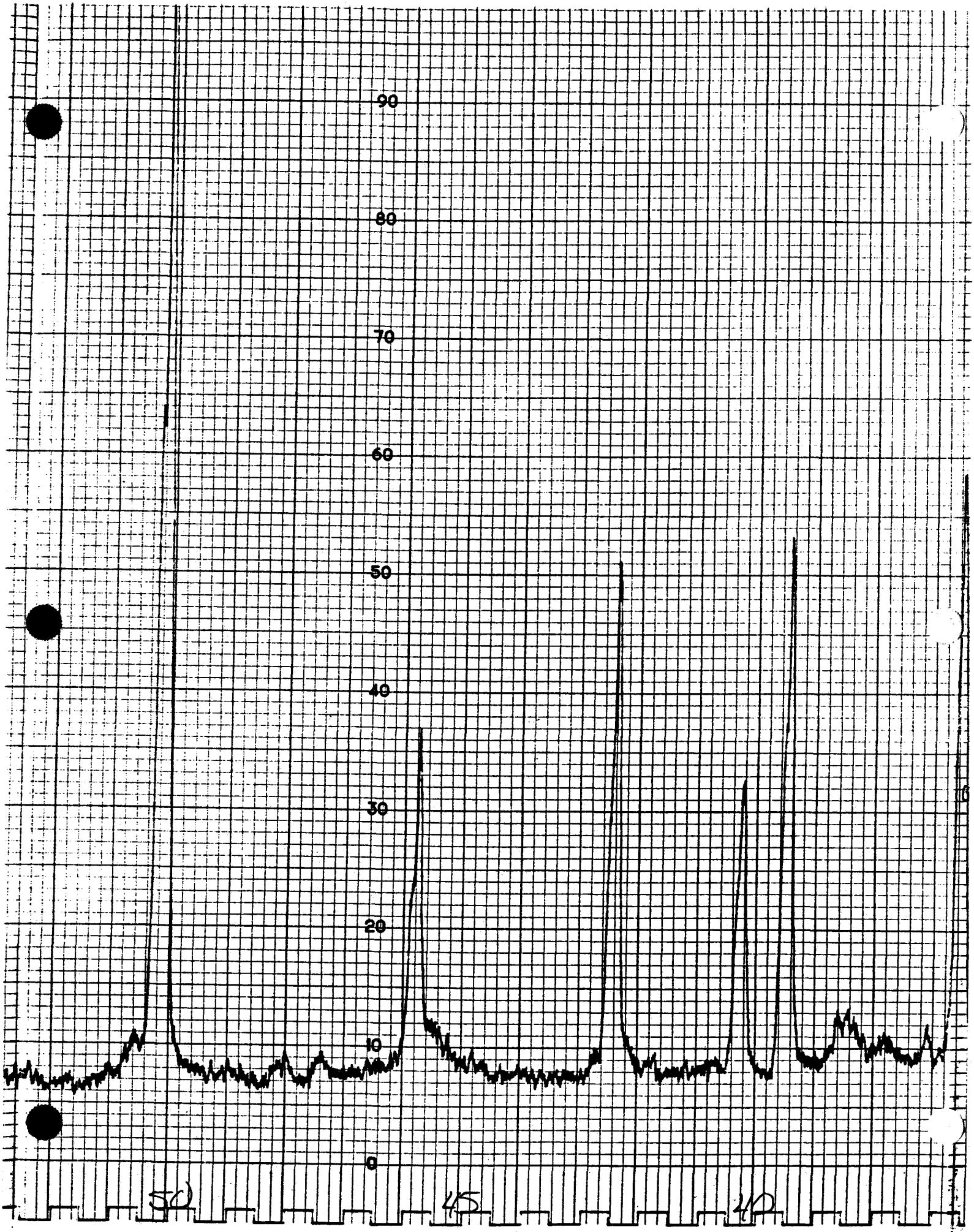




GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK



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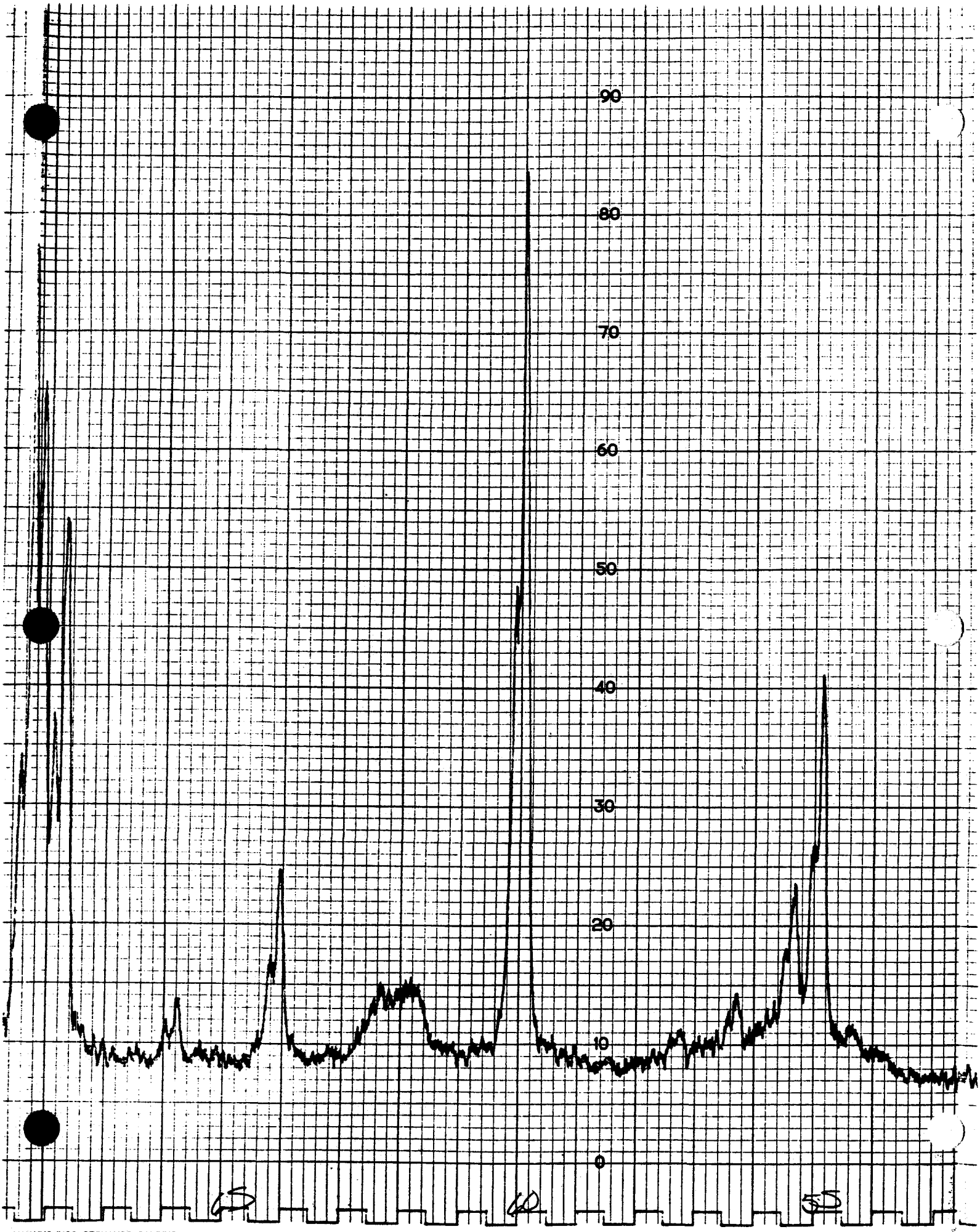

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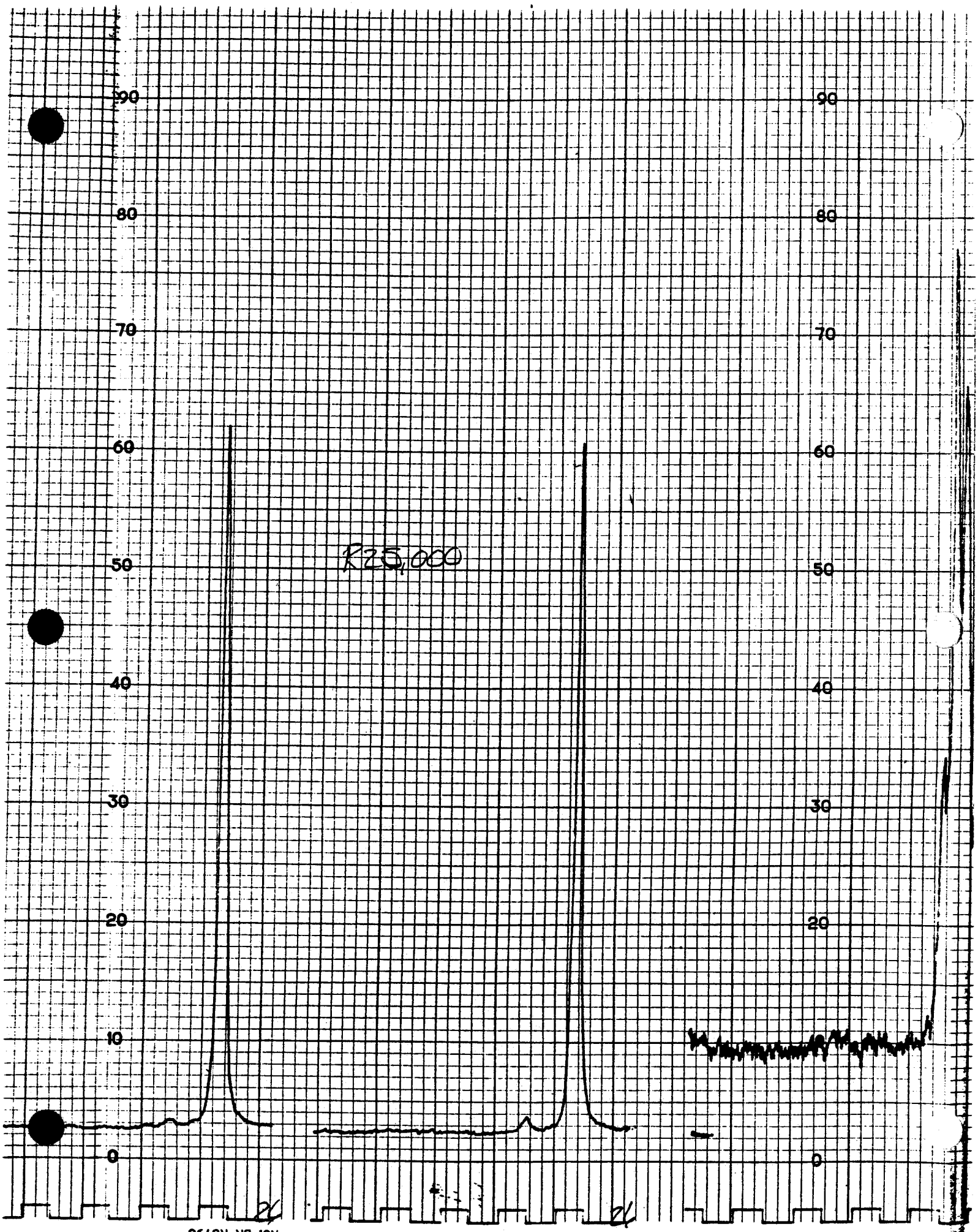
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BUFFALO, NEW YORK

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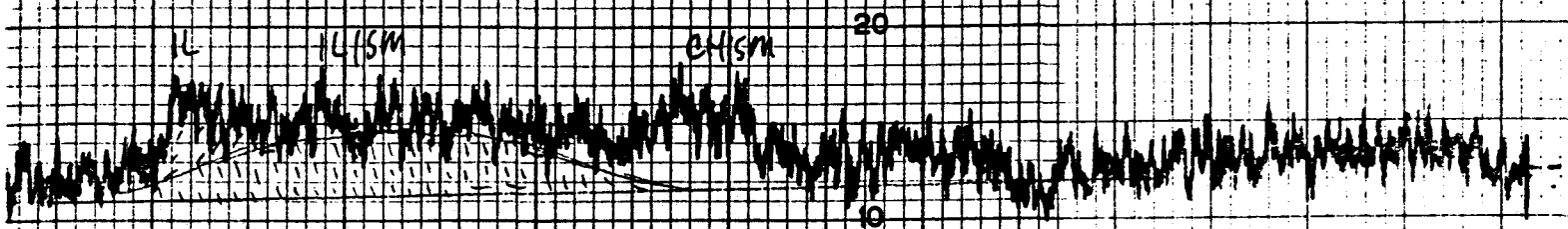
EARTH FAX ENGINEERING, INC.

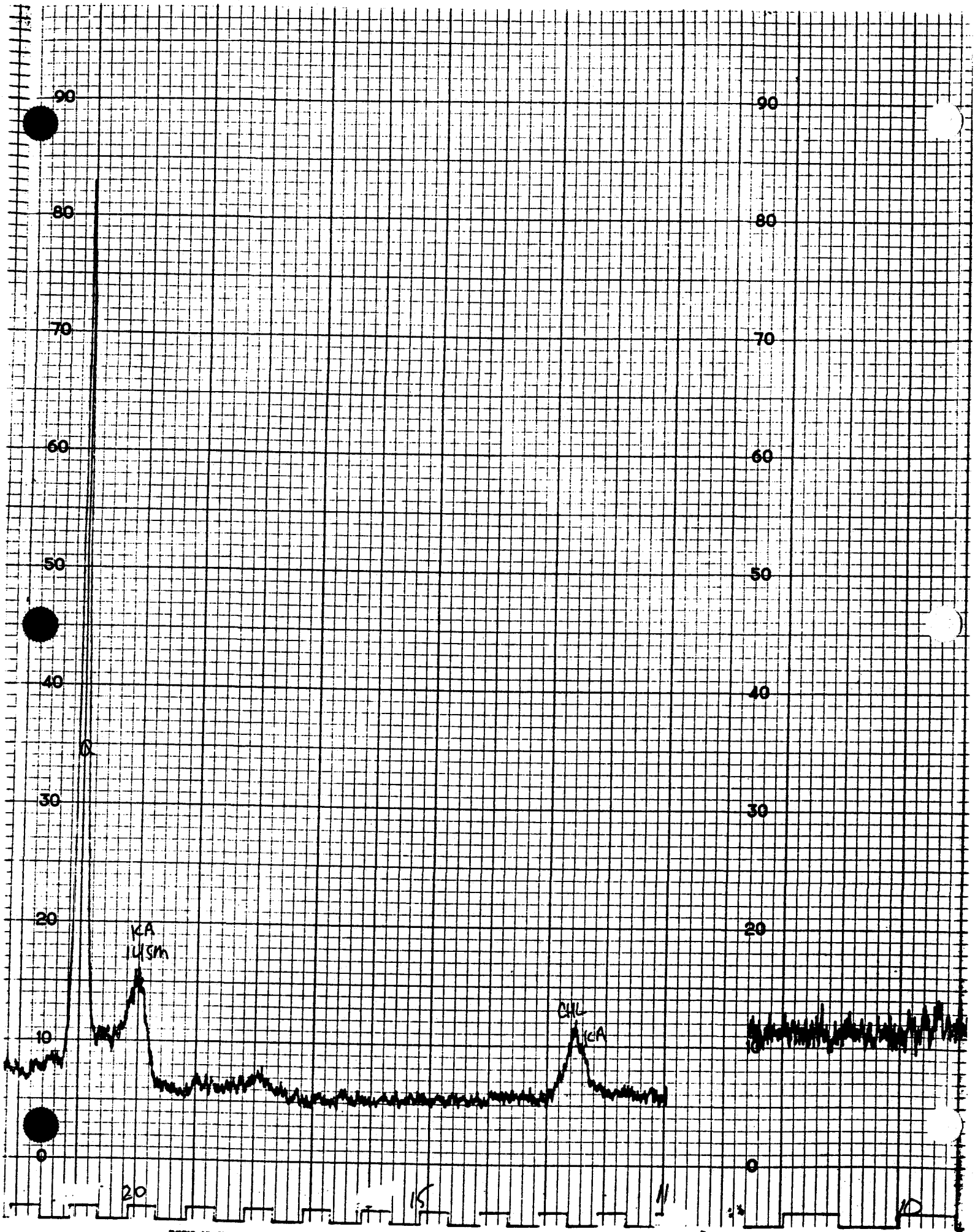
Castlegate

OH - 6 556.5-557'

Bulk

Q	quartz	52
PL	Plagioclase	1
KF	K-Feldspar	4
CA	Calcite	1
SID	Siderite	17
DOL	Dolomite	13
PY	Pyrite	1
KA	Kaolin	4
CHISM	Mixed-layer chlorite-smectite	5
IL	Illite + 10Å Mica	2
ILISM	Mixed-layer illite-smectite (~30% smectite interlayers)	16

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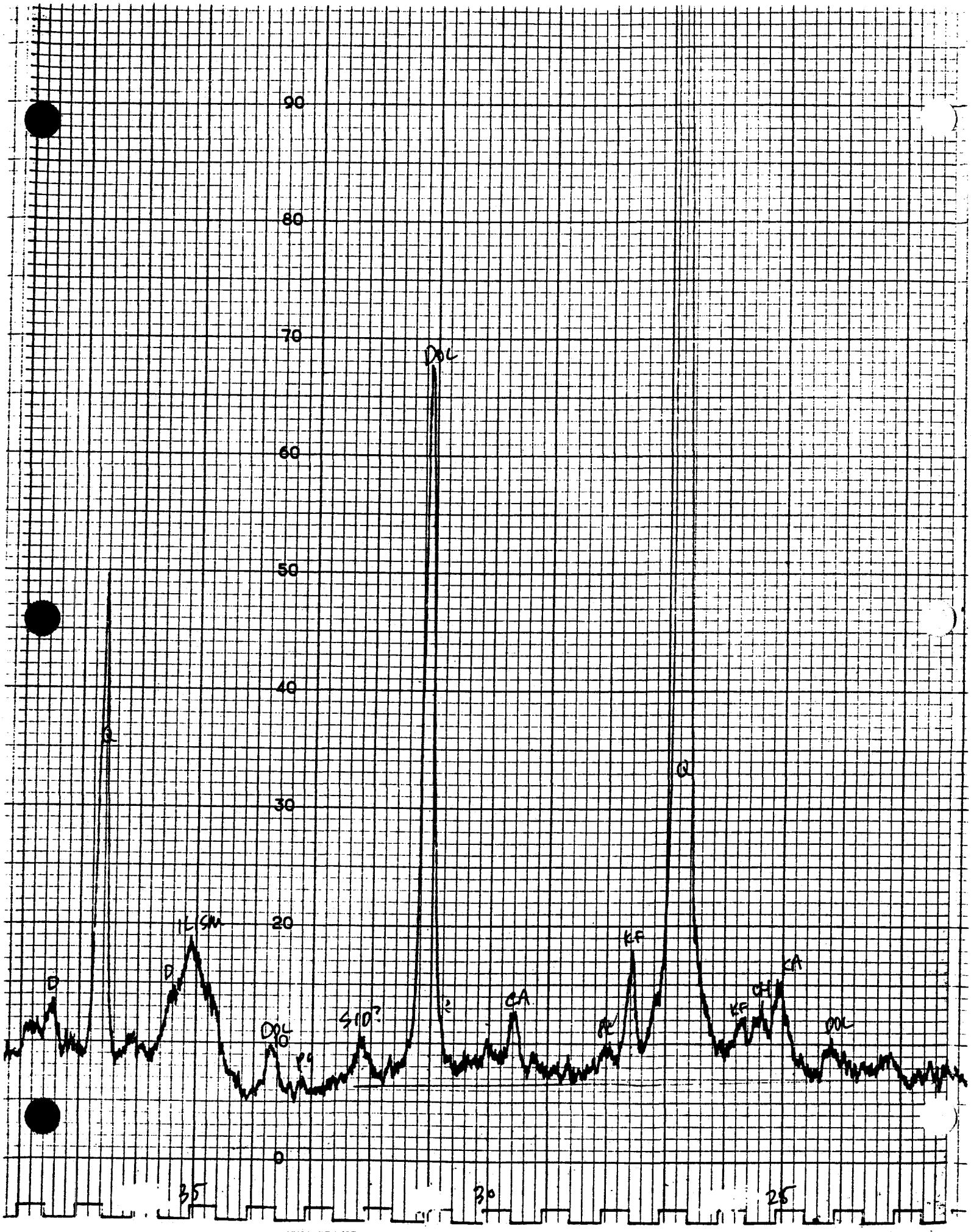

GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

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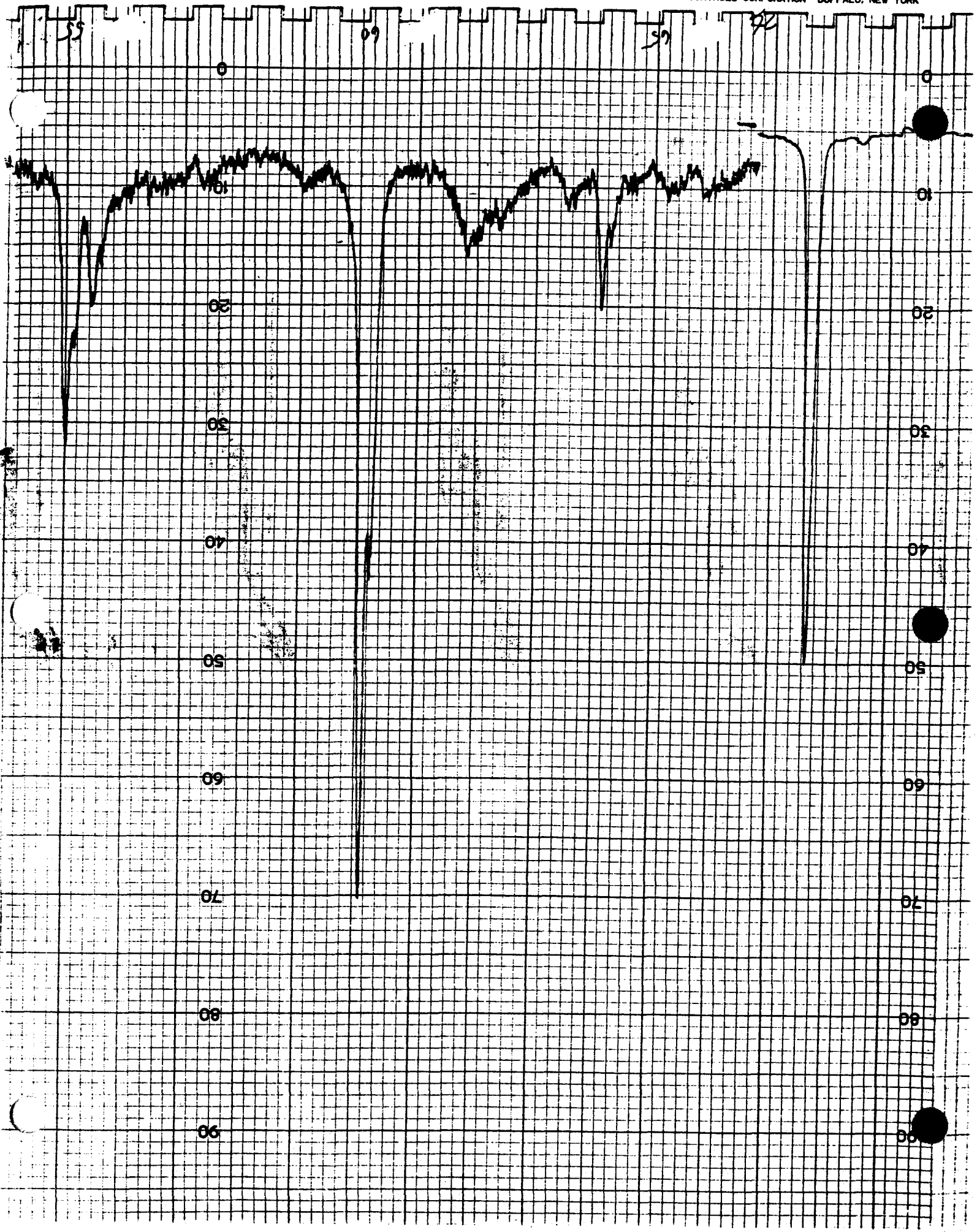
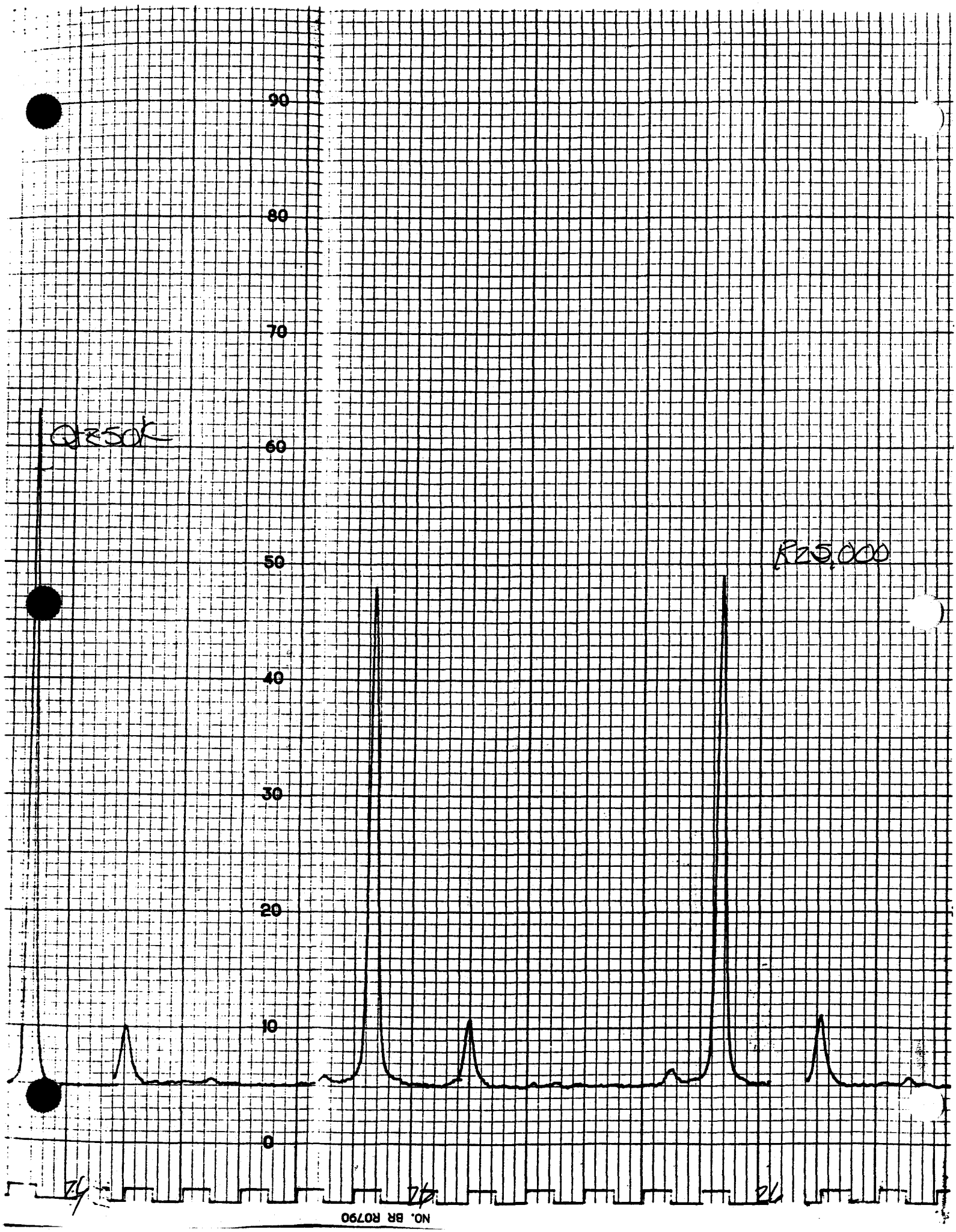
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

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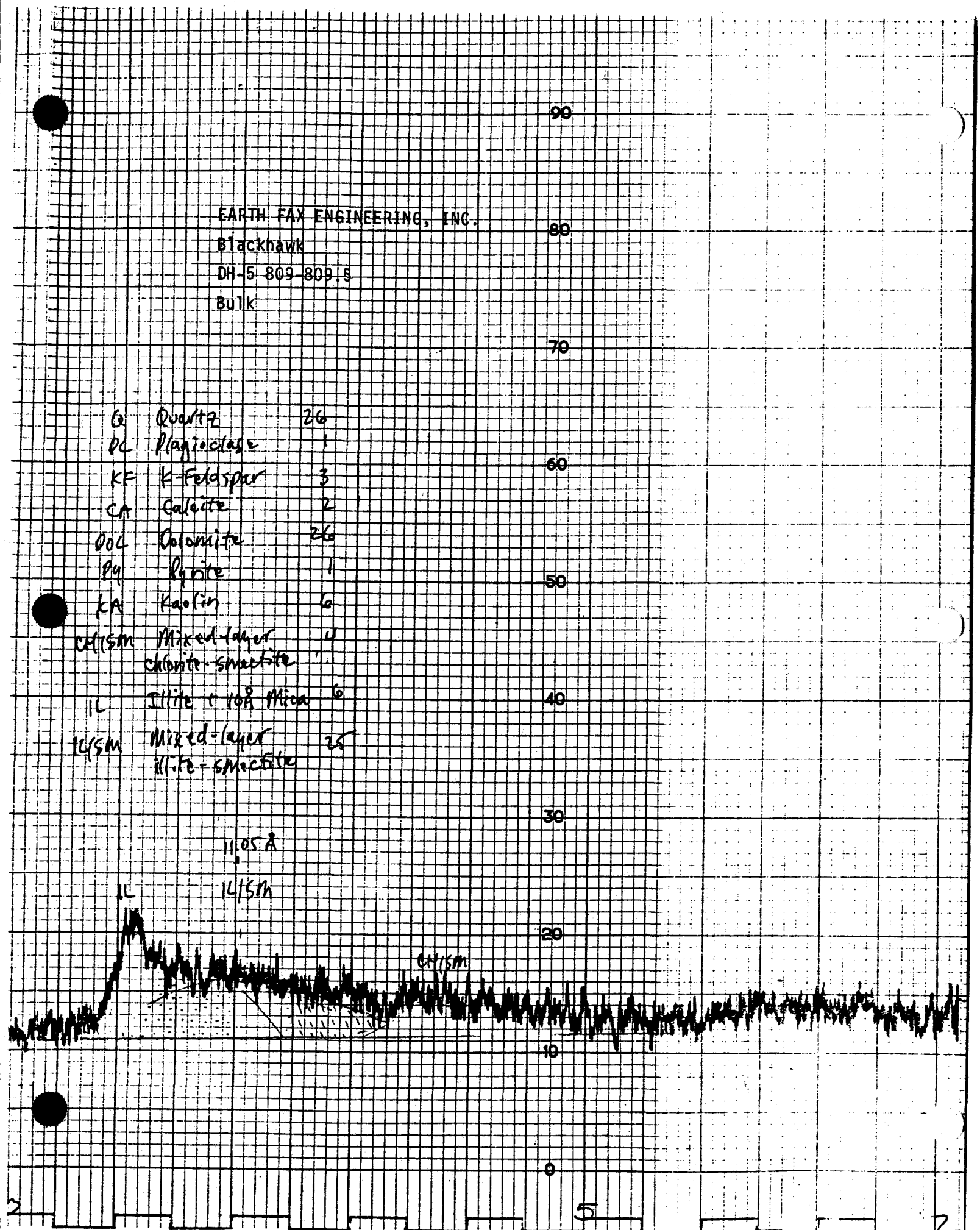
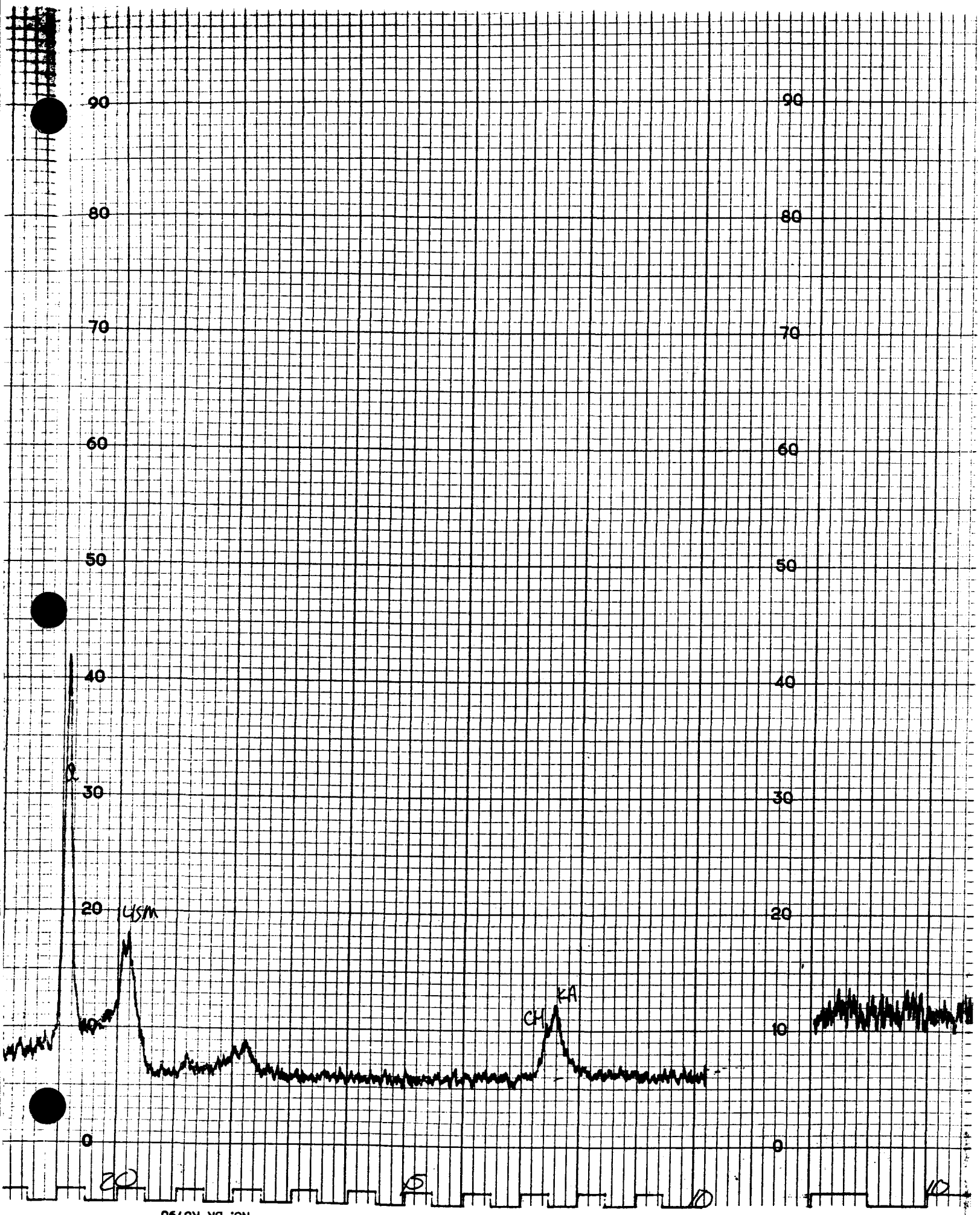
NO. BR R0790

EARTH FAX ENGINEERING, INC.
Blackhawk
DH-5 809-809.5
Bulk

Q	Quartz	26
PL	Plagioclase	1
KF	K-Feldspar	3
CA	Calcite	2
DOL	Dolomite	26
PY	Pyrite	1
KA	Kaolin	6
CH/SM	Mixed-layer chlorite-smectite	4
IL	Illite + 10Å Mica	6
IL/SM	Mixed-layer illite-smectite	25





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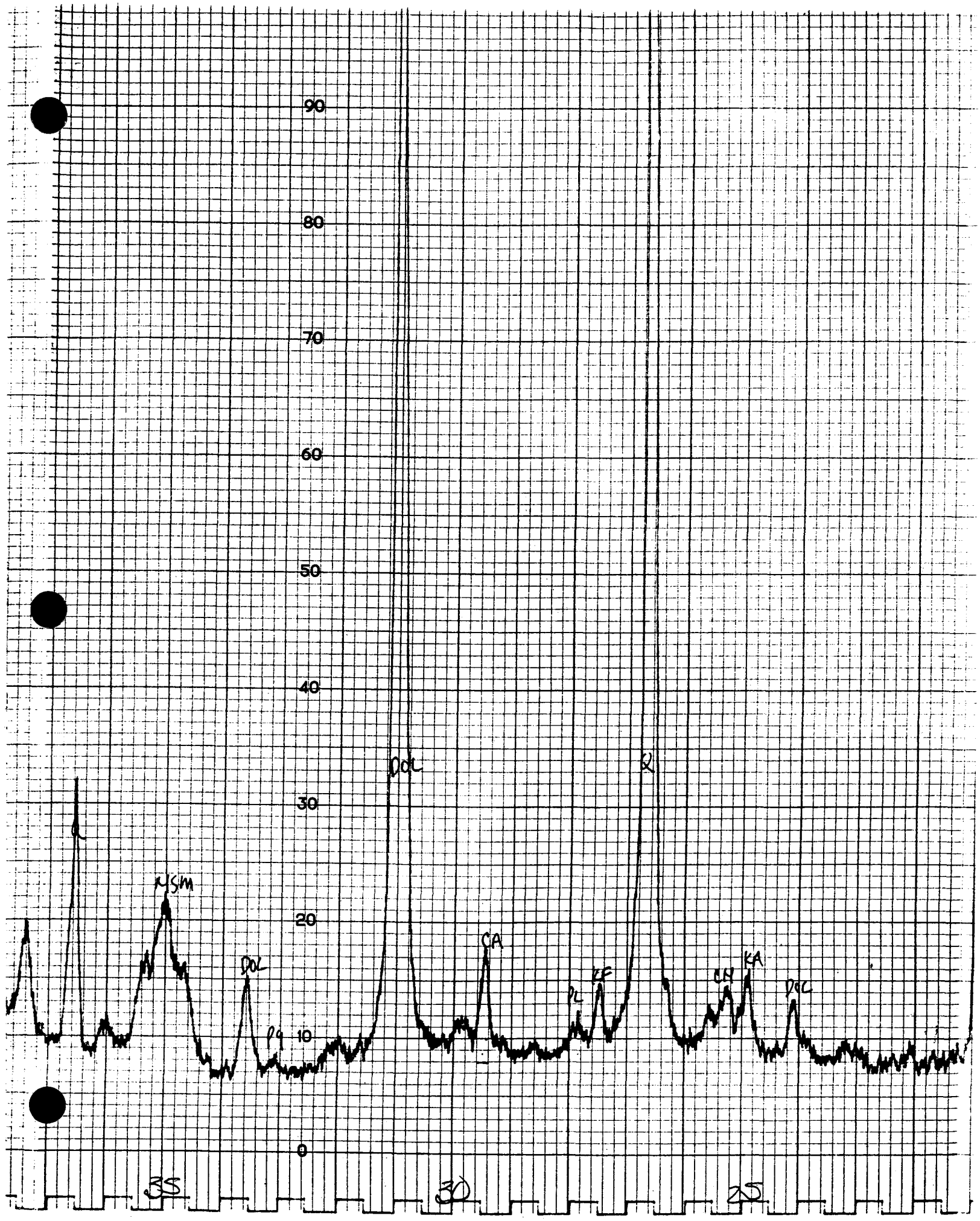
S CORPORATION BUFFALO, NEW YORK



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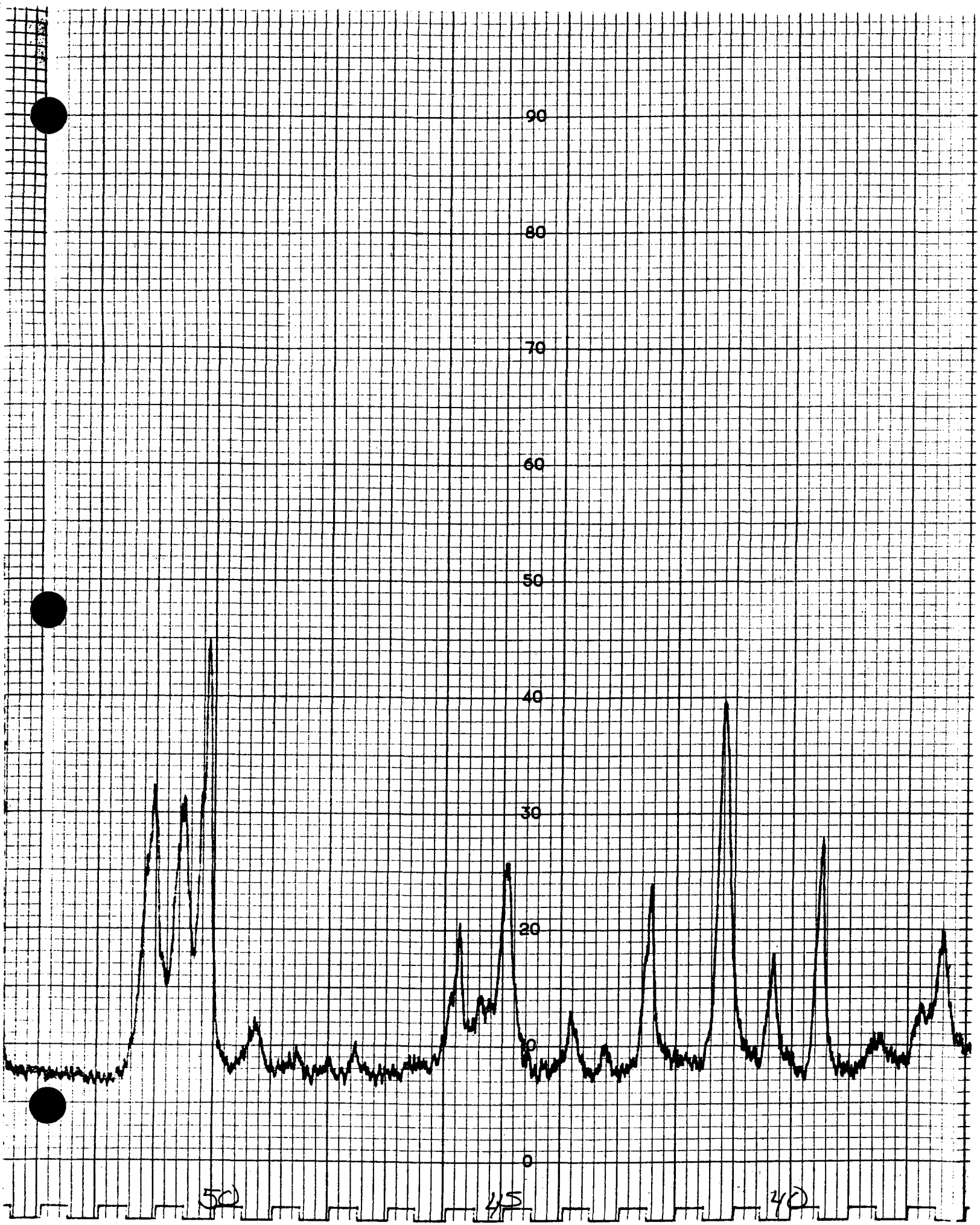

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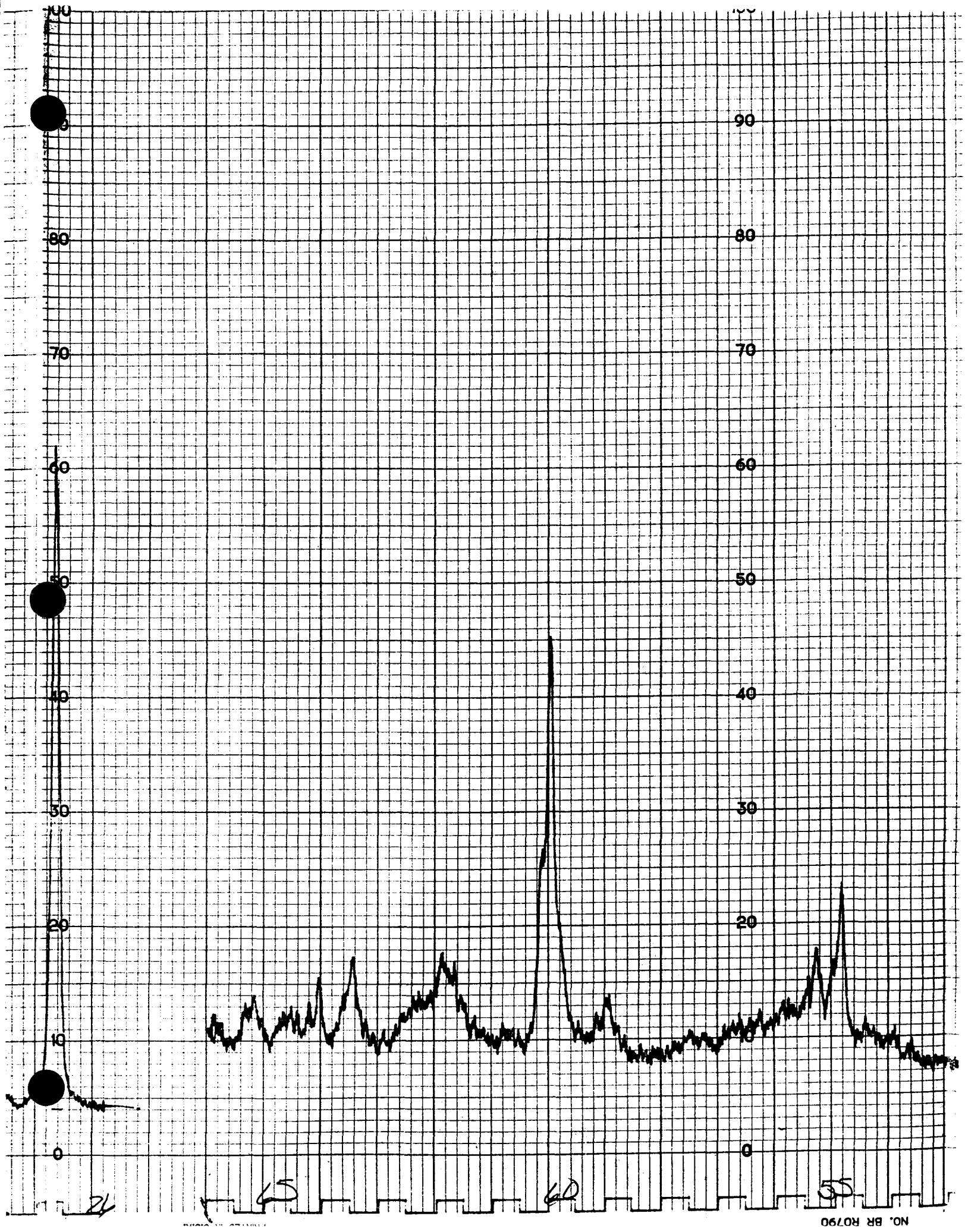
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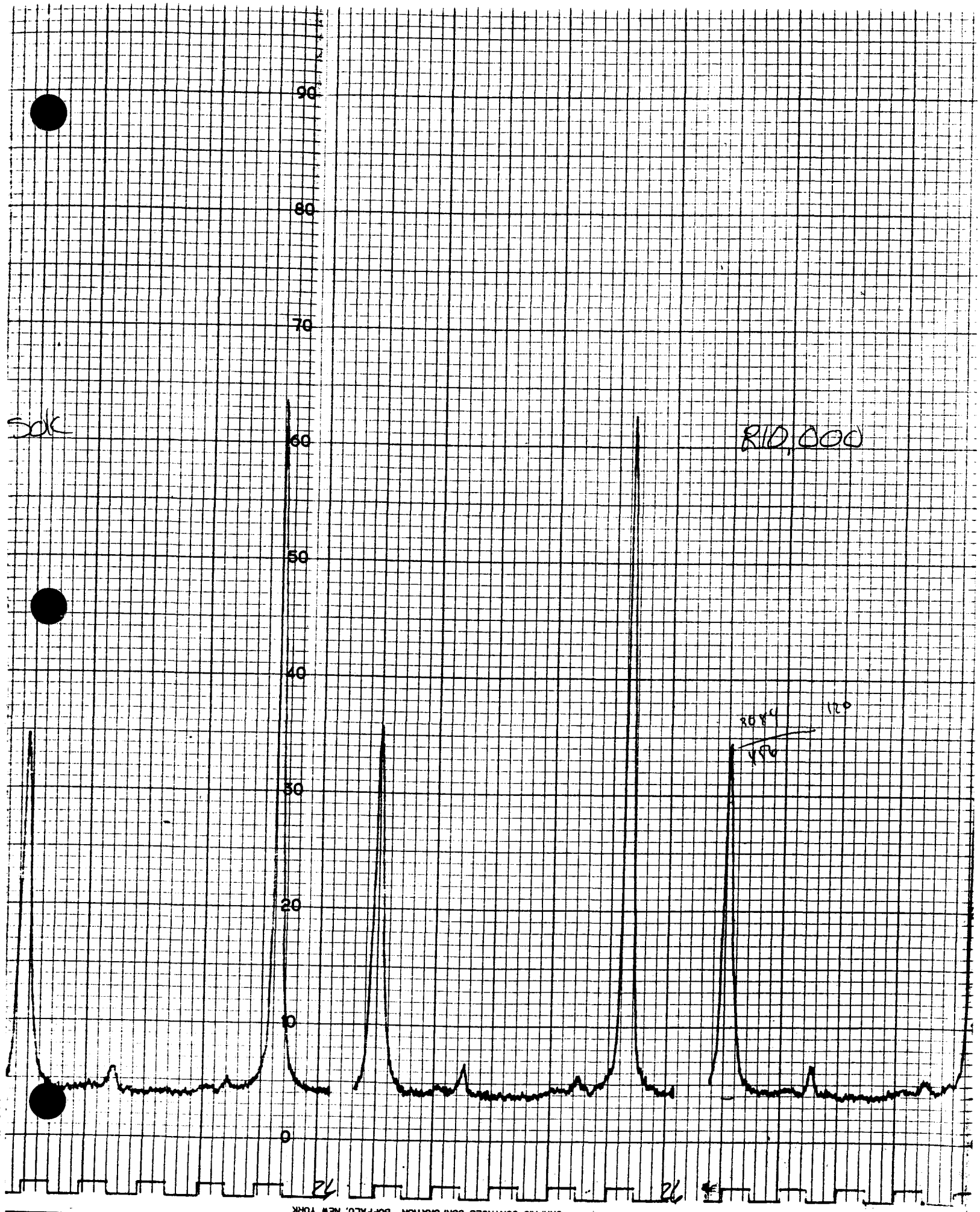
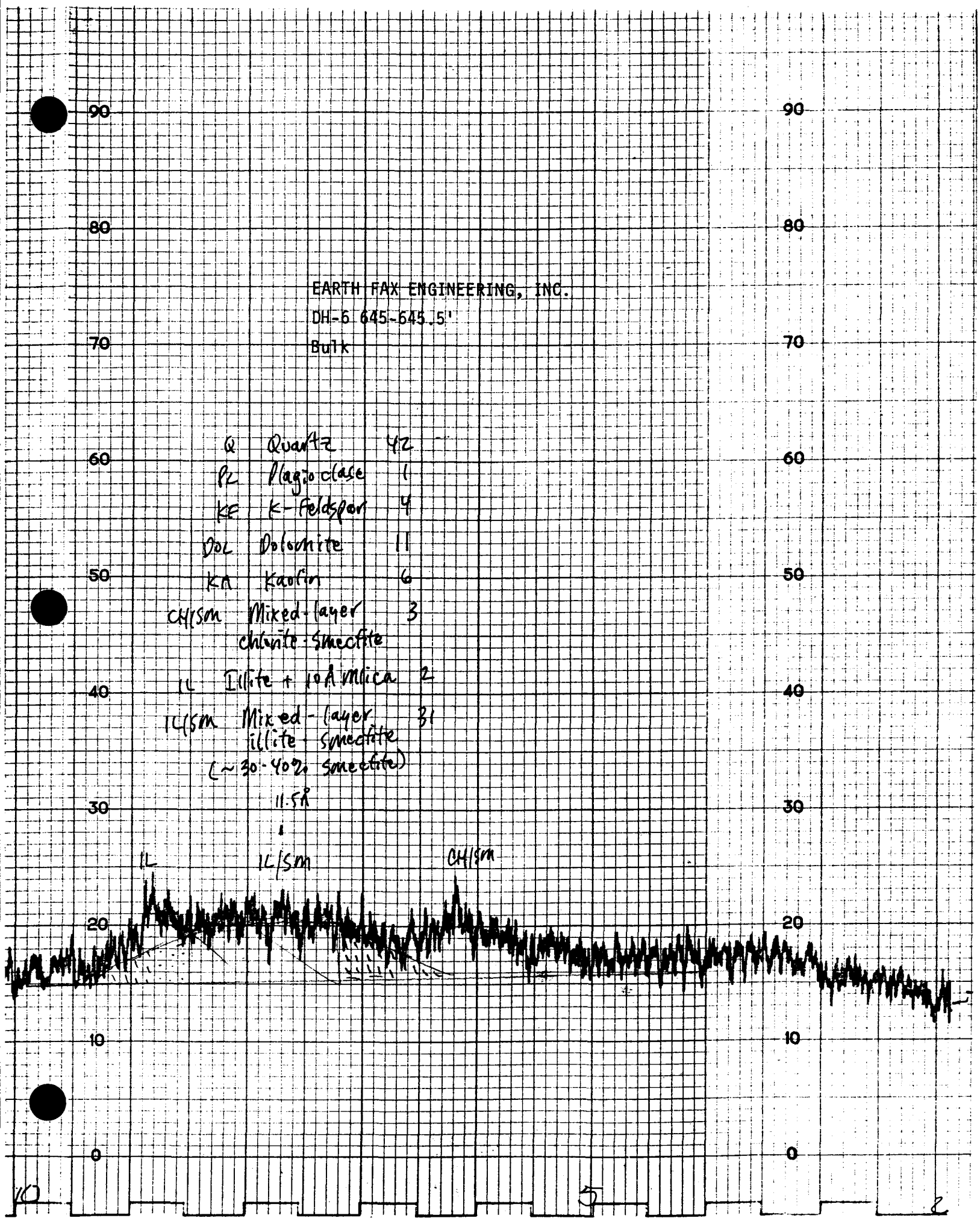


GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

EARTH FAX ENGINEERING, INC.
DH-6 645-645.5'
Bulk

Q	Quartz	42
PL	Plagioclase	1
KF	K-feldspar	4
DOL	Dolomite	11
KA	Kaolin	6
CH/SM	Mixed-layer chlorite-smectite	3
IL	Illite + 10Å mica	2
IL/SM	Mixed-layer illite-smectite (~30-40% smectite)	31



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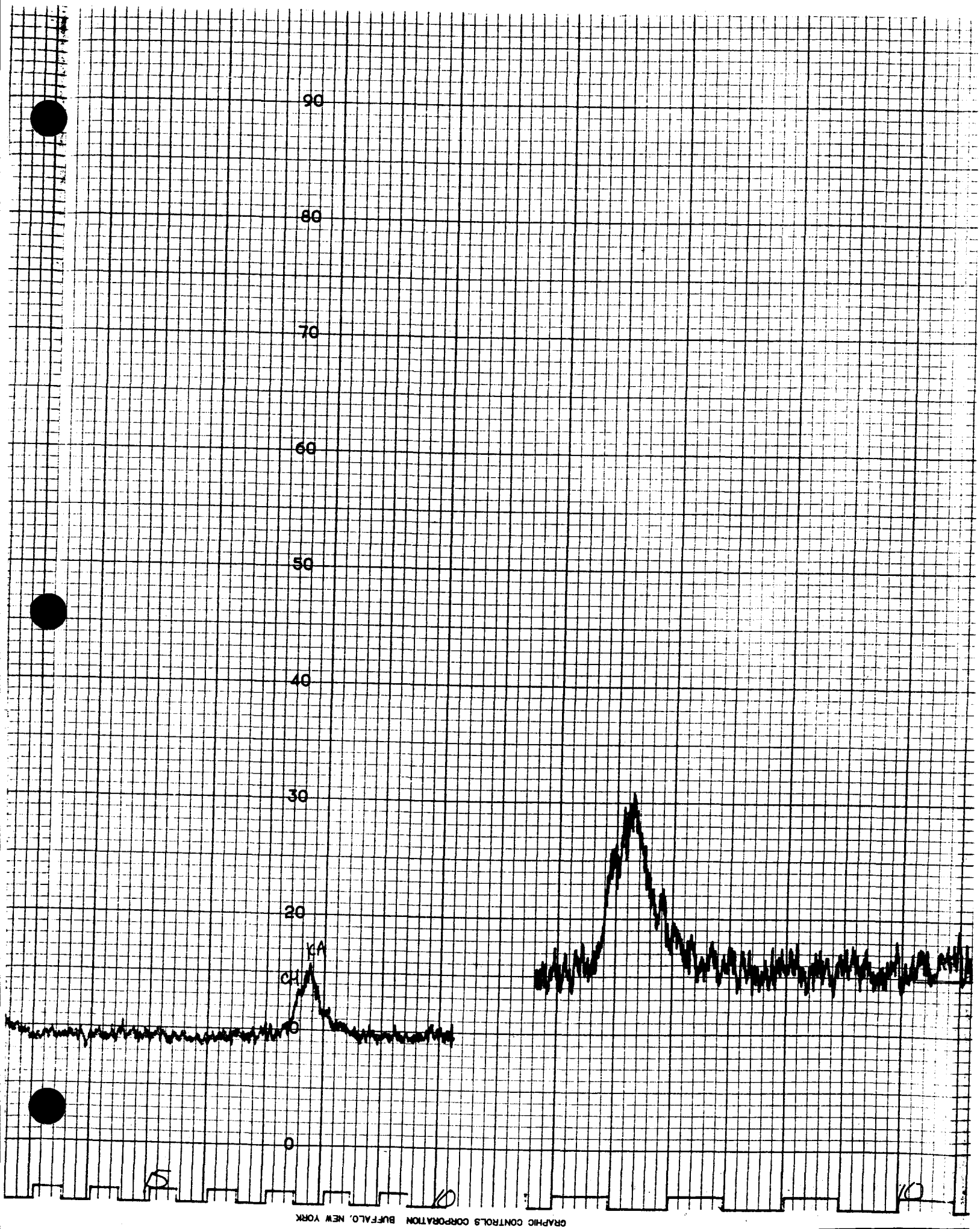
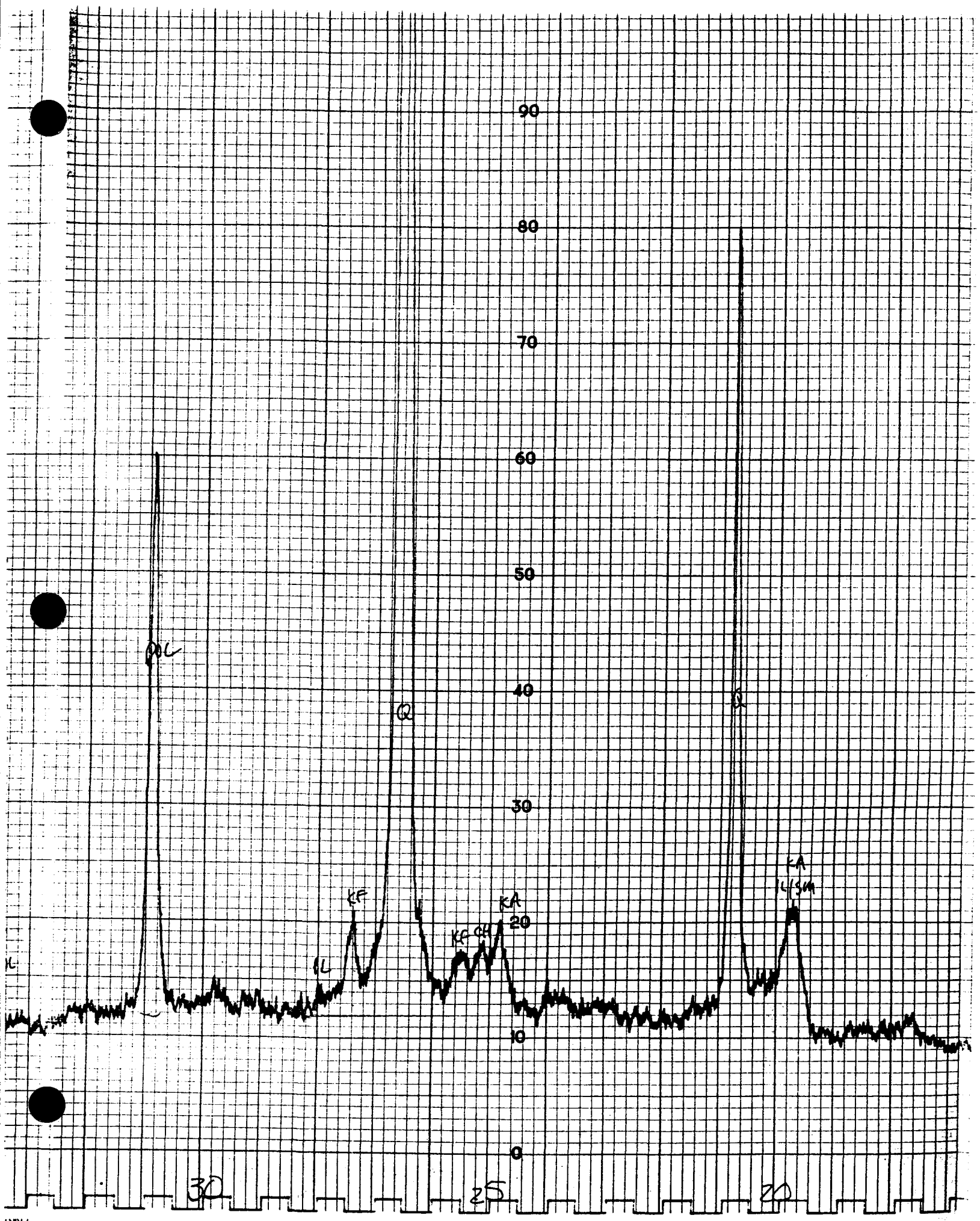


GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK



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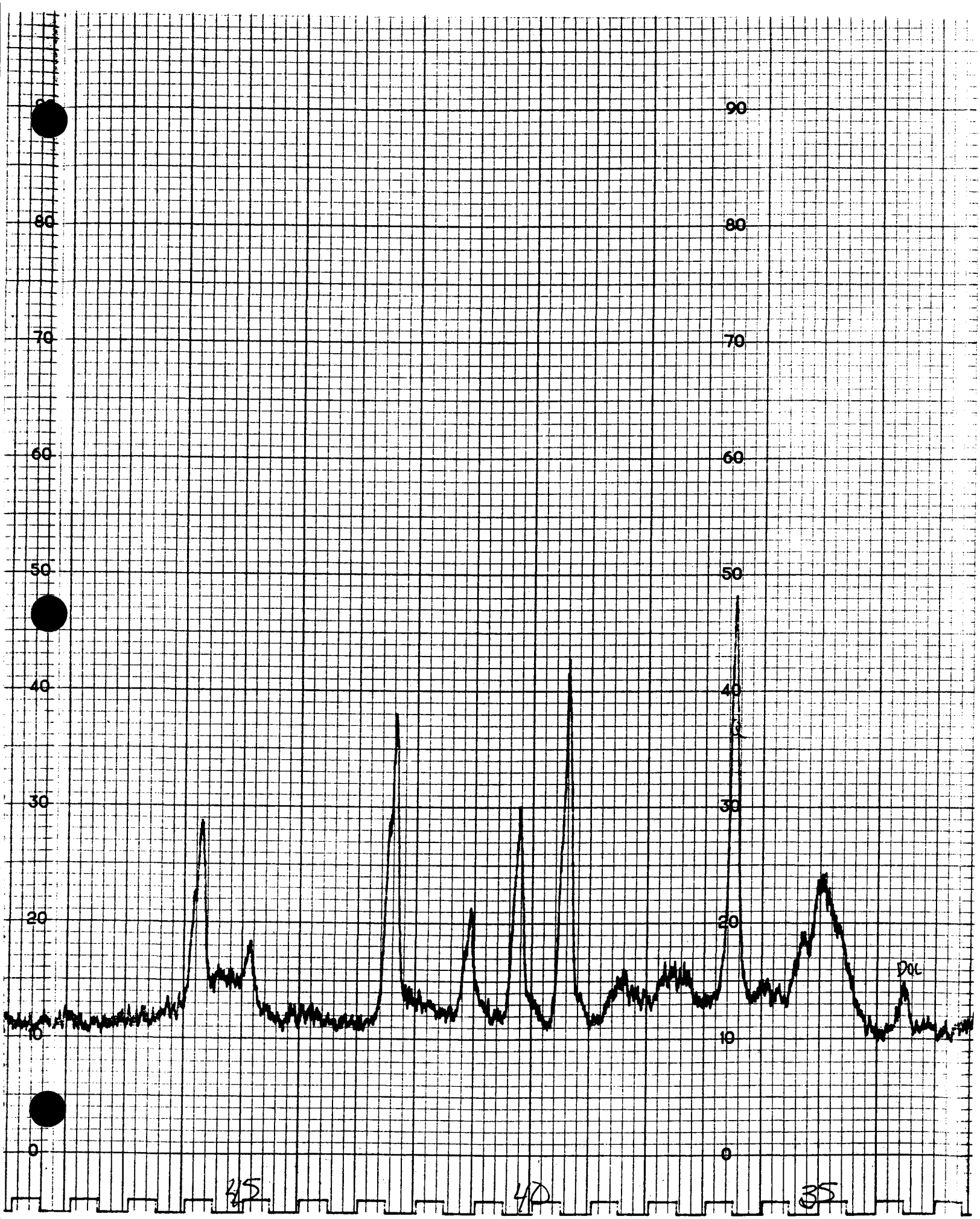

GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK
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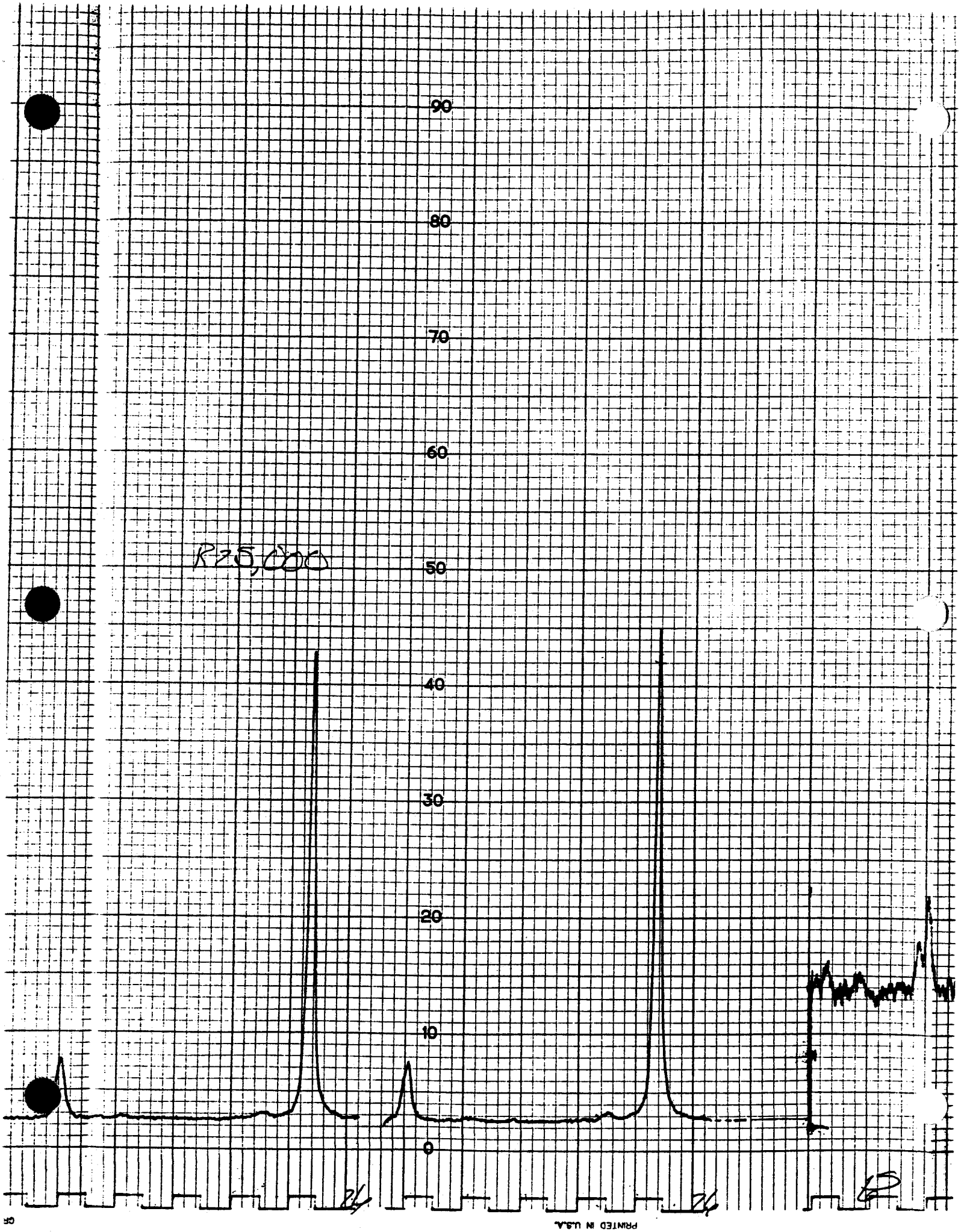
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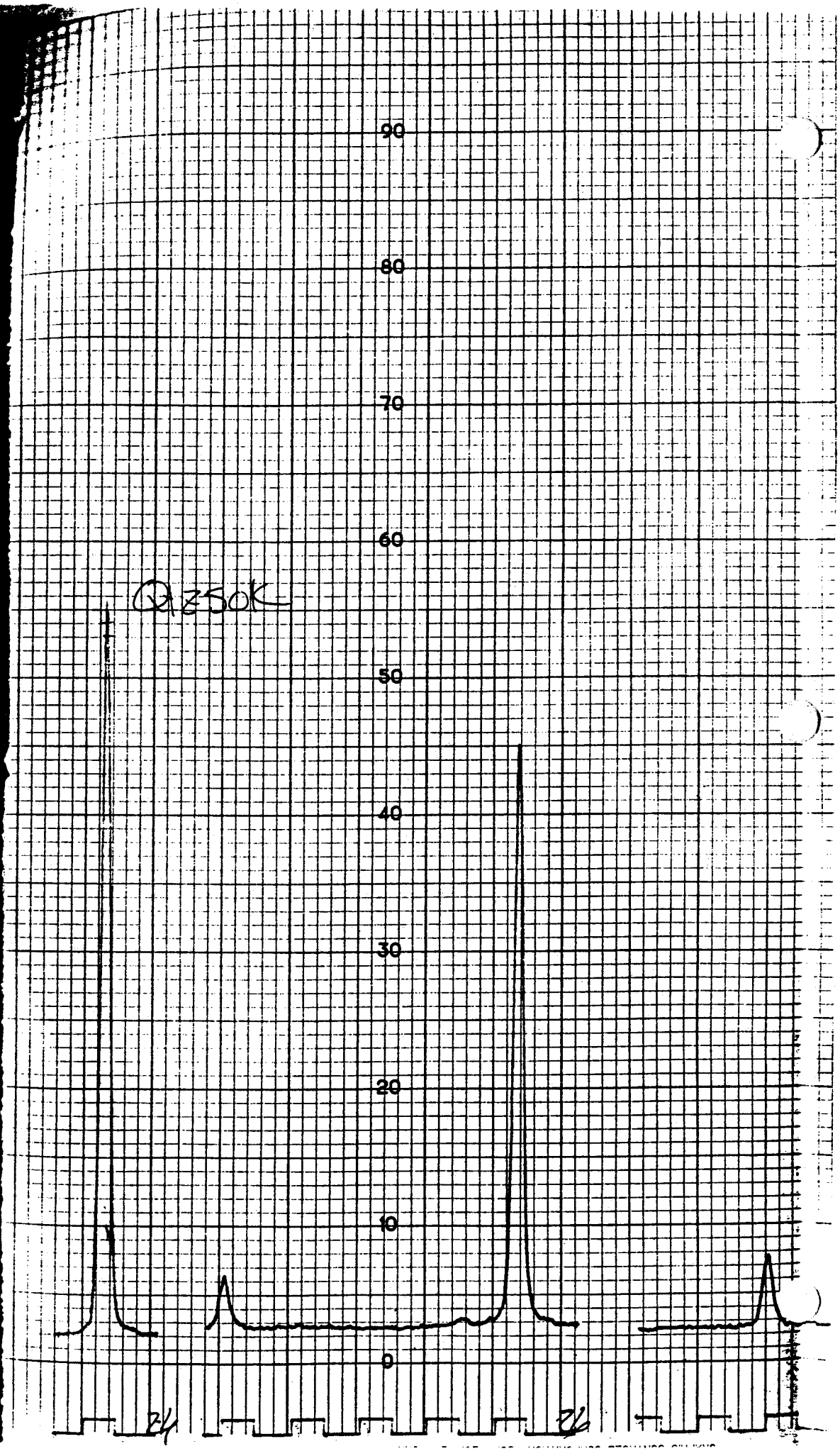
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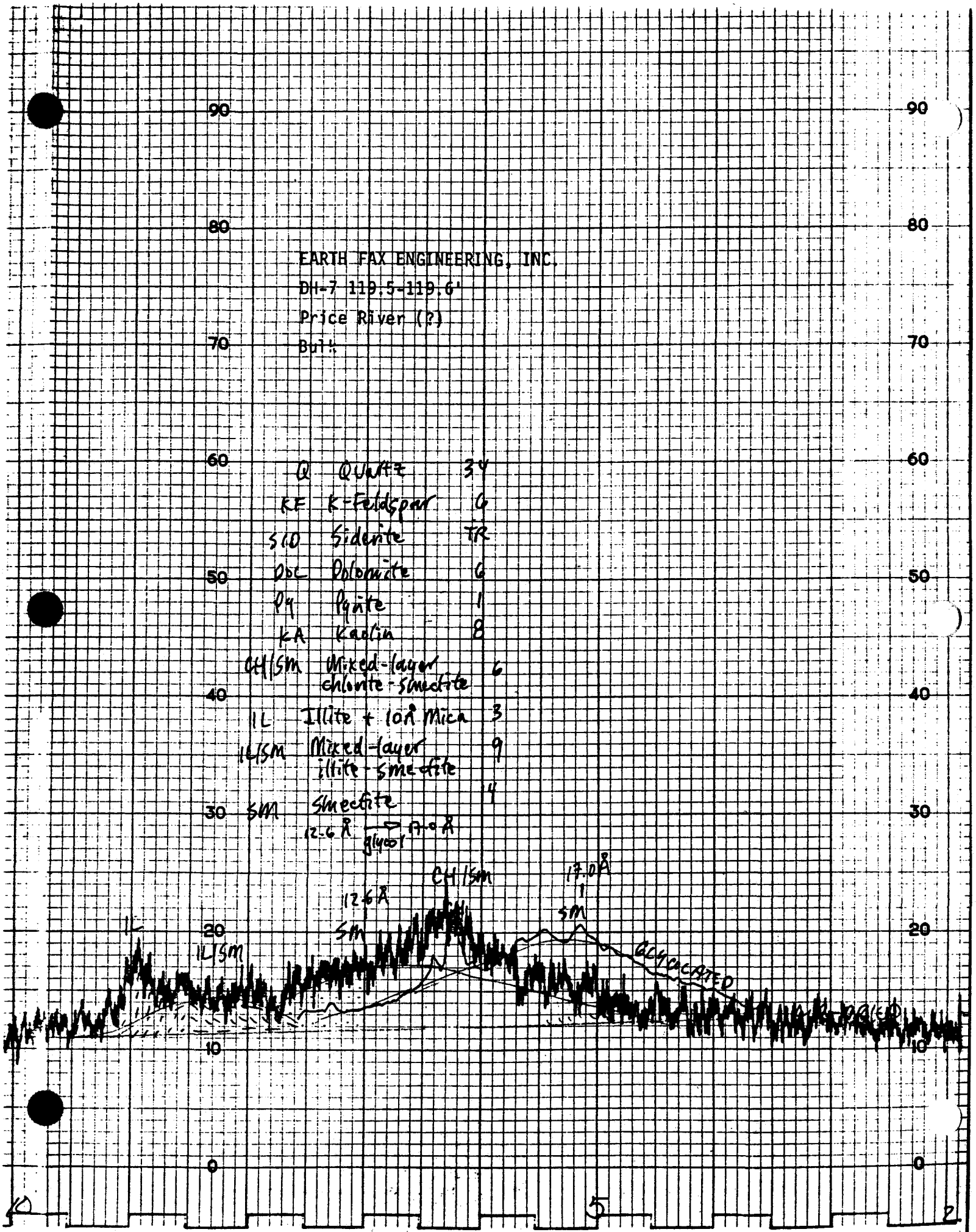
EARTH FAX ENGINEERING, INC.

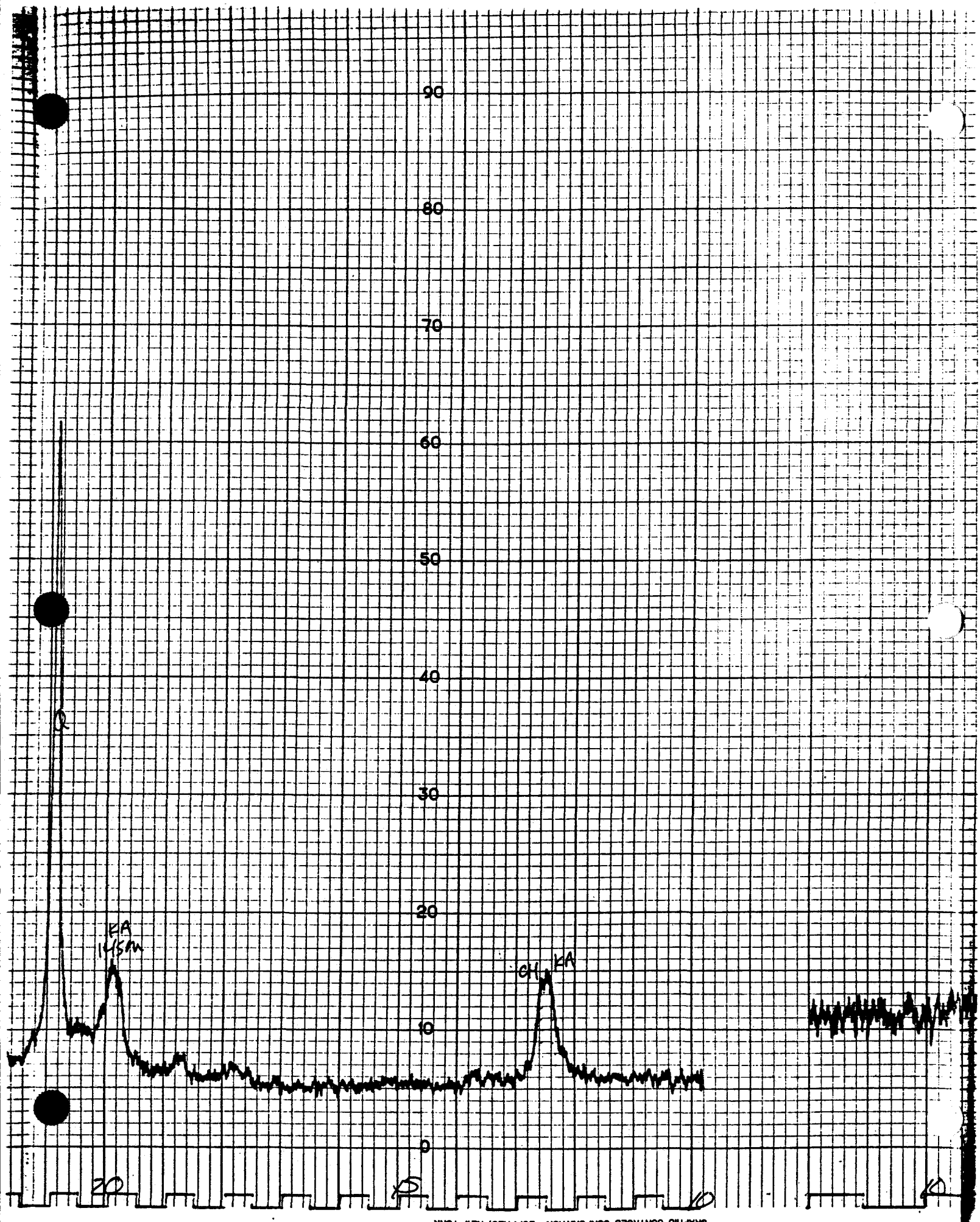
DH-7 119.5-119.6'

Price River (?)

Bulk

Q	Quartz	34
KF	K-Feldspar	6
SID	Siderite	TR
DOL	Dolomite	6
PY	Pyrite	1
KA	Kaolin	8
CH/SM	Mixed-layer chlorite-smectite	6
IL	Illite + 10Å Mica	3
IL/SM	Mixed-layer illite-smectite	9
SM	Smectite	4





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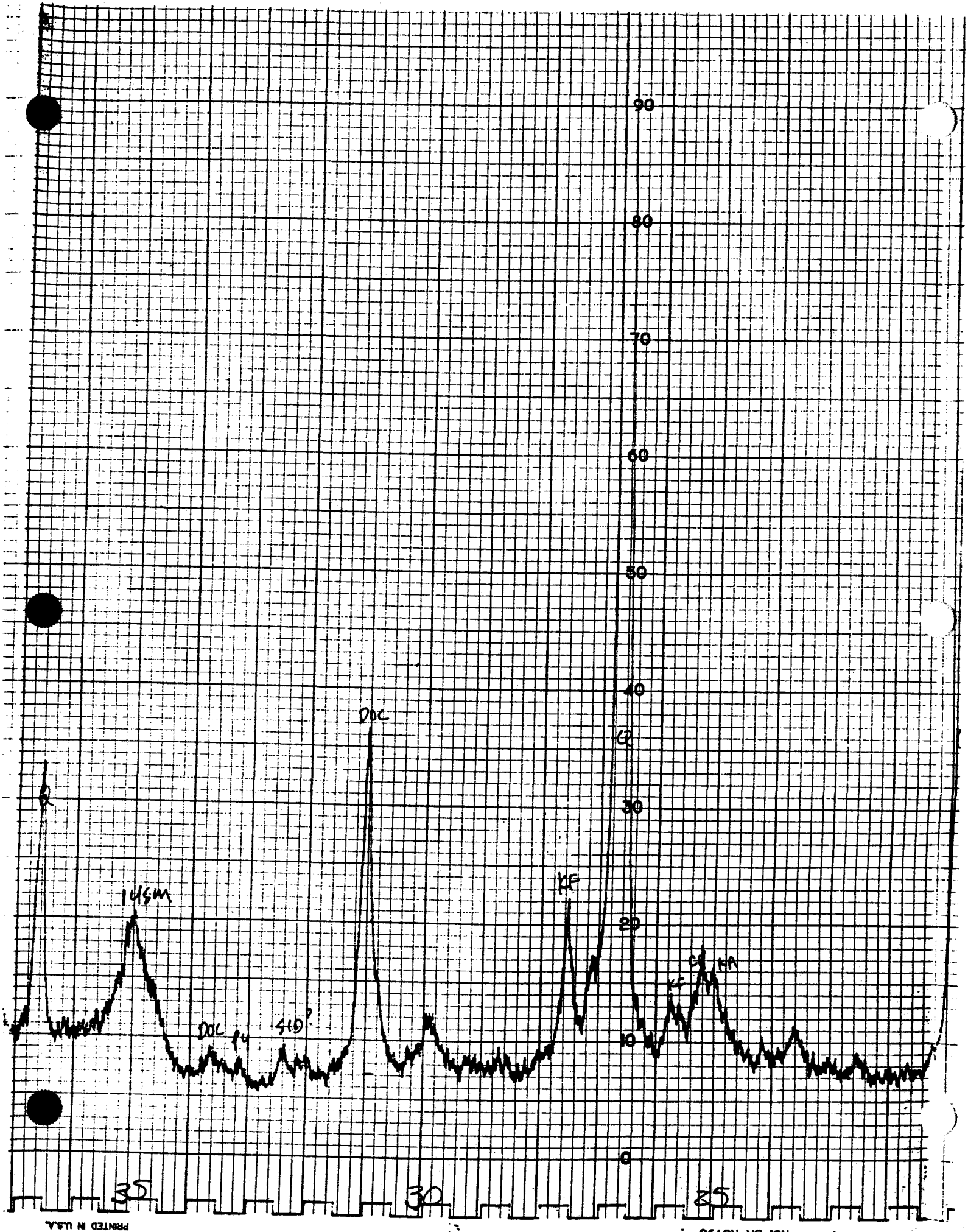

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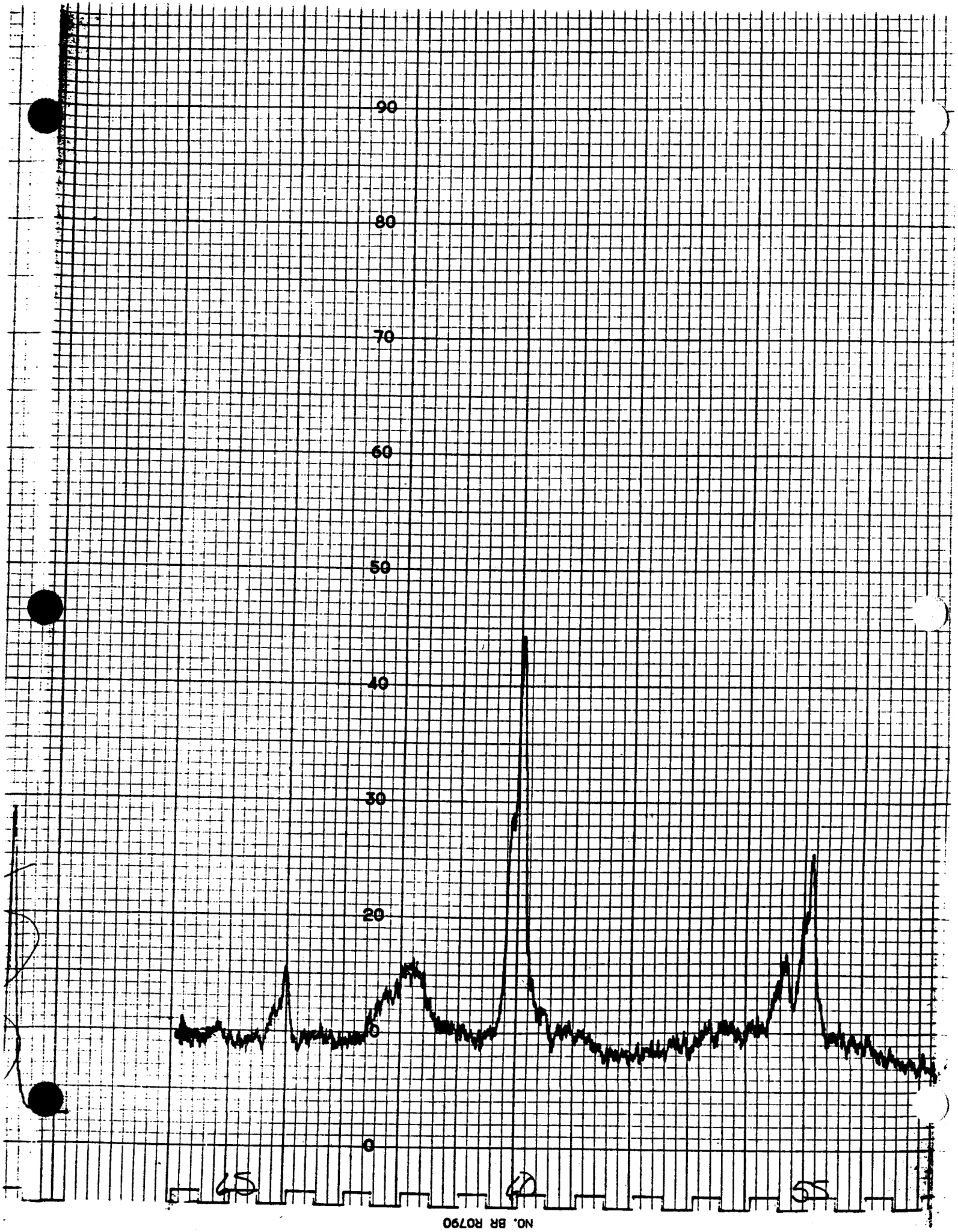
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK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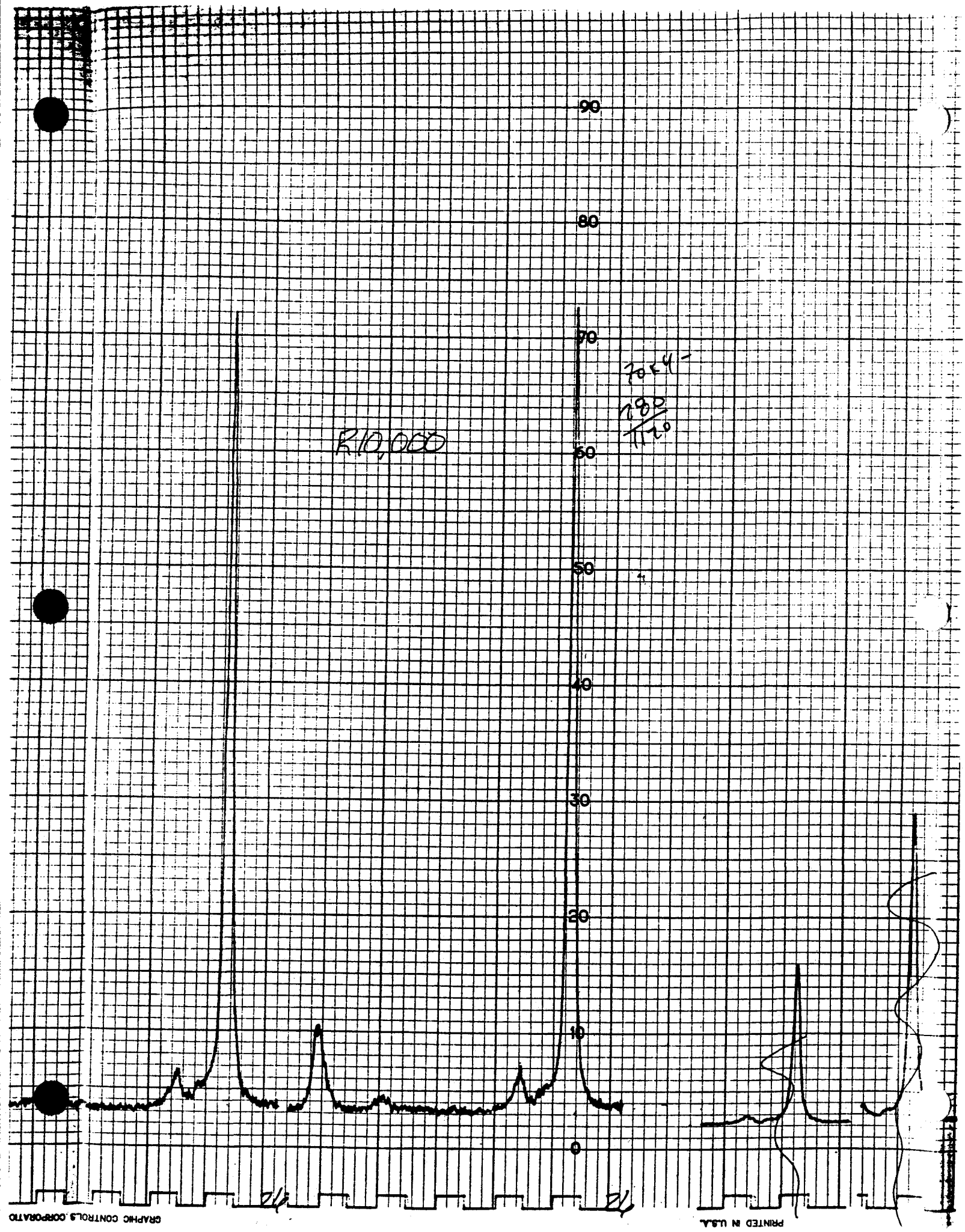
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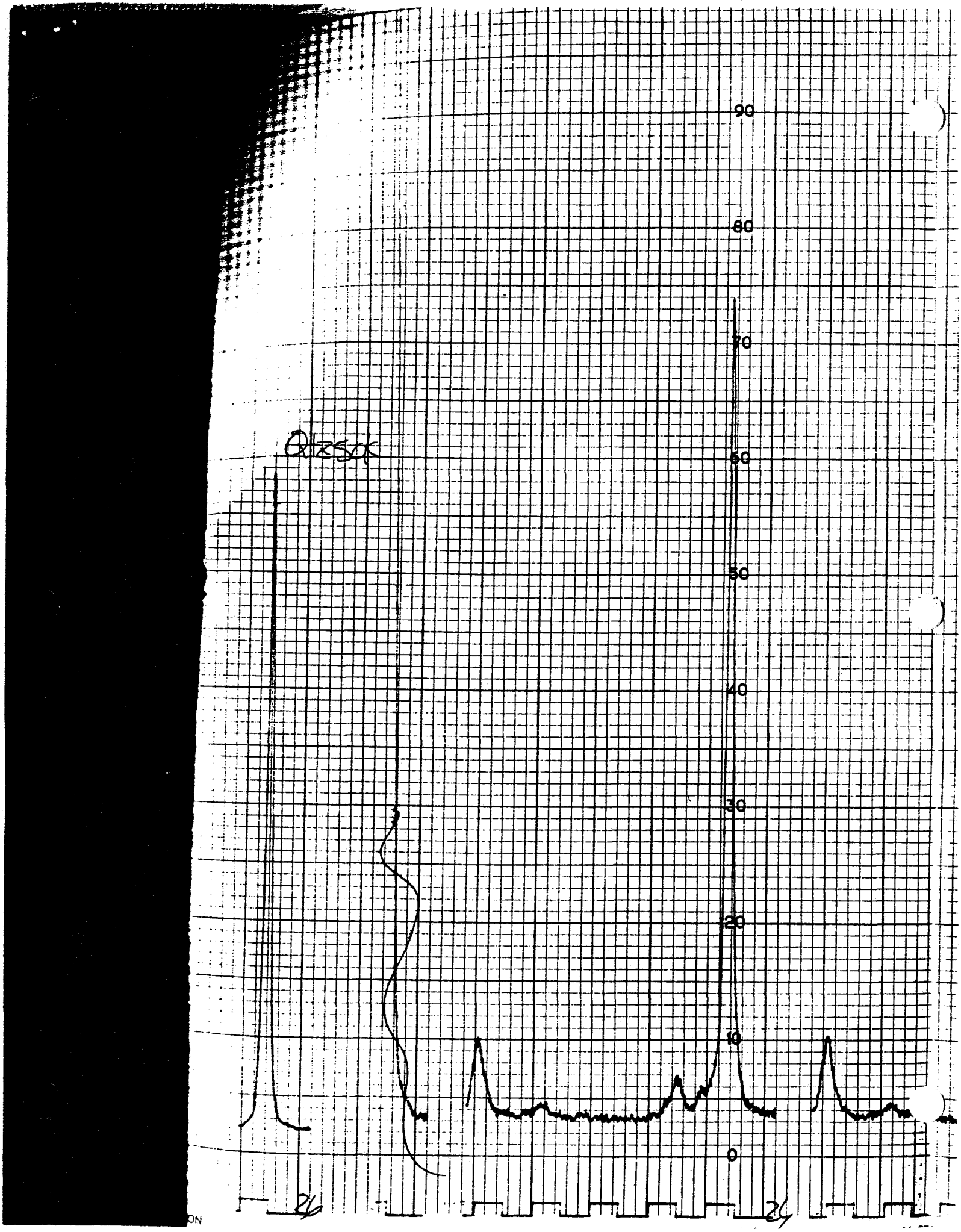
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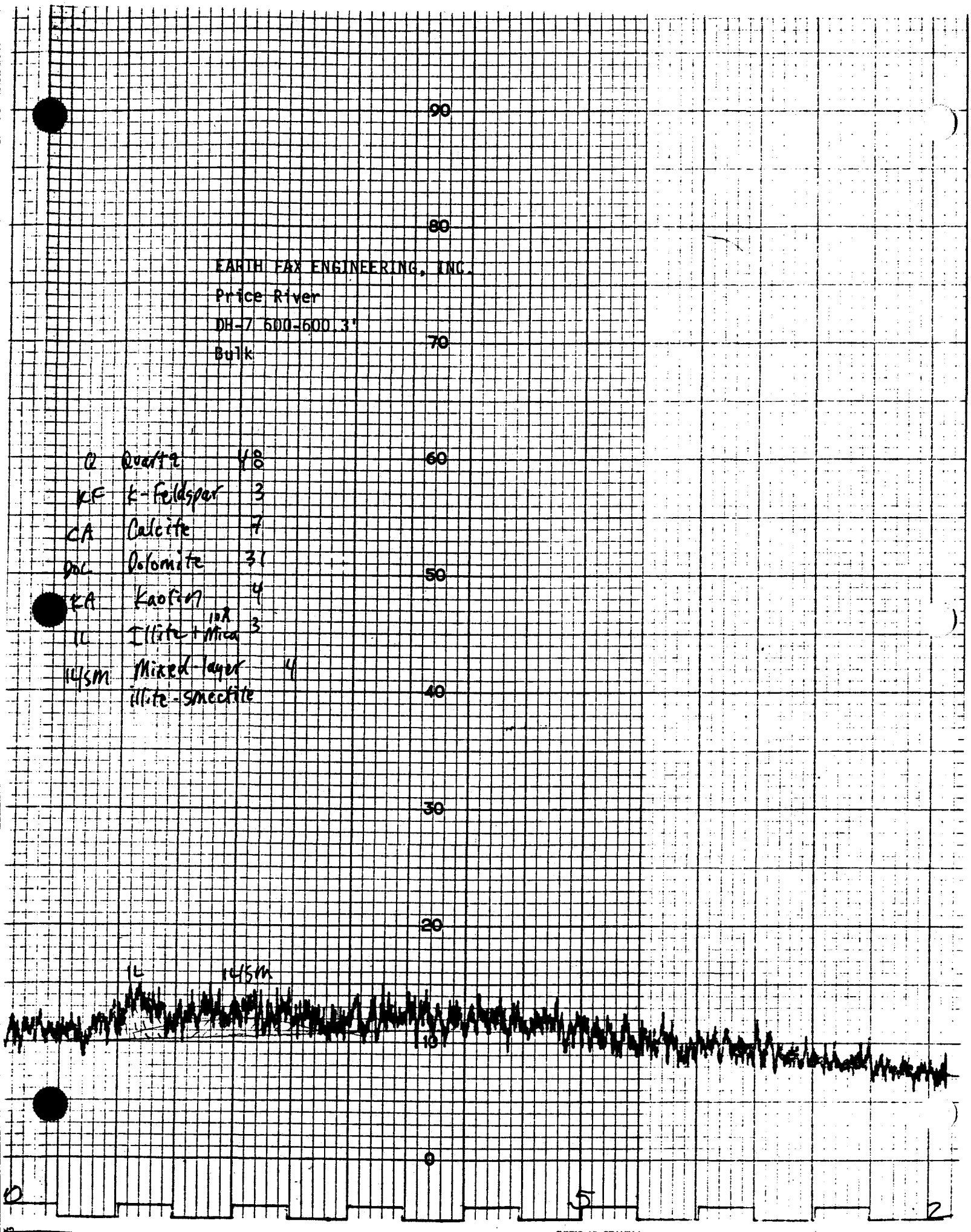
EARTH FAX ENGINEERING, INC.
Price River
DH-7 600-600.3'
Bulk

Q	Quartz	48
KF	K-Feldspar	3
CA	Calcite	7
DOL	Dolomite	31
KA	Kaolin	4
IL	Illite + Mica 10Å	3
I4SM	Mixed-layer illite-smectite	4



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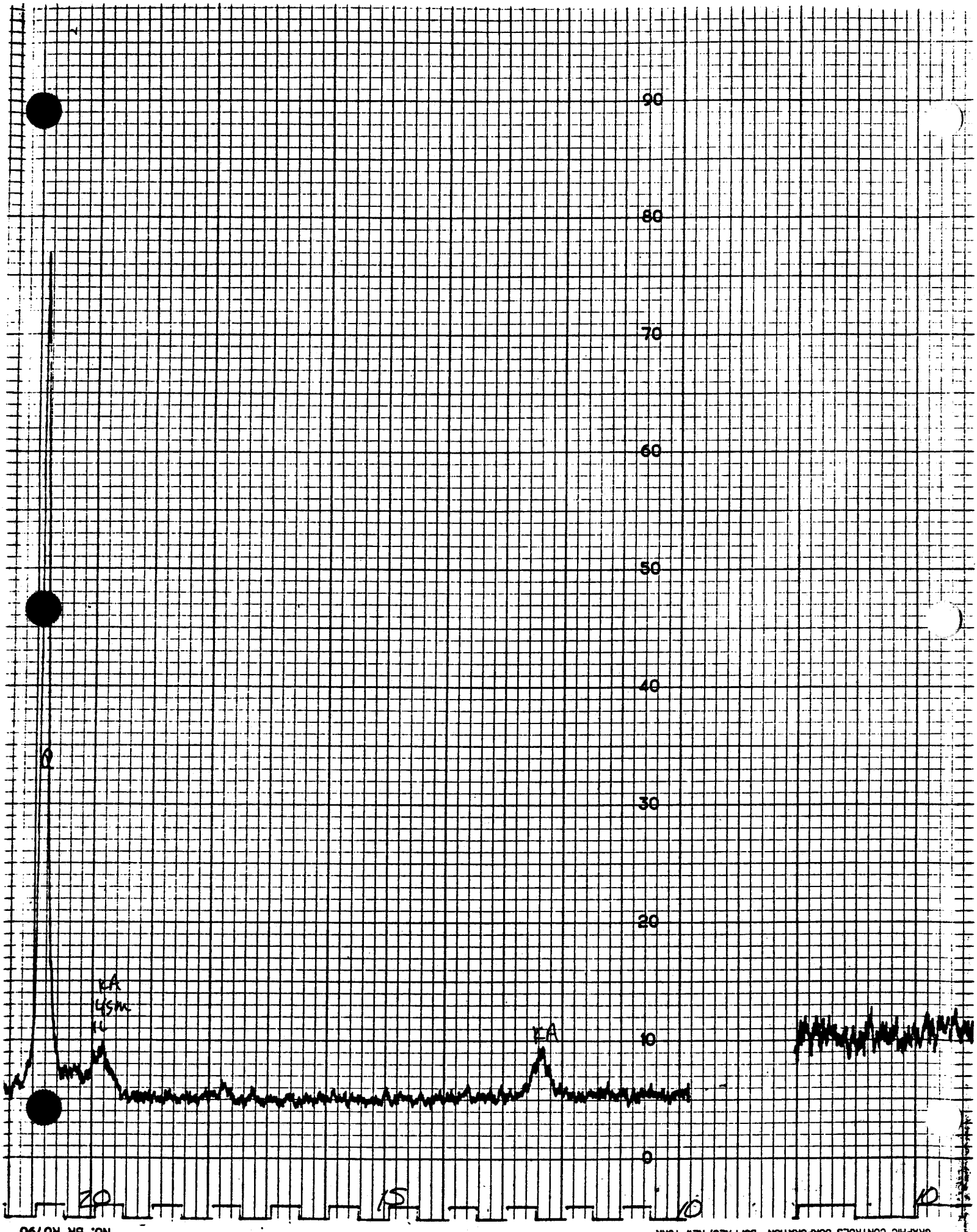

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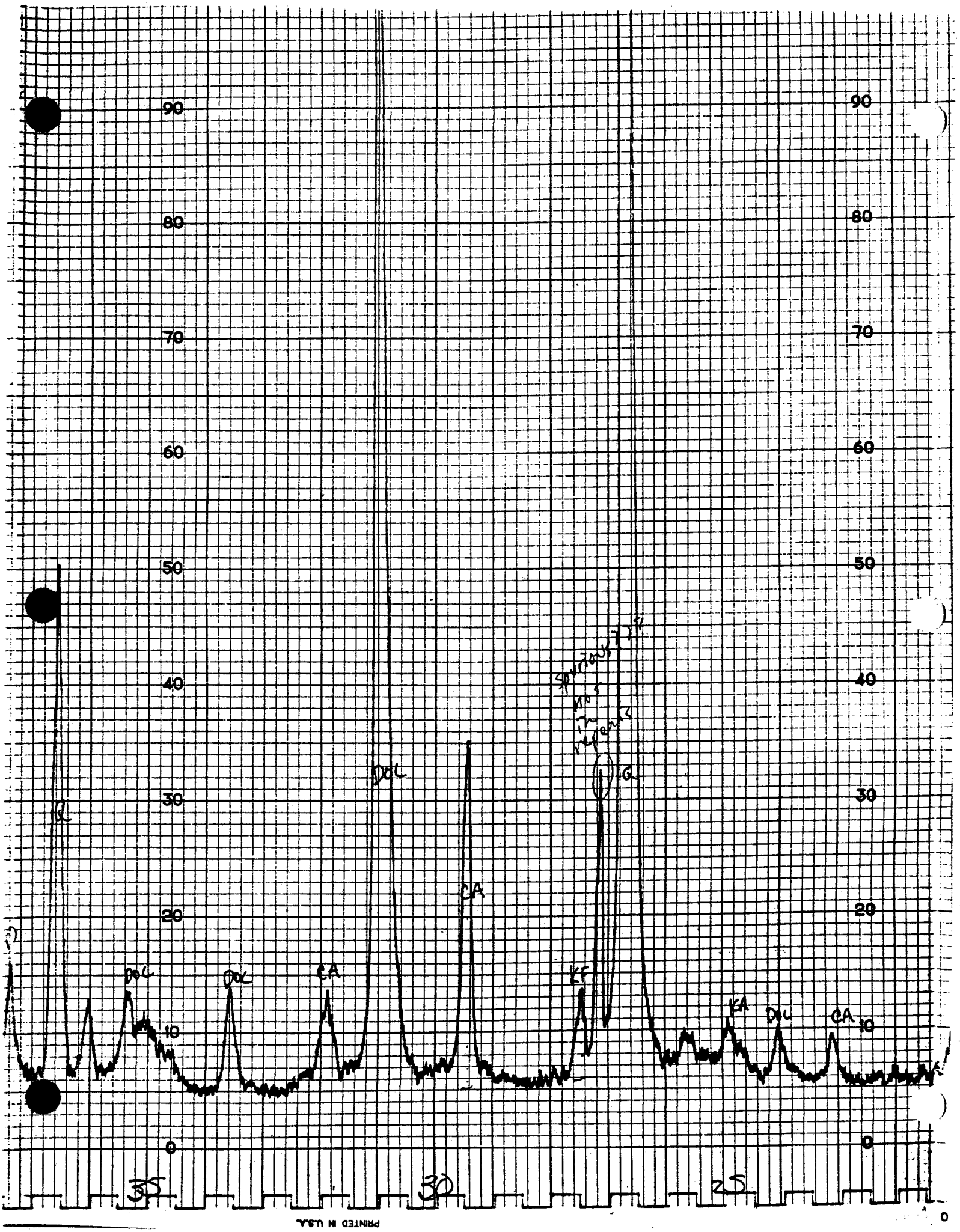
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK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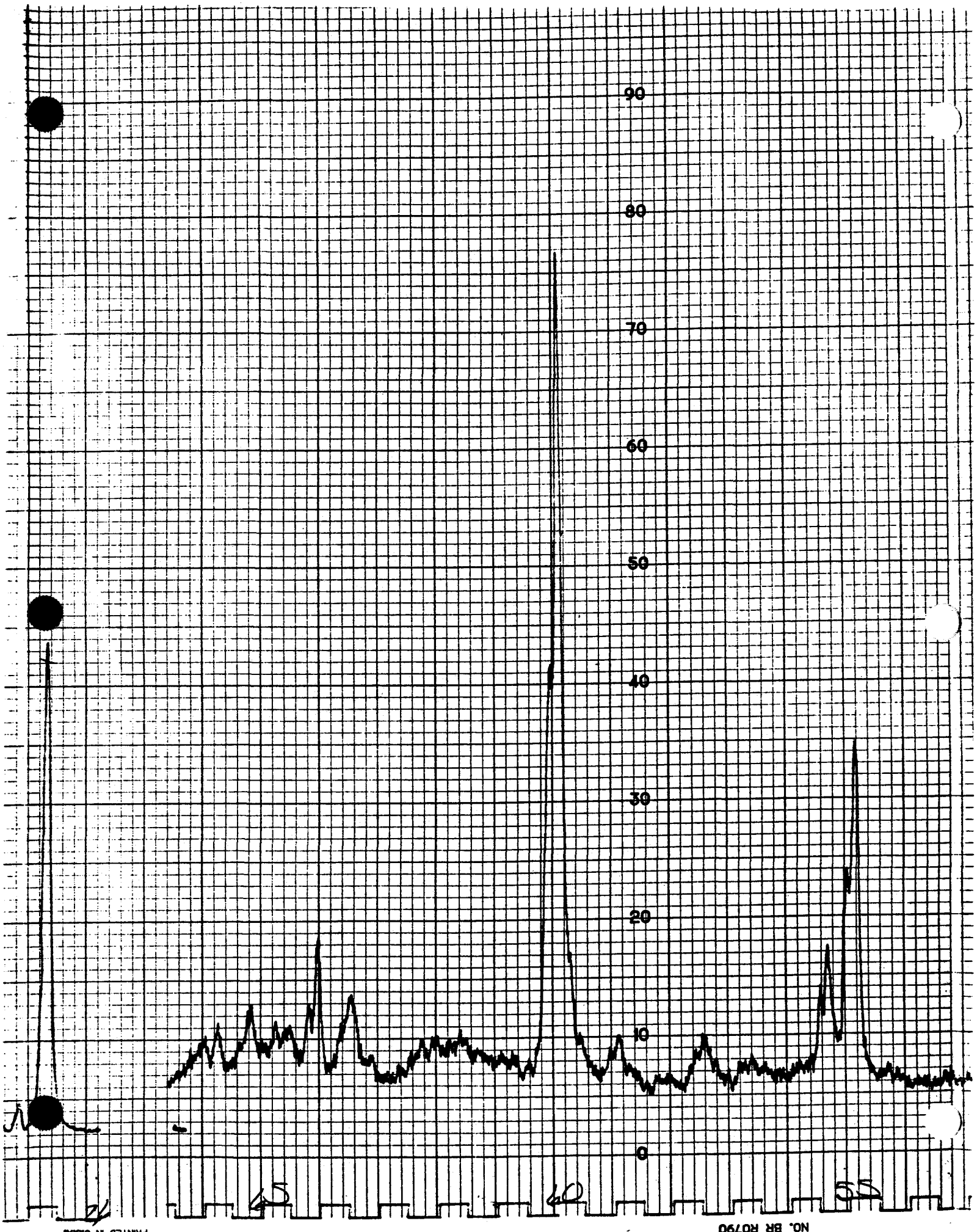
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK



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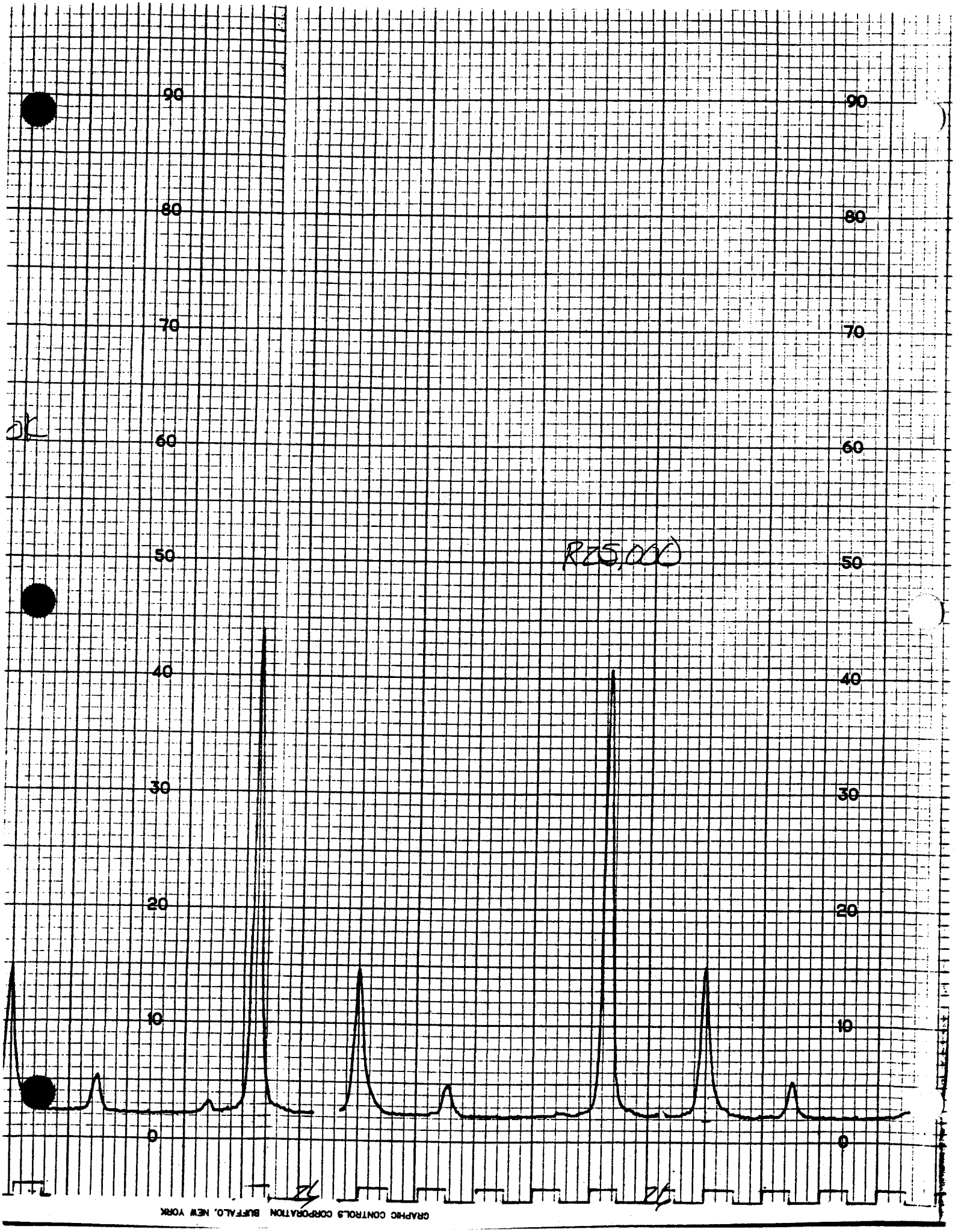
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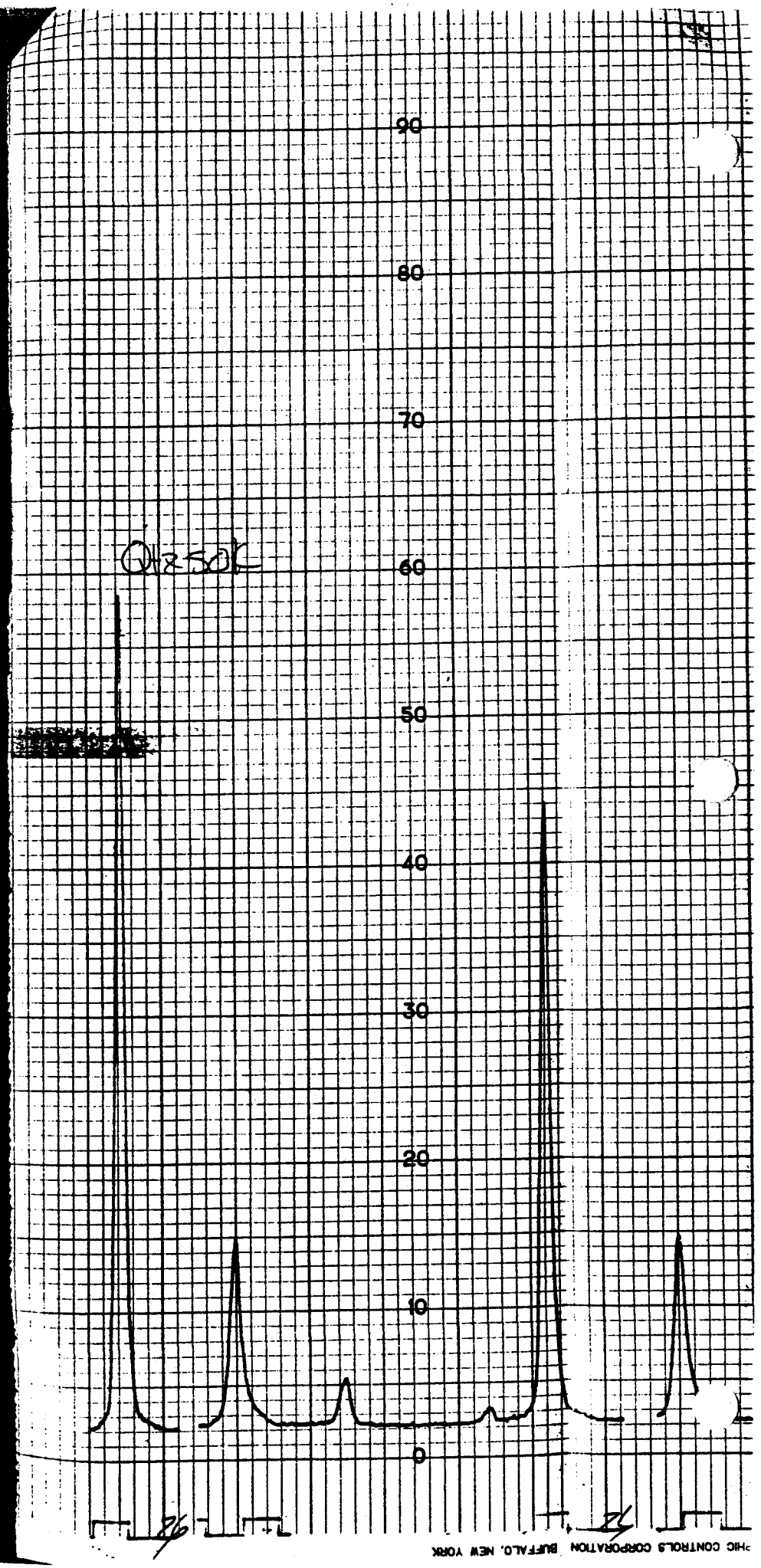
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK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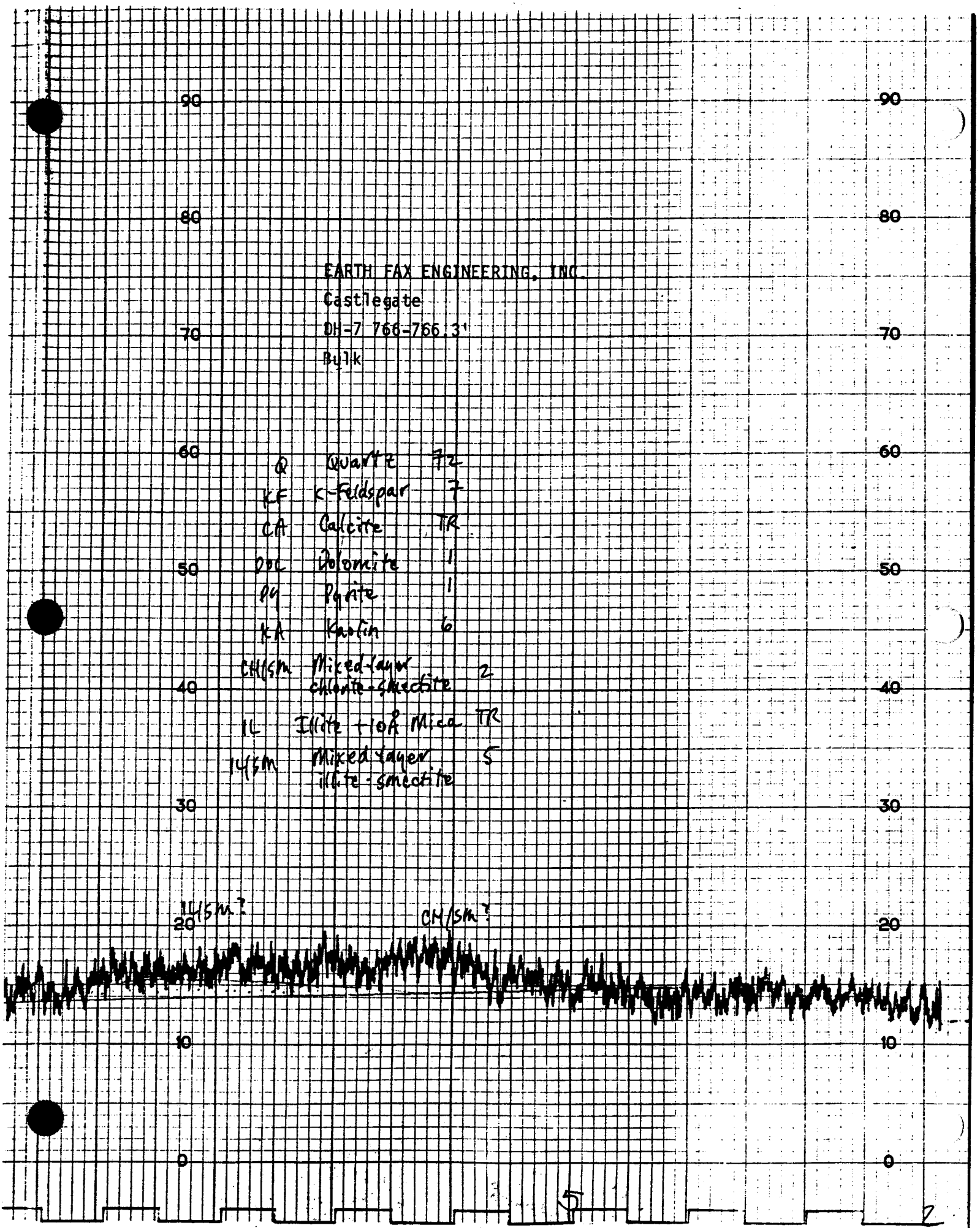
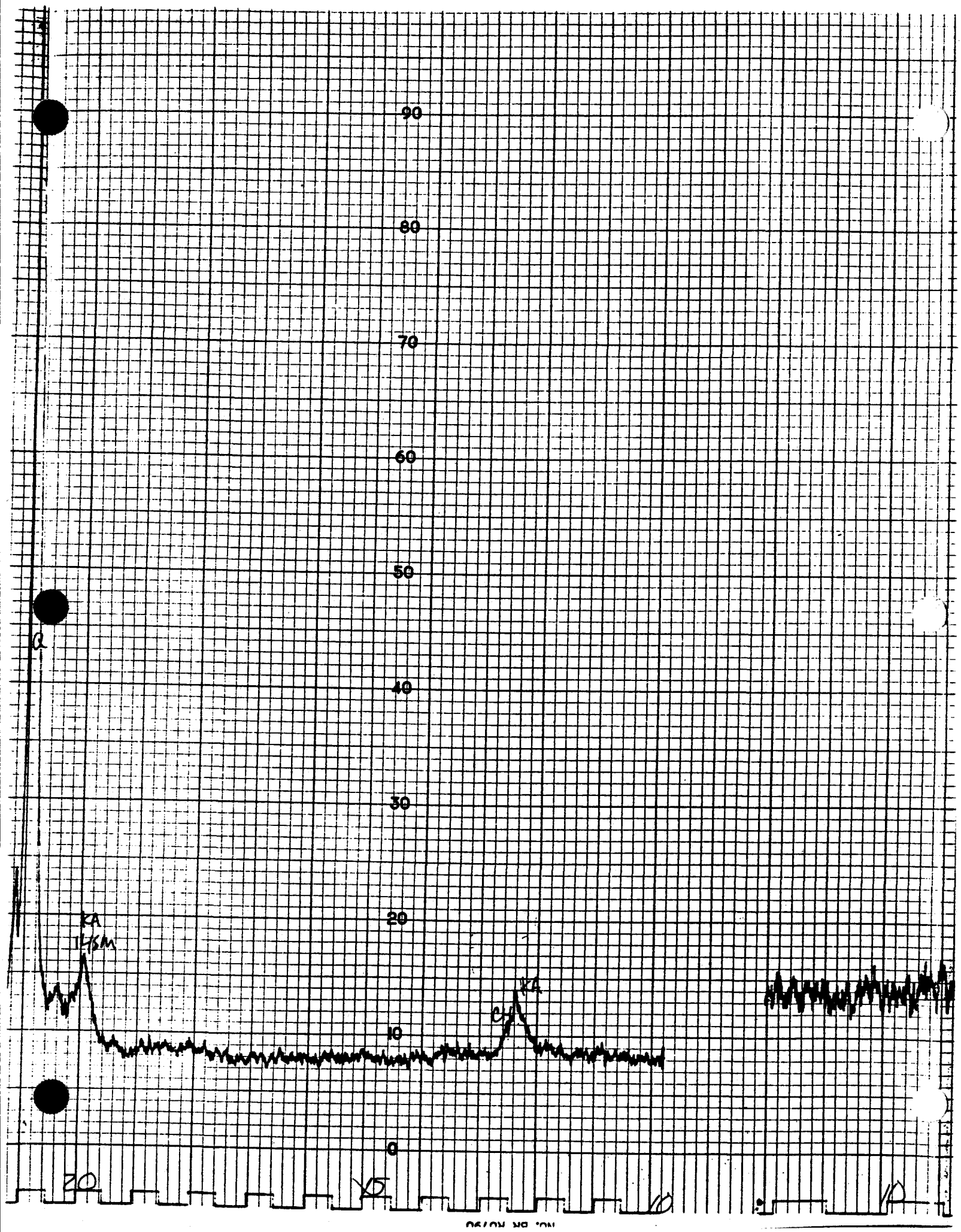
PHIC CONTROLS CORPORATION BUFFALO, NEW YORK

EARTH FAX ENGINEERING, INC.
Castlegate
DH-7 766-766.3'
Bulk

Q	Quartz	72
KF	K-Feldspar	7
CA	Calcite	TR
DOL	Dolomite	1
PY	Pyrite	1
KA	Kaolin	6
CH/SM	Mixed-layer chlorite-smectite	2
IL	Illite + 10Å Mica	TR
IL/SM	Mixed layer illite-smectite	5

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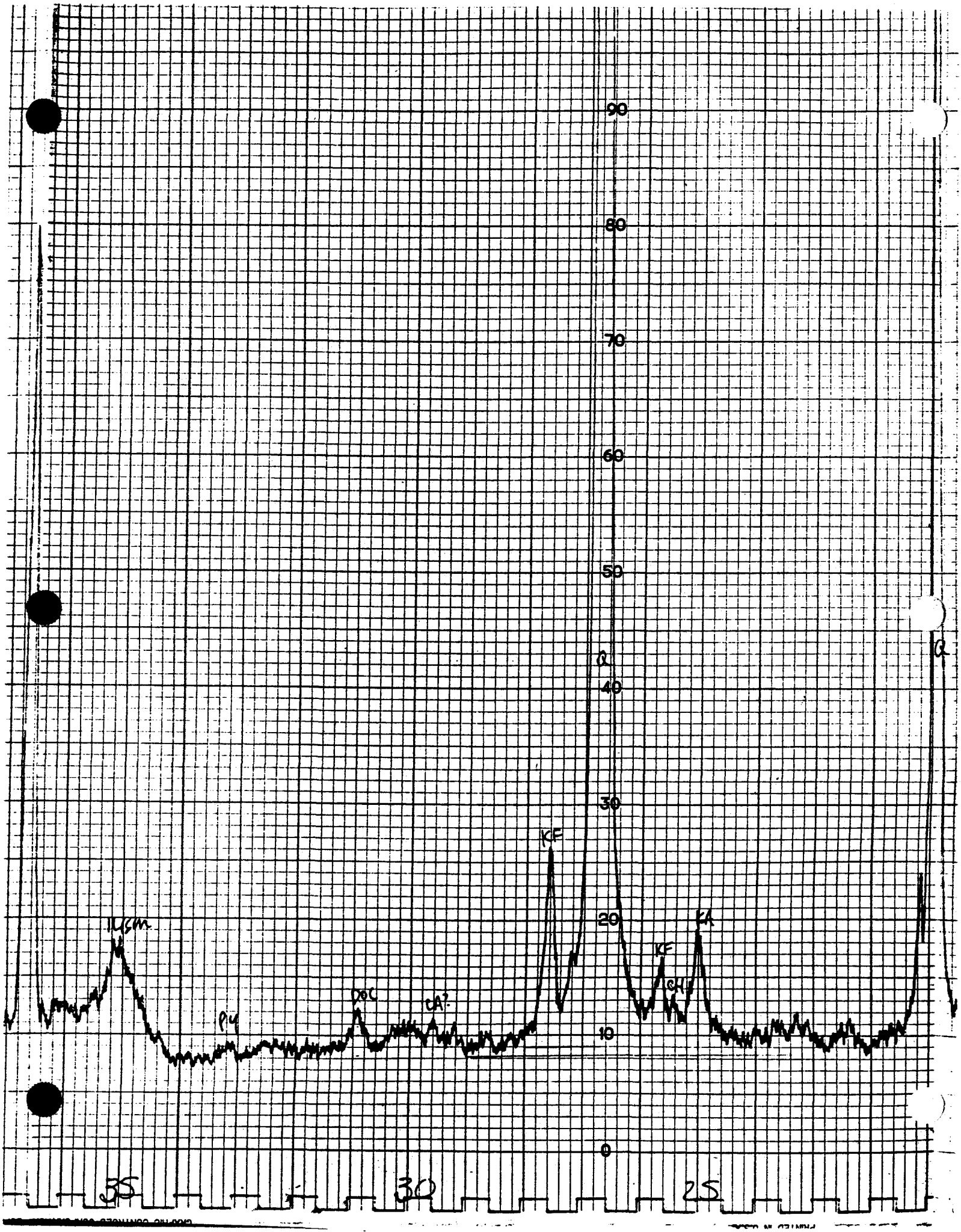

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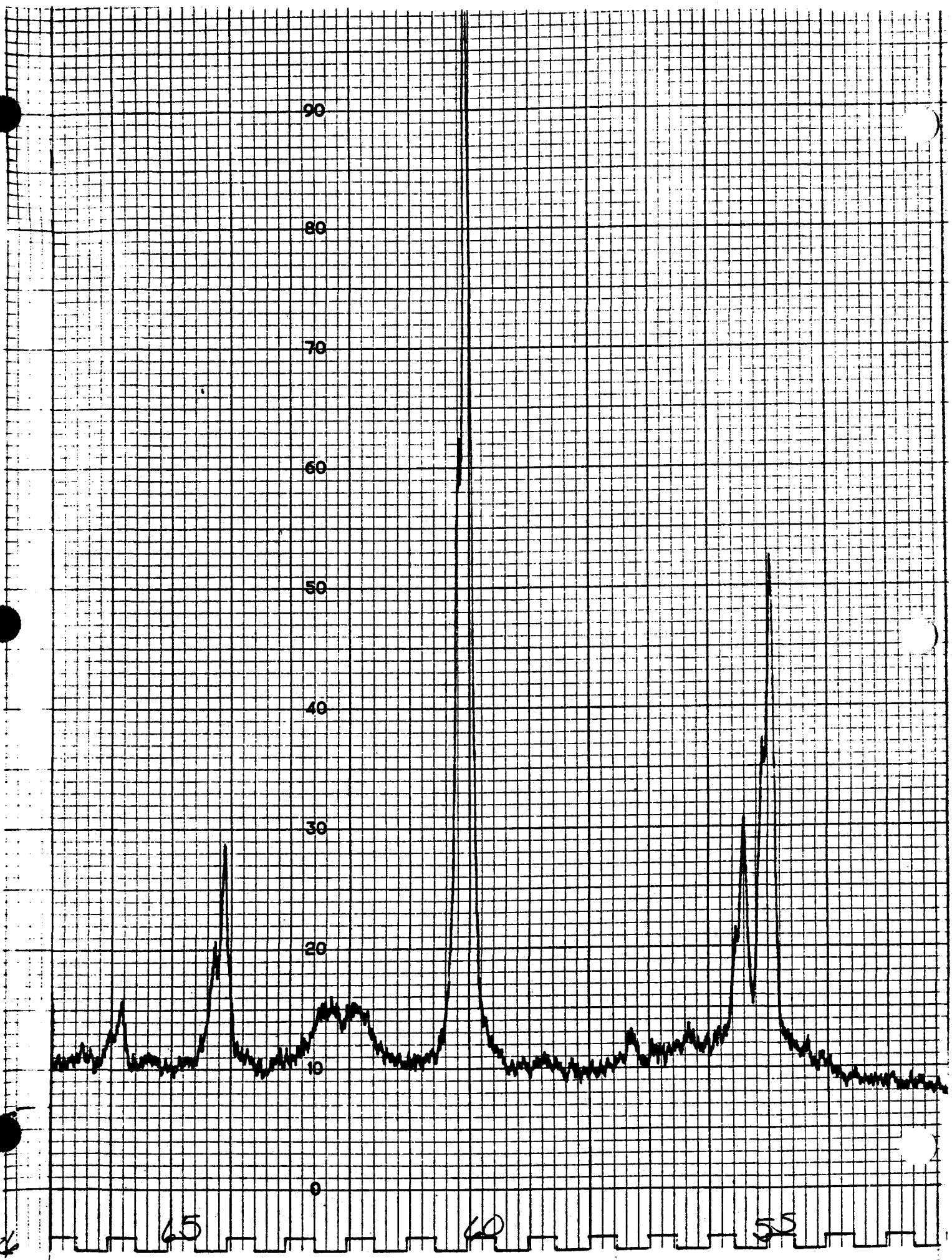

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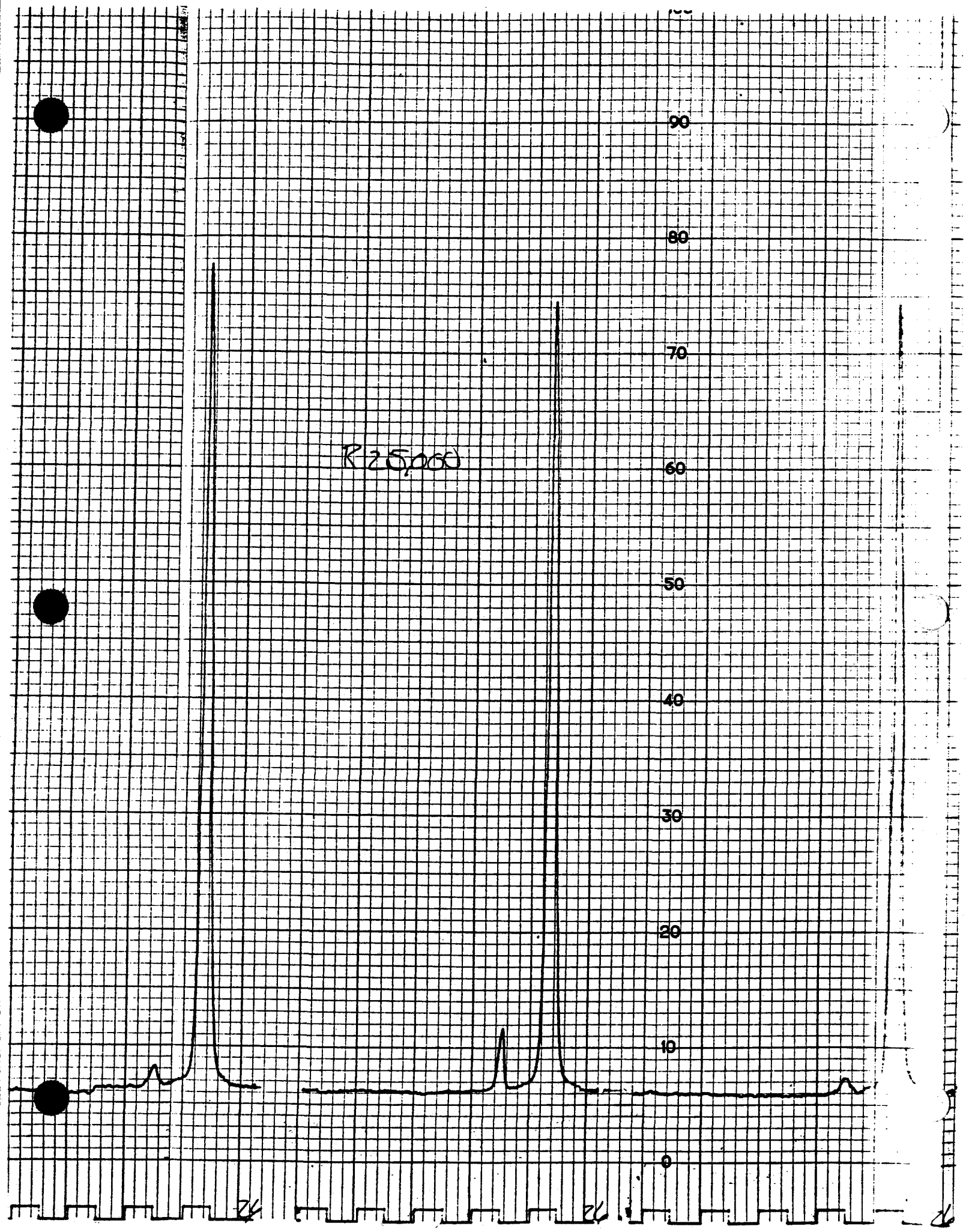
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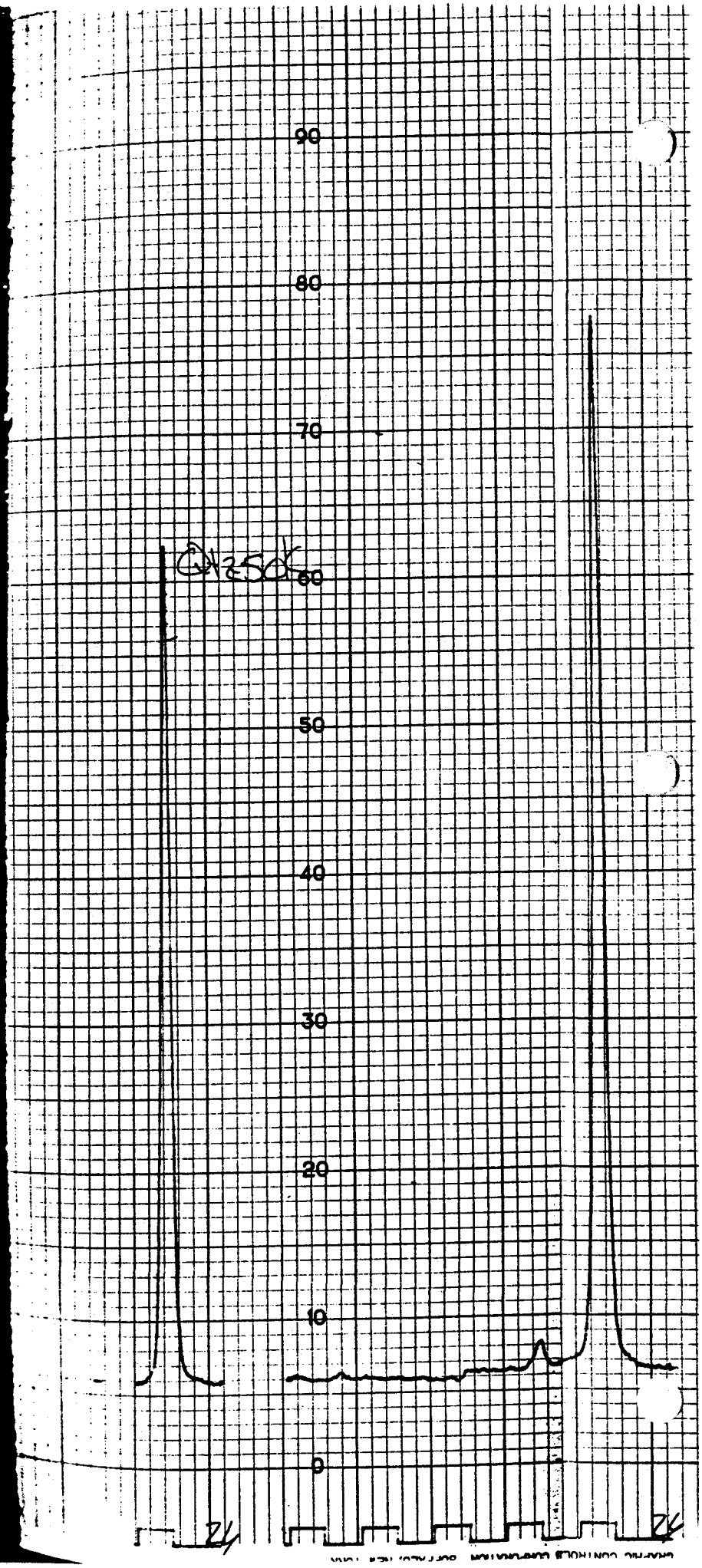
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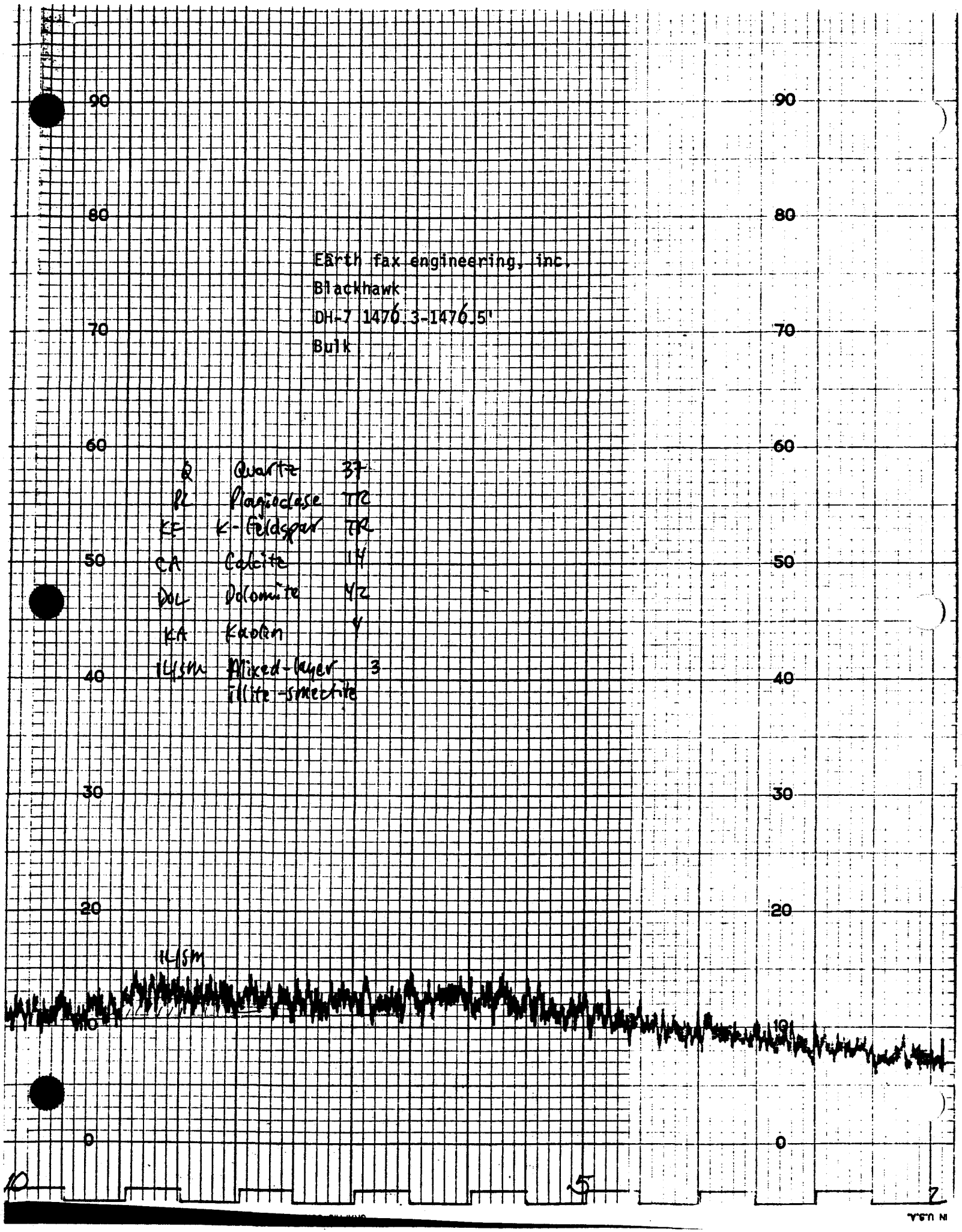
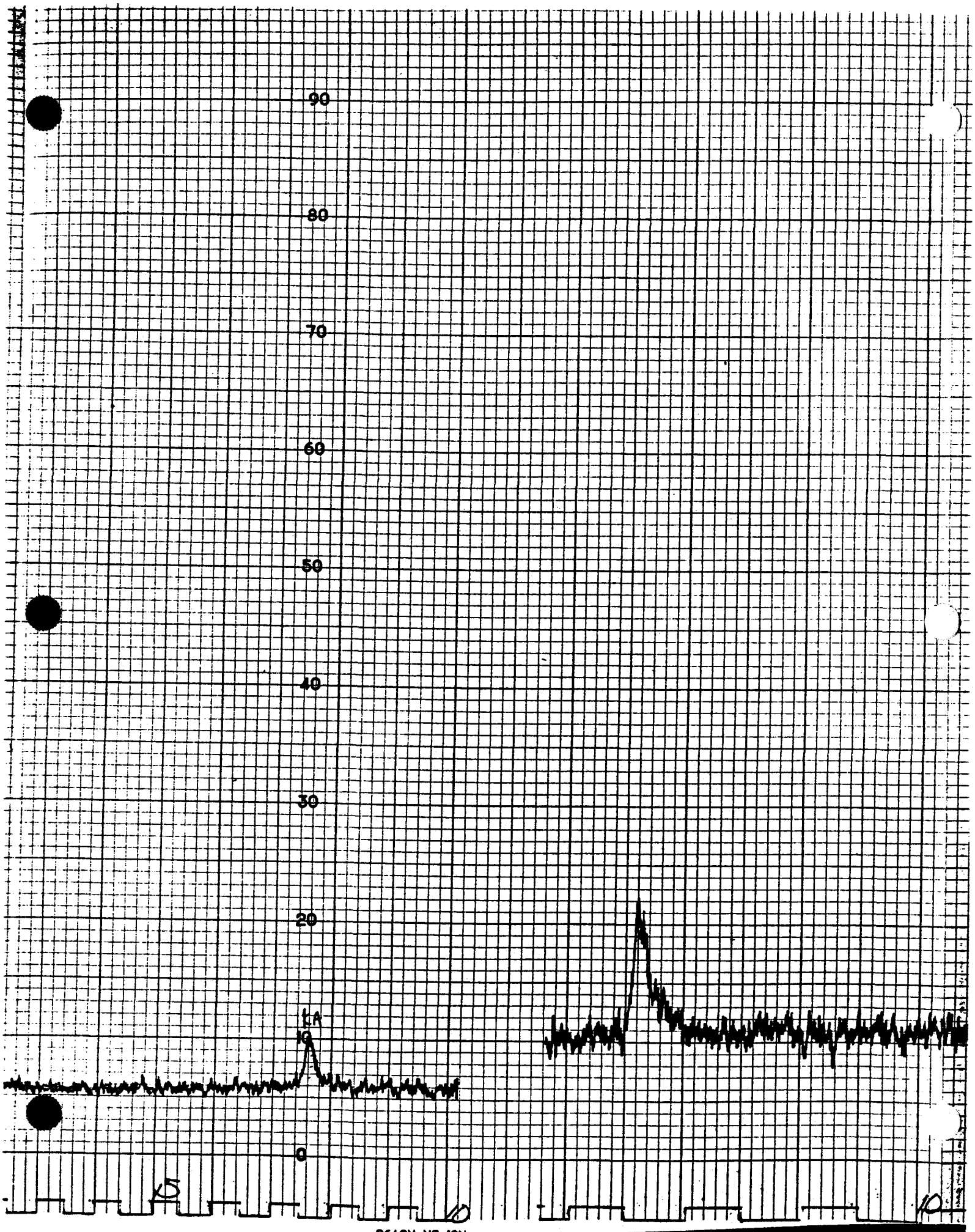
Earth fax engineering, inc.
Blackhawk
DH-7 1476.3-1476.5'
Bulk

Q	Quartz	37
PL	Plagioclase	TR
KF	K-Feldspar	TR
CA	Calcite	14
DOL	Dolomite	42
KA	Kaolin	4
I-S/M	Mixed-layer illite-smectite	3





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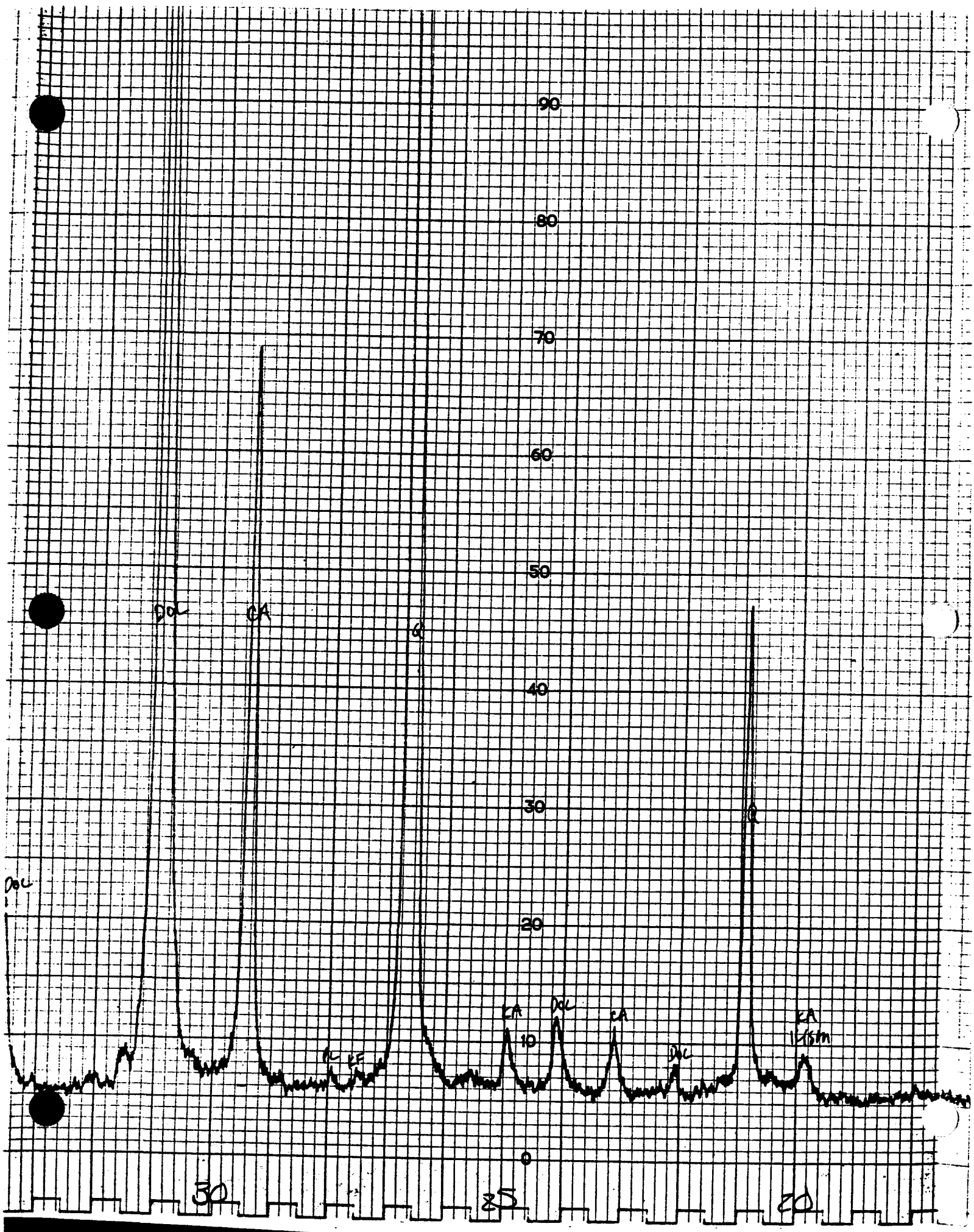

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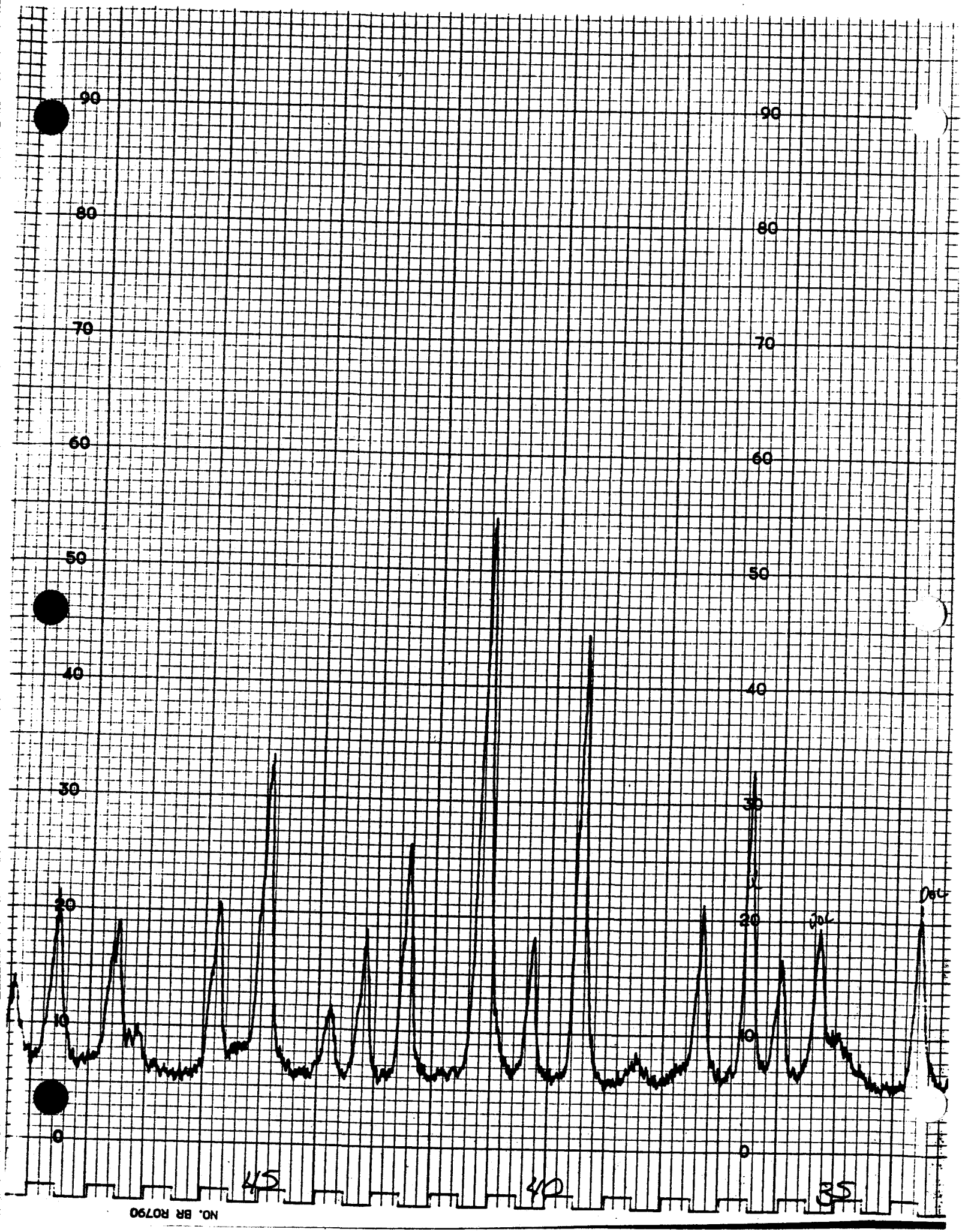
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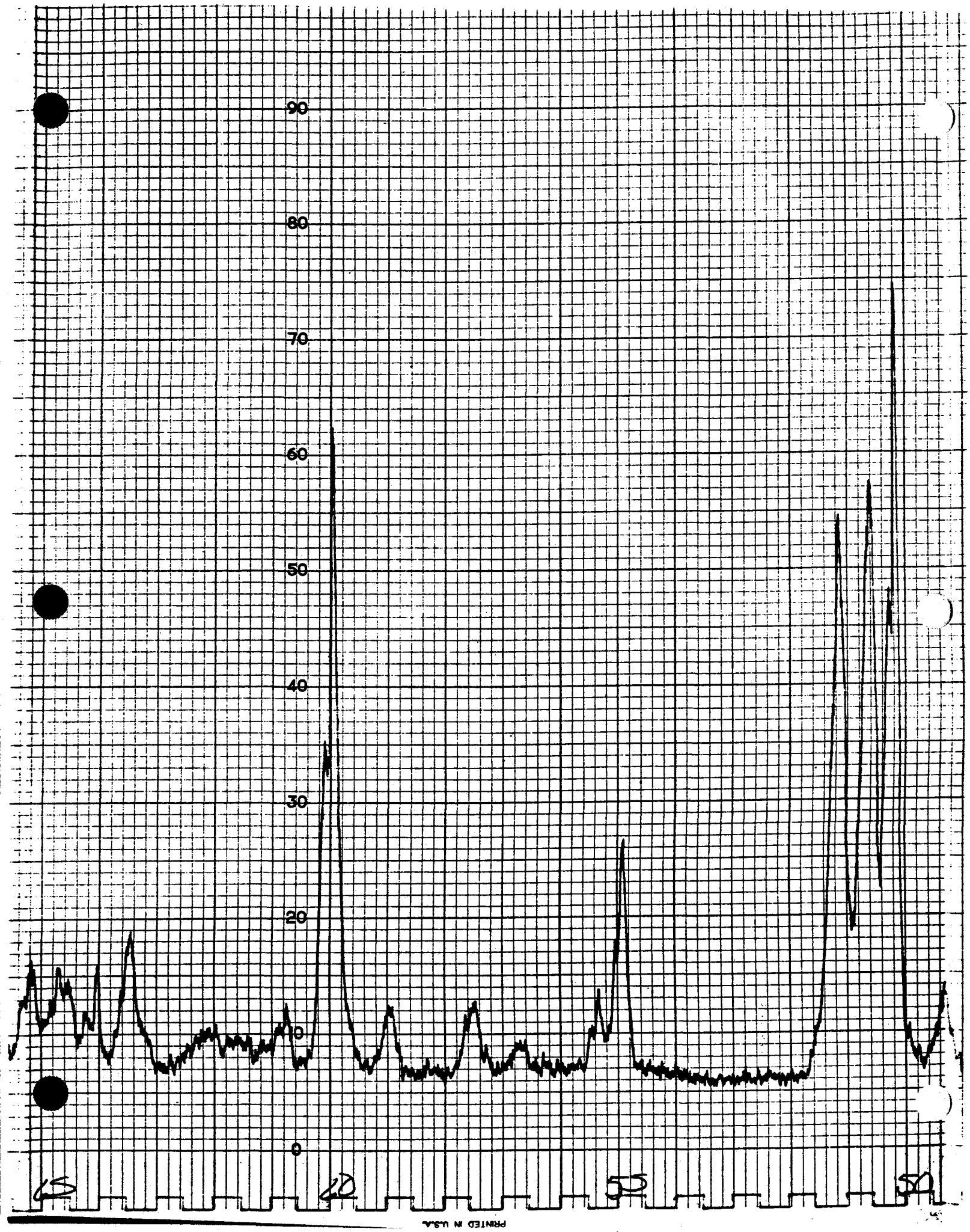

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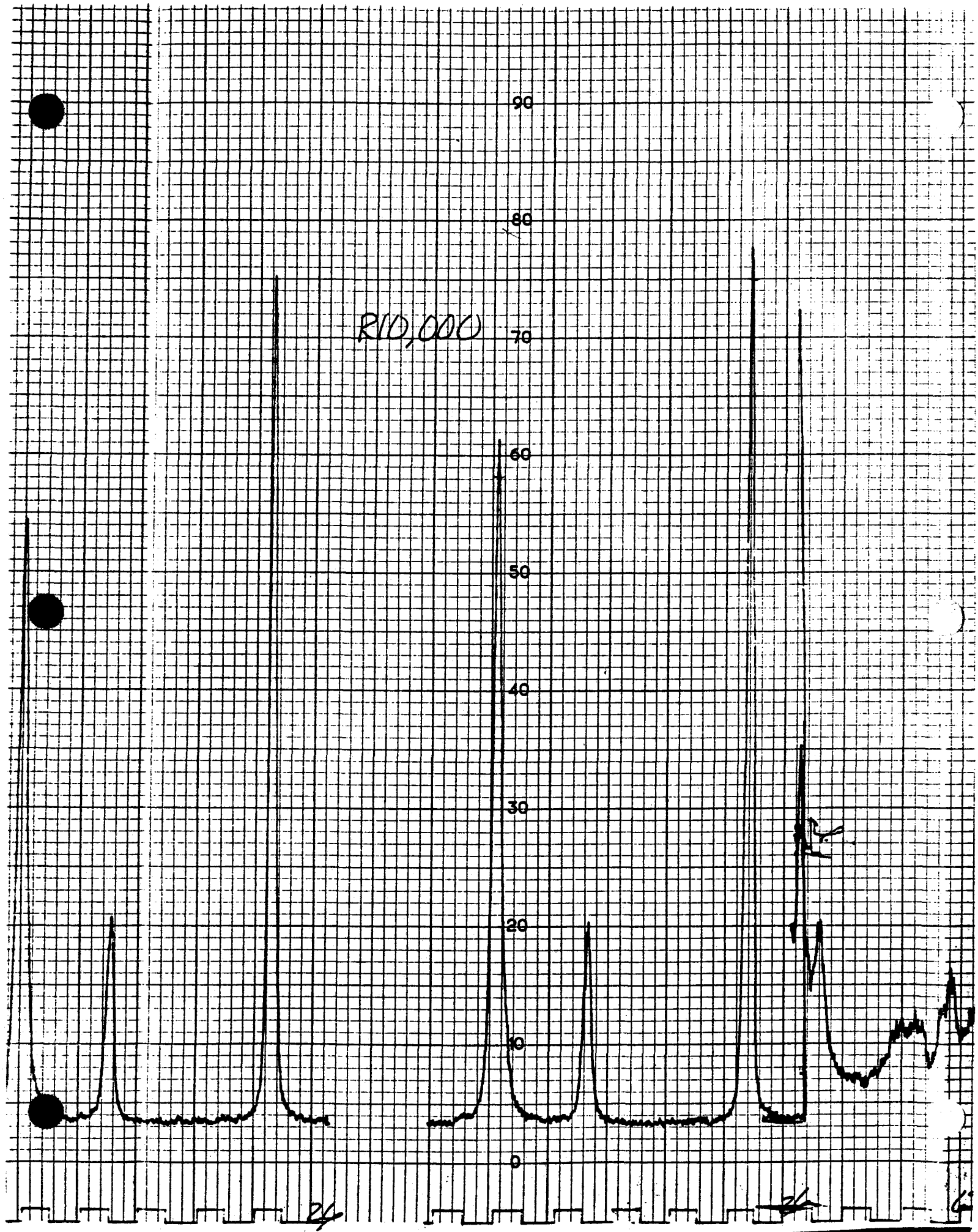
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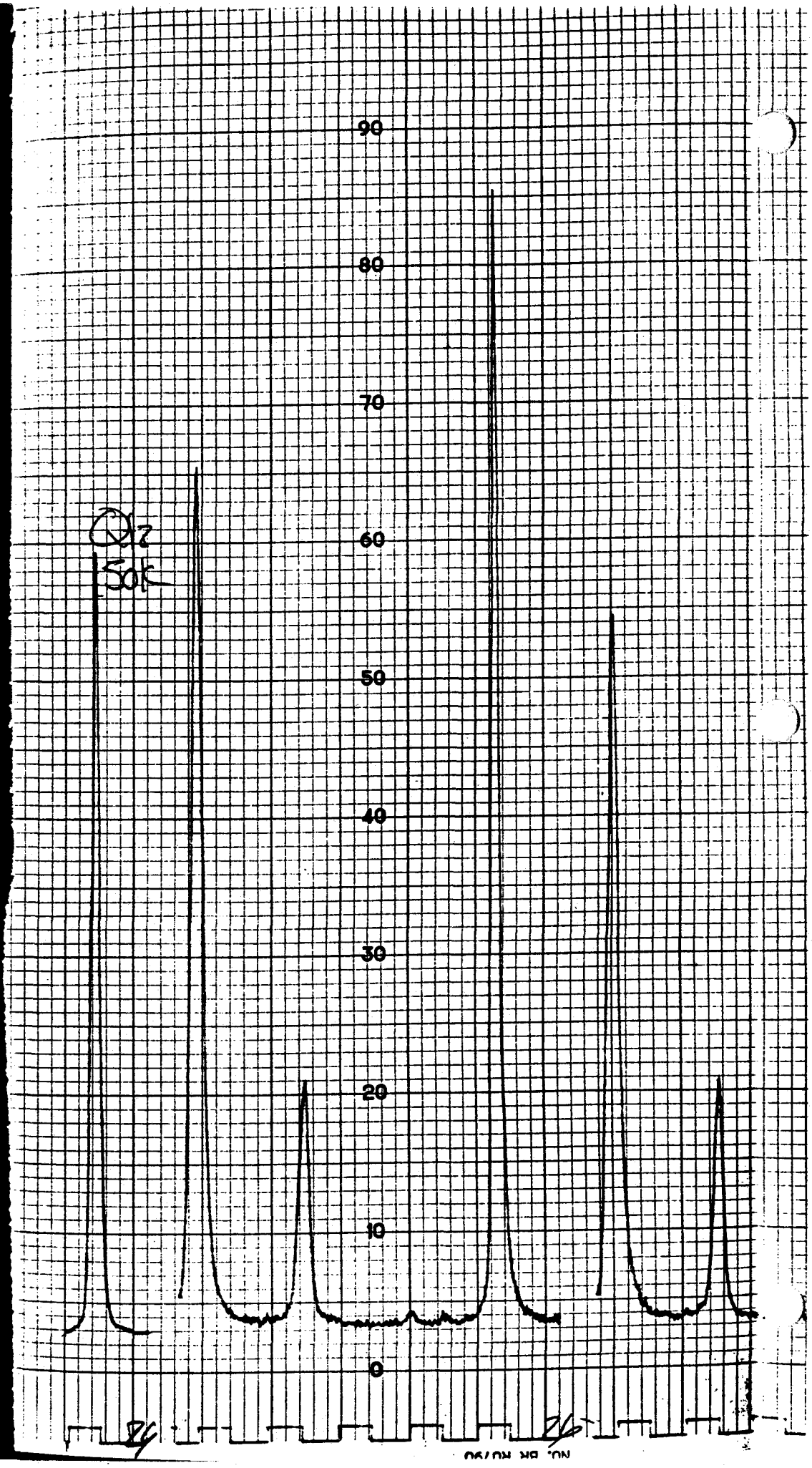
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EARTH FAX ENGINEERING, INC.
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Blackhawk
Bulk Glycol

Q Quartz 27
KF K-Feldspar 1
CA Calcite 5
Dol Dolomite 32
Pla Plagioclase
KA Kaolin 5
I/SM Mixed-layer illite-smectite 19
(~20% smectite interlayers)

I/SM
10.6 Å

RENEW CHART RENEW

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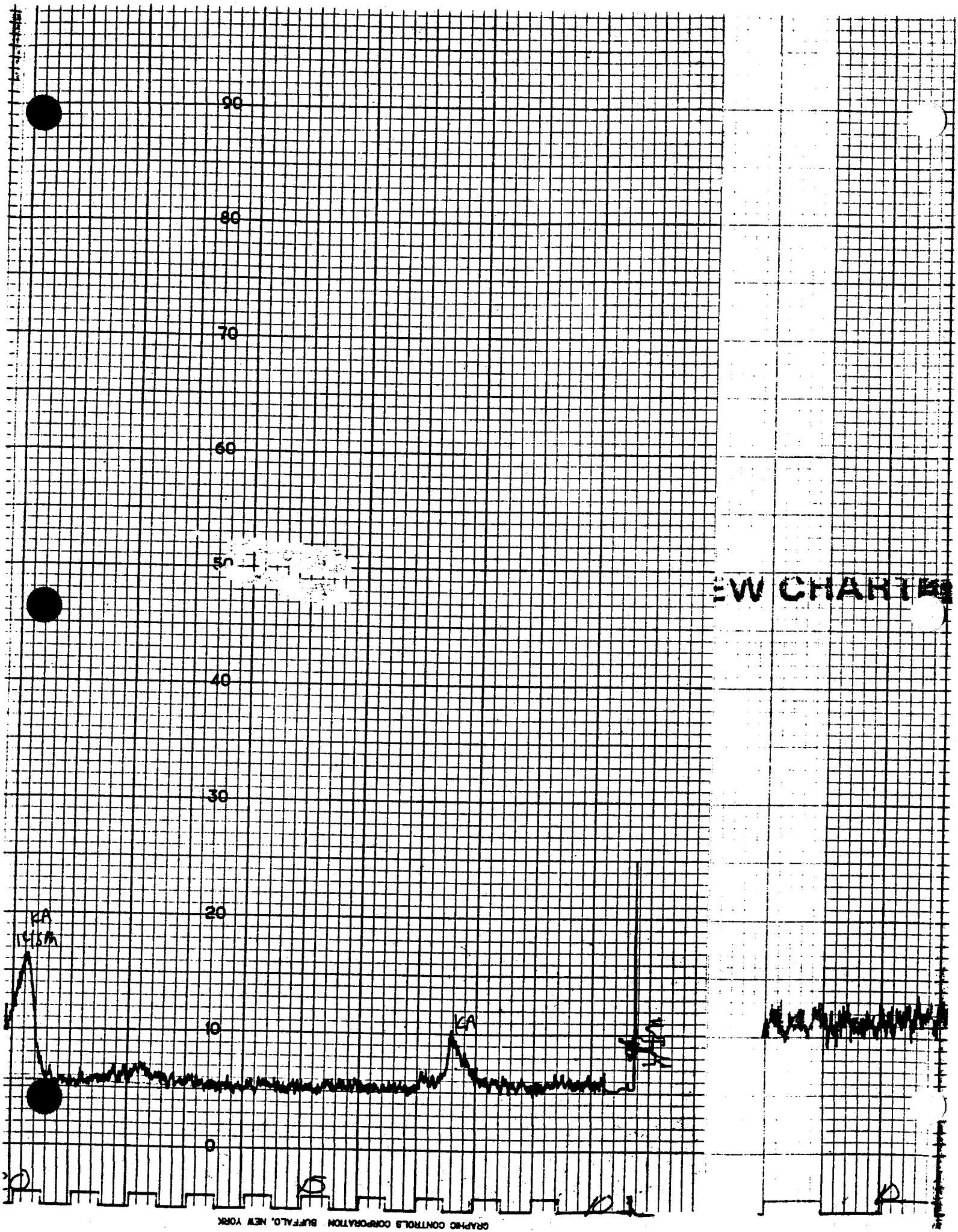
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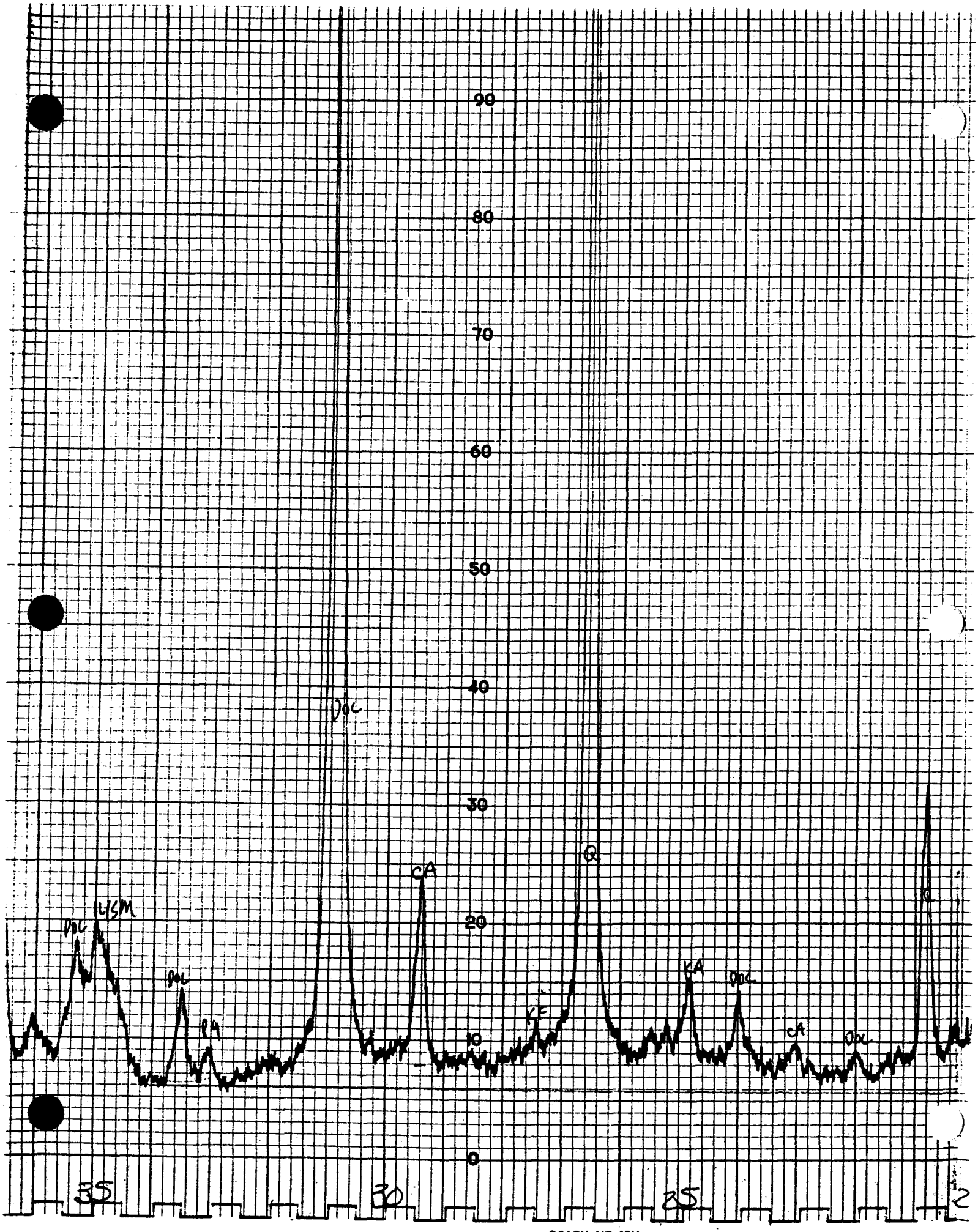
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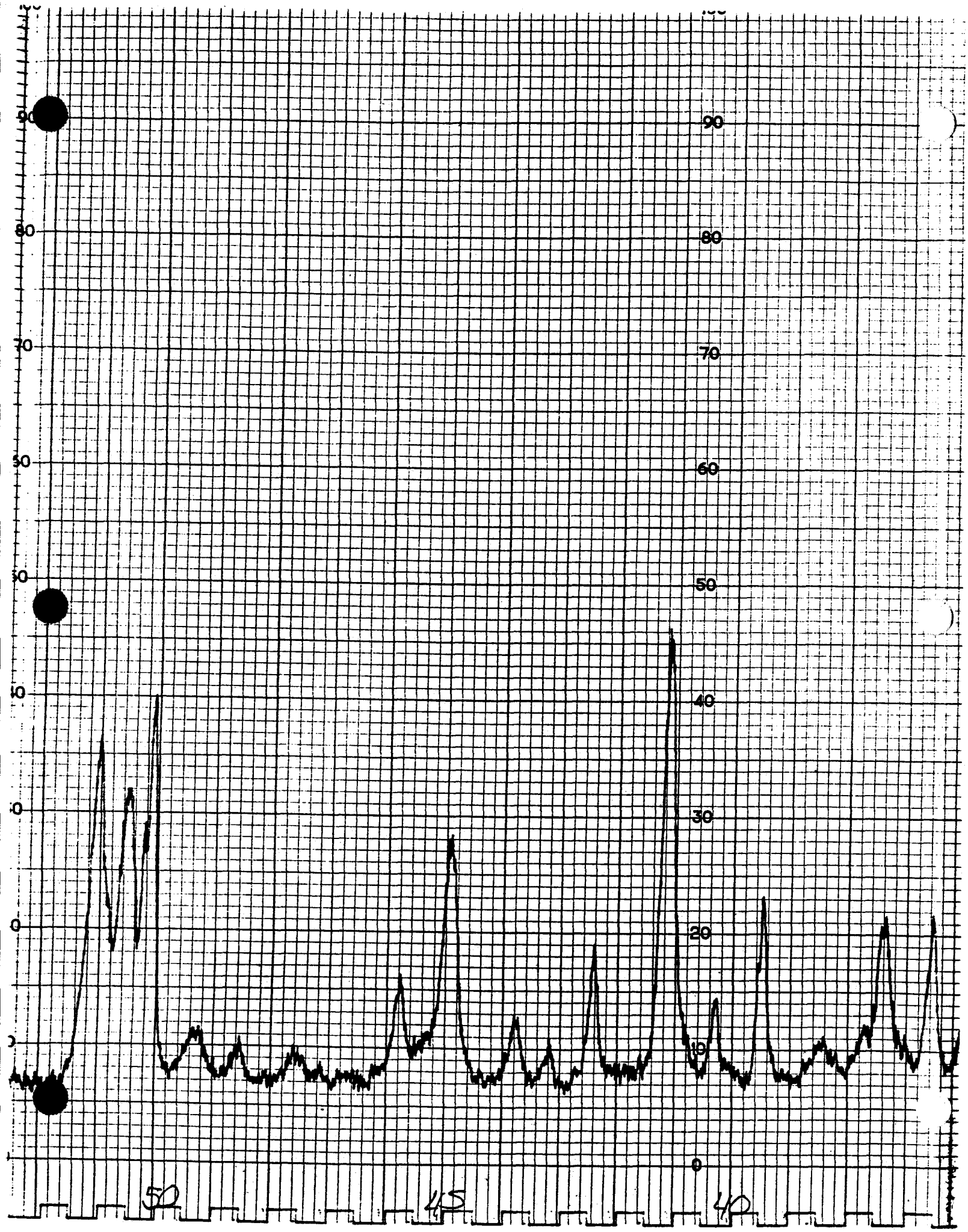
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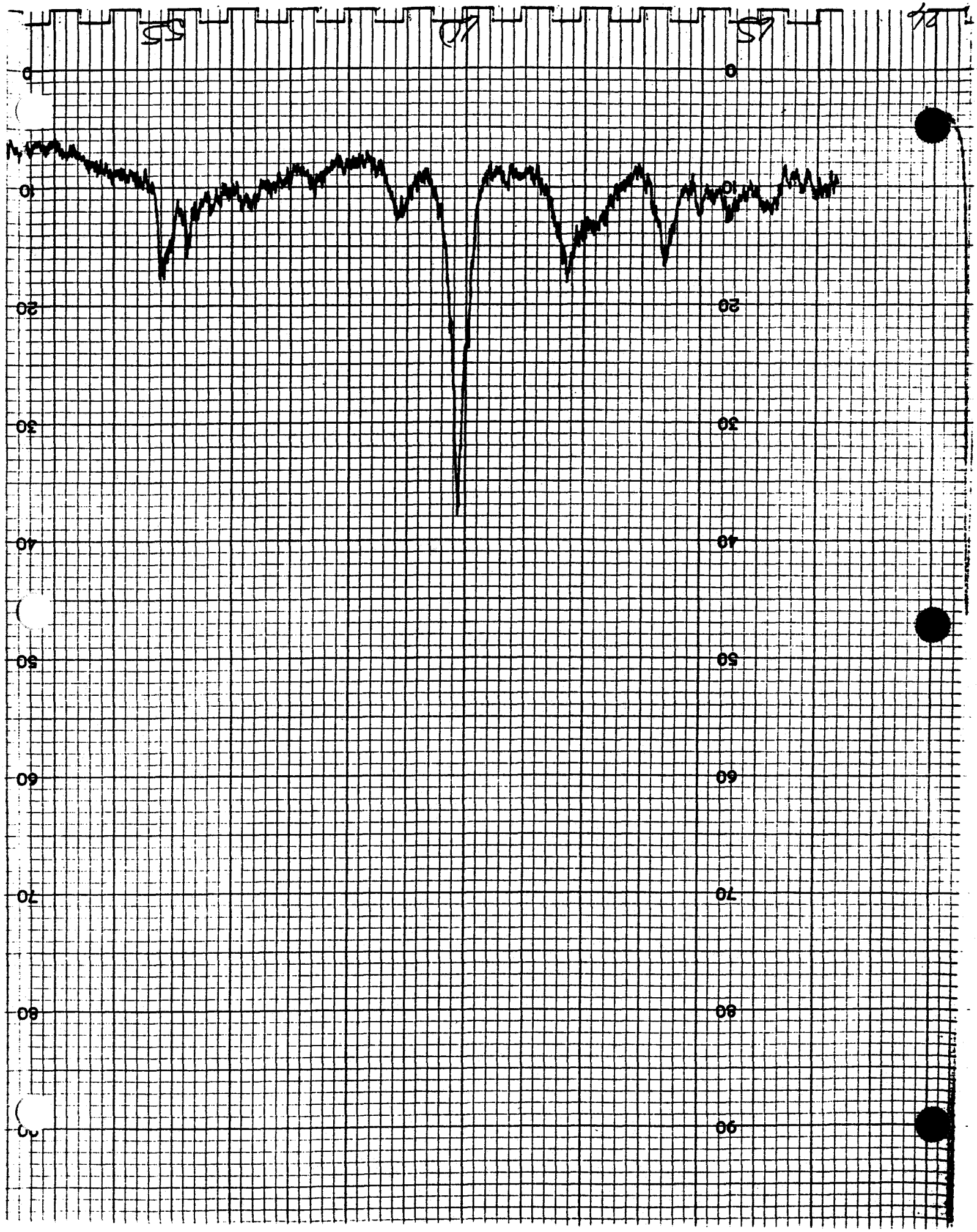

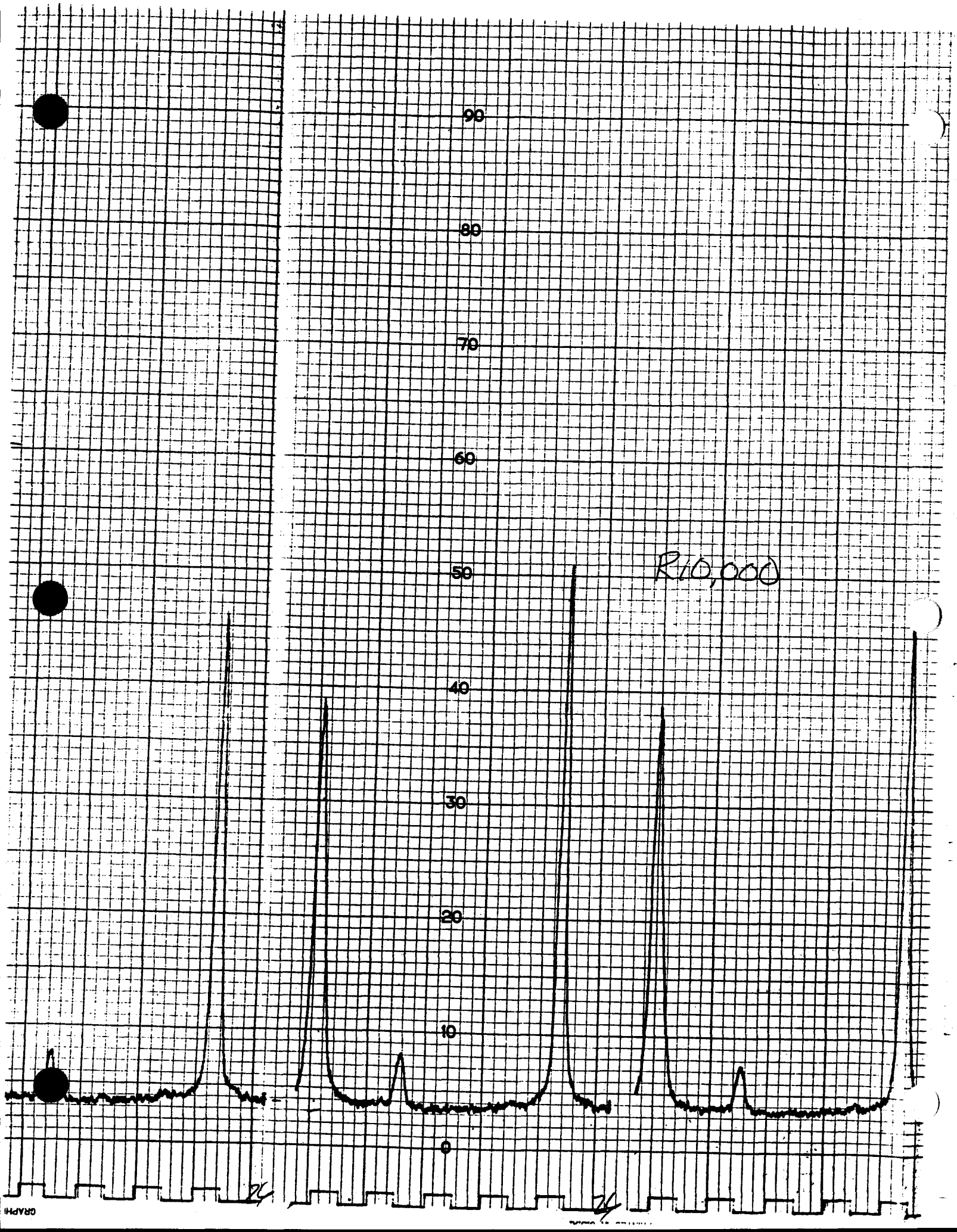
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