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NOT FOR PUBLICATION

KENTUCKY DEPARTMENT OF HIGHWAYS

RESEARCH REPORT

EXPERIMENTAL CONCRETE PAVEMENT
CONTAINING FLY-ASH ADMIXTURES
KYHPR-64-1; HPR-1 (1)

U 553 (1), Poplar Level Road, Jefferson County

by

Ronald D. Hughes,
Research Engineer

July, 1966

Division of Research

LEXINGTON

No. 237

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

July 28, 1966

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
DIVISION OF RESEARCH
132 GRAHAM AVENUE
LEXINGTON, KENTUCKY 40506

H-2-1

MEMORANDUM

TO: W. B. Drake, Assistant Projects Management Engineer
Chairman, Kentucky Highway Research Committee

SUBJECT: Research Report; "Experimental Concrete Pavement Containing Fly-Ash Admixtures"; KYHPR-64-1; HPR-1(1), Part II; U 553(1), Poplar Level Road, Jefferson County

The attached report summarily presents records of the construction and performance of a portland cement concrete pavement containing fly-ash as an admixture. Although construction was completed September 5, 1963, preliminary laboratory studies began in 1956. A pilot study then (Research File C-2-7) indicated that partial replacement of cement with fly-ash was attended by a retardation in early strength gain; at 28 days, however, strengths equaled or exceeded normal concrete strengths. In this pilot series, the concrete was not air-entrained, and freeze-thaw tests were started when the concrete was 14 days old; the 35 percent replacement concrete failed in 9 cycles; whereas the 25 percent replacement concrete failed in 31 cycles; the 15 percent substitution failed in 105 cycles; normal concrete lasted 130 cycles. Of course, the low strengths at the onset of freezing and the fact that the concretes were not air-entrained account fully for those results. A more exhaustive study ensued (cf, Whitney, April 1958), and the retardation in early strength gain was affirmed. In that study, a 6-bag mix was supplemented with fly-ash (replacing sand); and, in a companion series, fly-ash was substituted for a portion of the cement. Supplements of 10 percent to 15 percent by weight of cement were accompained by reductions in mix-water requirements and increases in strengths;

but further enrichment or "sweetening" increased the water requirement; water reduction was greater in the air-entrained mixes. A gradual reduction in water requirement was obtained when fly-ash was substituted for cement in air-entrained mixes--to 35 percent substitution. Altogether, it appeared that 15 percent to 25 percent substitution for cement resulted in no loss in quality other than reduction in early strength; whereas, 10 percent to 15 percent supplements improved all qualities of the concrete---including resistance to freezing and thawing. In another study (Hardymon, March, 1958), blends of hydrated limes and fly-ashes and various soils treated with blends of lime and fly-ash were tested for strength development. The results from the blends of limes and fly-ashes may be interest here: 1) lime blended with coarse fly-ash developed little strength, 2) lime interground with coarse fly-ash developed about as much strength in six months as lime blended with fine fly-ash, 3) autoclave curing for 1 hour at 300 psi pressure resulted in greater strengths than curing for 6 months at 70°F, 4) the maximum strengths (unconfined compression) obtained by autoclave curing were in the order of 700 psi, 5) the optimum blends contained 15 percent to 25 percent lime. These results indicate that lime and fly-ash react slowly under ordinary conditions; however, the products from this reaction (tobermorite, possibly) may not be exactly the same as those produced in the presence of hydrating portland cement. It seems very probable that stronger cementing products are formed in the concrete than in the isolated blend. In the 1958 tests, the control mix (6 bags per cu. yd.) yielded 5400 psi in 60 days; the same mix containing supplemental fly-ash tested 6700 psi; the substituted mix containing 5.1 bags of cement and fly ash tested 5900 psi. It is rather interesting to note: 1) the per-bag contribution to strength of the control mix is 900 psi, 2) the strength of the same mix containing supplemental fly-ash may be represented approximately by $6 \times 900 \div .89 + 700 = 6780$, and 3) the strength of the substituted mix is similarly represented by $5.1 \times 900 \div .89 + 700 = 5850$. A similar relationship appears in the 1-year strength data from Poplar Level Road mixes (Table II), as follows: 1) the per-bag contribution to the strength of the control concrete was $7129 \div .6 = 1188$ psi; 2) for the substituted mix, $5 \times 1188 \div .89 + 700 = 7380$, as compared to 7431, actual; and 3) for the Section-B mix, the relationship also yields 7380, as compared to 7600, actual. The factor .89 is based on the assumption that each bag of cement produces 10.4 lbs. of CaO which does not contribute to strength; thus, 10.4 ÷.94 = .11, and 1.00 - .11 = .89. Dividing the per-bag strength contribution by .89 gives a compensated strength---that is, as if the CaO were replaced with strength-contributing cement; however, this correction does not suffice and fails to account for approximately 700 psi. The 700 psi seems to be meaningful---as has been mentioned previously.

Prior to paving, trial mixes were made in the laboratory and using aggregates from the contractor's stock. Significant reductions in water requirements were obtained then in the mixes containing fly-ash; but commensurate reductions were not realized in the paving operation.

Considering the performance of the pavement sections and the results from the durability and strength tests, I recommend that the Department take the necessary actions to enable the further use of flay-ash in pavement concrete and in bridges. The replacement or substitution schedule should not exceed 1 bag of cement in a normal 6-bag mix---that is to say, cement requirements of less than 5 bags per cu. yd. remain questionable. It is suggested that fly-ash supplements to Class "A" concrete would equal Class "AA" as provided in the Departments' Special Provisions, approved July 15, 1966. General, permissive, alternative provisions might be in order.

We will continue to observe the Poplar Level Road project and report its performance from time to time.

Respectfully submitted,

Jas. H. Havens
Director of Research
Secretary, Highway Research Committee

Attachment
JHH:em
cc: Research Committee
A. O. Neiser
R. O. Beauchamp
T. J. Hopgood
R. A. Johnson

Research Report

EXPERIMENTAL CONCRETE PAVEMENT CONTAINING FLY-ASH ADMIXTURES

KYHPR-64-1; HPR-1(1)

U 553(1), Poplar Level Road, Jefferson County

by

Ronald D. Hughes

Research Engineer

Research Division

DEPARTMENT OF HIGHWAYS

Commonwealth of Kentucky

in cooperation with the

BUREAU OF PUBLIC ROADS

U.S. Department of Commerce

132 Graham Avenue

Lexington, Kentucky

July, 1966

INTRODUCTION

Portland cement contains very little or no free calcium hydroxide (lime); however, the hydration of portland cement is accompanied by the liberation of lime. The free lime contributes little, if any, to strength and may actually have a weaking effect. The lime carbonates progressively, but may be leached out and leave the concrete relatively porous. In addition, lime combines with sulfates in aggressive waters and causes expansion. Lime deposits are frequently in evidence along fine cracks within concrete structures. The lime liberated by the hydration of portland cement is a result of the degradation of $3\,CaO \cdot SiO_2$ to $2\,CaO \cdot SiO_2 \cdot 2H_2O$ + CaO. Portland cement concrete is strongly alkaline when freshly mixed and remains so unless it is severely leached. Normal portland cement, Type I, contains about 45 percent $3\,CaO \cdot SiO_2$; thus the stoichiometric yield of CaO is:

$$\frac{CaO}{3\,CaO \cdot SiO_2} = \frac{56}{3X\ 56+60} \times 100 = 24.6\%$$

or 24.6% X 45% = 11.1% lime by weight of cement. One bag of normal cement might thus contain 10.4 pounds of available lime or a 6 bag concrete mixture would contain approximately 62 pounds of lime per cubic yard. In the event all of the lime were leached from the mass, the porosity would increase appreciably, and the durability might be greatly reduced. Progressive carbonation of the lime, however, reduces the likelihood of all the lime being leached from the mass.

Long ago, it was observed that certain siliceous materials when mixed with lime produced hydraulic cement. One such material was a volcanic ash found near Pozzuoli, Italy. As a result, the term pozzolana was applied to similar deposits found in southern Europe, and from this has evolved the more common term pozzolan. A pozzolan is defined as a siliceous or siliceous and aluminous substance which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with lime ($CaO + SiO_2 + H_2O \rightarrow CaO \cdot SiO_2 \cdot H_2O$ and $2 CaO \cdot SiO_2 \cdot 2H_2O$) to yield a product having an average composition of $1.5 CaO \cdot SiO_2 \cdot 1.5 H_2O$. Stoichiometrically speaking 10.4 pounds of lime from each bag of cement would combine with 7.43 pounds of SiO_2. If fly ashes or pozzolans contain 30 to 50 percent available, reactive silica, the blending proportions would range from 25 to 15 pounds of pozzolan per bag of cement -- or, as an average, say 20 pounds per bag.

Pozzolans are classified as natural or artifical--artifical being those derived from industrial processes. Fly ash is probably one of the most common as well as important of the artifical pozzolans and is produced under conditions closely simulating the natural conditions under which volcanic ashes are produced. The chemical composition and physical properties of fly ash are quite variable and depend upon the source of coal, method of burning, equipment, and method of collecting. Generally, fly ash produced at a particular plant using coal from a common source and operating at a steady load is fairly uniform. The chemical and physical analysis of fly ash generally fall within the following ranges:

CHEMICAL COMPOSITION

Silica (SiO_2)	28.10-51.26%
Alumina (Al_2O_3)	15.12-34.02%
Iron Oxide (Fe_2O_3)	3.86-26.43%
Magnesia (MgO)	0.55-1.91%
Sulfur Trioxide (SO_3)	0.23-3.59%
Lime (CaO)	1.00-10.59%

PHYSICAL PROPERTIES

Ignition Loss	0.56-31.56%
Specific Gravity	1.88-2.84
Passing No. 16 Sieve	99.4-100%
Passing No. 325 Sieve	62.4-97.9%
Blaine Fineness	2,007-6,073

From the foregoing, it may be noted that fly ash might contain from 43 to 85 percent reactive ingredients; but, of course, SiO_2 is the essential one. The addition of fly ash to portland cement concrete thereby provides a pozzolan for reaction with the lime liberated during hydration of the cement. Whereas the quantity of fly ash necessary to "fix" the lime in a given concrete mixture may be estimated theoretically from the chemical analyses of the fly ash and cement, pozzolanic activity of a fly ash cannot be established from chemical composition alone--that is to say, all of the silica present may not be available or be reactive toward lime. Also, the addition of fly ash to a concrete mixture may appreciably affect the physical properties of the fresh and/or hardened mixture and thereby must be considered when proportioning mixes. The optimum quantity of fly ash to use in mixtures adjusted to obtain a reduction in cement content should be established from tests using the proposed job cement and aggregates.

Carbon content significantly affects the amount of air-entraining agent required to maintain a given level of entrained air. Fly ashes containing high percentages of carbon reportedly require more air-entraining agent than those with lower carbon contents. Carbon is one of the more controversial constituents of fly ash, and no one appears to know definitely whether it has any harmful effects upon concrete. Specifications limit carbon content to a relatively low-percentage as a precautionary measure. It is suspicioned that carbon acts as a diluent of the active pozzolan in fly ash and therefore affects the rate of pozzolanic action.

The incombustible particles in fly ash are generally spherical and thereby impart a lubricating effect to most concrete mixtures. Fineness affects the pozzolanic activity, and the finer the fly ashes generally exhibit accelerated pozzolanic activity and thus higher early strengths. Fineness and roundness of the fly ash also affects the water requirement for concrete mixtures, and most studies indicate a reduced water requirement when using fly ash having a high fineness and low carbon content. Fly ash generates only 40 to 50 percent as much heat of hydration as cement, and this is of benefit when it is used as a cement replacement in mass concrete. The Bureau of Reclamation has utilized fly ash in several dams--thus permitting a reduction in artifical cooling or the casting of larger units. Fly ash reportedly improves workability and plasticity, reduces bleeding and segregation, and increases ultimate compressive strength and modulus of elasticity.

A definite disadvantage in the use of fly ash in concrete is the added effort in batching and controlling an additional material. The material is also difficult to handle since its flow characteristics are similar to those of water or fluidized powders. Mixtures containing high percentages of fly ash are reportedly difficult to finish and have a somewhat gummy property. Lower early strengths are most commonly experienced in mixtures in which the fly ash is used in replacement of a portion of the cement. There is also evidence that fly ash concrete is less resistant to freezing and thawing when cured for a short period and then followed by drying. Fly ash is also reported to reduce the resistance of concrete to de-icing salts, abrasion and increases creep in prestressed concrete.

PROJECT DESCRIPTION

In 1962, the Department initiated an investigation in the use of fly ash in portland cement concrete for pavements.* Project U553(1), Poplar Level Road, Jefferson County, was chosen as the site for the investigation. The paving project began just north of the Eastern Parkway (Sta. 93 + 50) and ended at Lincoln Avenue and Redwood Drive (Sta. 219 + 60) for a length of 2.388 miles. Plans called for two parallel 26-foot wide dual-lane pavements 9 inches in thickness to be placed on a 4-inch insulation course of dense-graded limestone aggregate. The Control Section was placed in both dual lanes between station 93 + 50 and station 135 + 00. Experimental Section A was placed in the northbound lanes, and Experimental Section B was placed in the southbound lanes between stations 135 + 00 and 219 + 60. The general layout and typical sections are shown in Figures 1 and 2. The George M. Eady Company of Louisville was awarded the contract for this project.

The Control Section was placed with Type D, normal portland cement concrete containing 6 sacks of cement per cubic yard. Experimental Section A was proportioned to contain 5 sacks of cement and 94 pounds of fly ash per cubic yard and Experimental Section B was proportioned to contain 5 sacks of cement and 140 pounds of fly ash. Other variables were minimized. The materials

* R. D. Hughes, "Experimental Concrete Pavement Containing Fly Ash Admixtures", Highway Research Record No. 73, HRB; 1965.

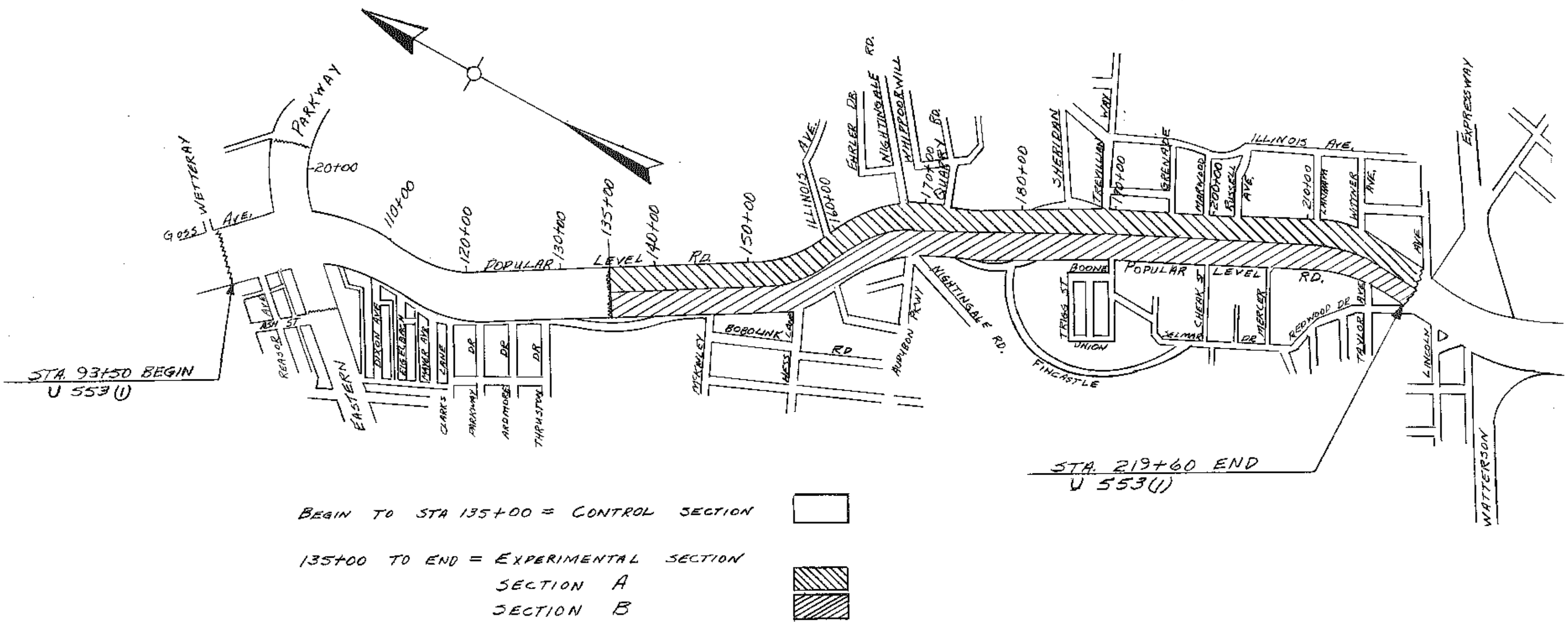

Fig. 1 - General Layout of Project Site

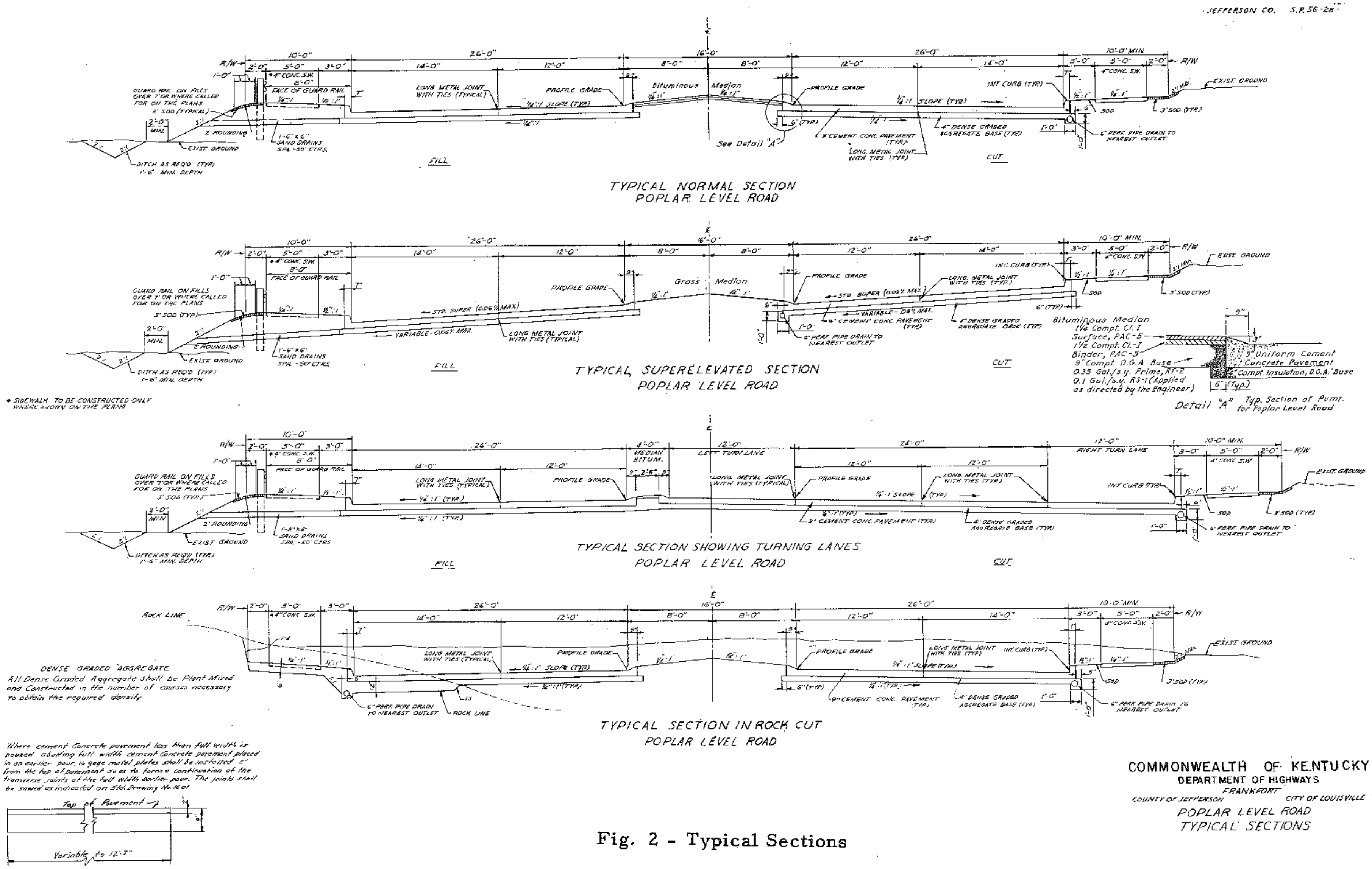

Fig. 2 - Typical Sections

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used in the control section conformed to the following requirements as contained in the 1956 edition of the Department's Standard Specifications for Road and Bridge Construction:

a.	Portland Cement	Article 7.1.2
b.	Water	Article 7.2.0
c.	Fine Aggregate	Article 7.3.2
d.	Coarse Aggregate	Articles 7.4.2.D, 7.4.3.D or 7.4.4.D
e.	Air-Entraining Agent	Article 7.39.0

Materials used in the experimental sections common to those listed for the control conformed to the listed requirements, and the fly ash conformed to the requirements listed under ASTM Designation: C 350-60T.

The cement was Type I produced by the Cosmos Cement Company, and the fly ash was obtained from the Louisville Gas and Electric Company's West End Power Plant. The fine aggregate was Ohio River sand from the Nuget Sand Company, and the coarse aggregate was No. 36, crushed limestone having a nominal size of 2 1/2 inches to 1/4 inches. Protex was used for air entrainment, and water was obtained from the county water lines. No particular difficulties were experienced with any of the materials in regard to meeting specification requirements. Both the fly ash and cement were supplied in bulk.

Mixtures for all sections were proportioned on a solid volume basis and were adjusted for slumps of approximately 2 1/2 inches and air contents of 4.5 percent plus or minus 1.5 percent. Mixtures placed within the Control Section were proportioned for a ratio of fine aggregate to total aggregate of 37 percent by weight. For the experimental sections, the fly ash in excess of that required to replace the solid volume of one sack of cement was considered as fine aggregate. Fly ash in excess of that required to replace a bag of cement for Experimental Sections A and B were 14 and 60 pounds respectively. The

Fig. 3 - Dry-Batch Plant Site

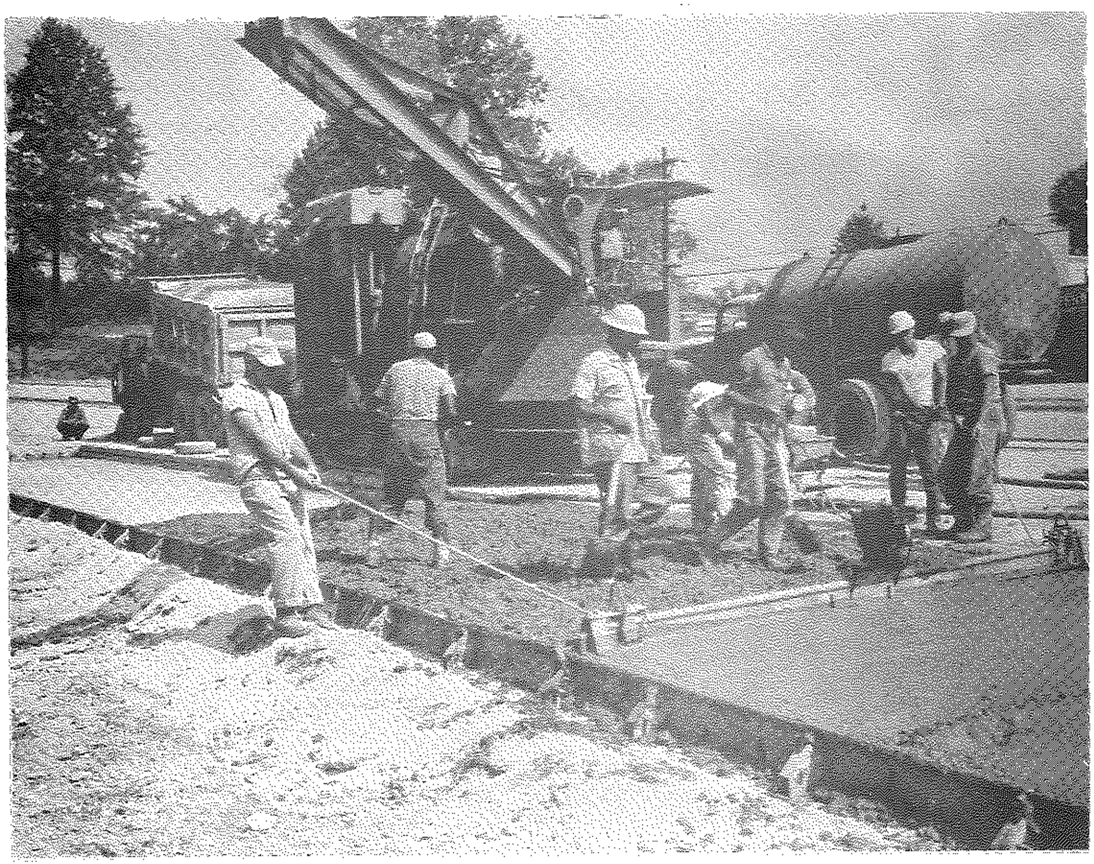


Fig. 4 - Koehring Paver, 34E, Twin-Batch Mixer

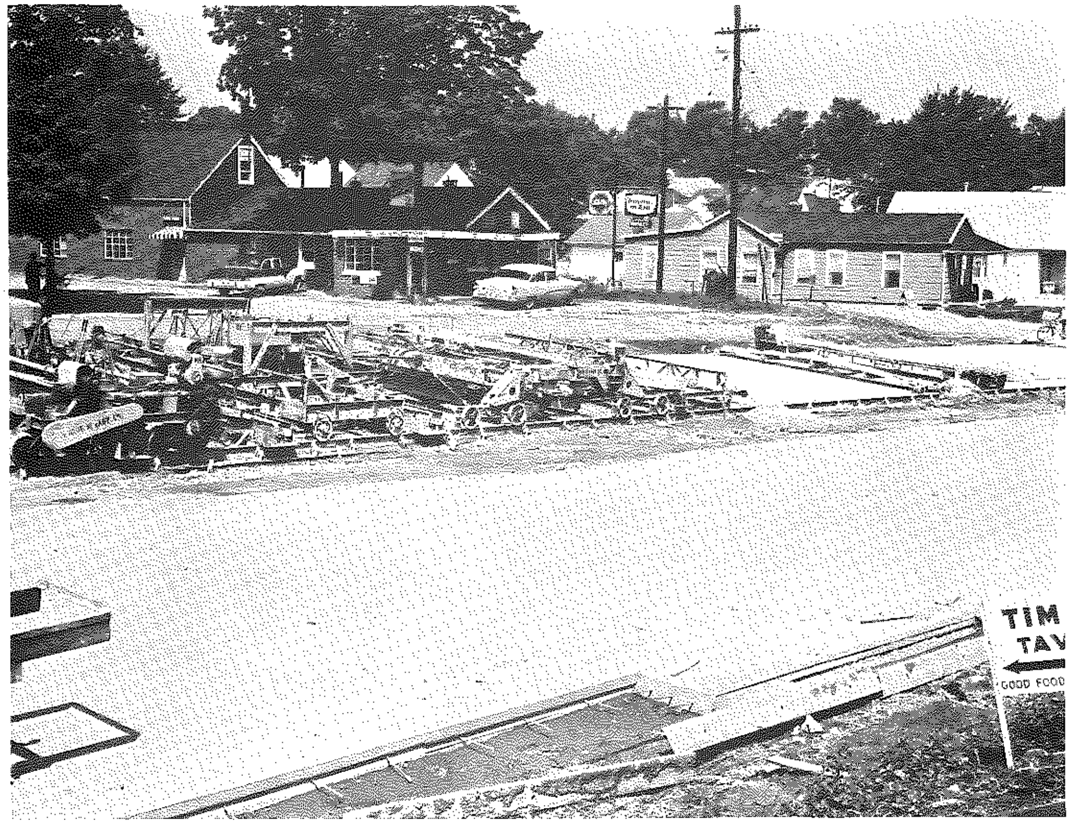


Fig. 5 - Paving Train

Fig. 6 - Consolidating and Striking-off

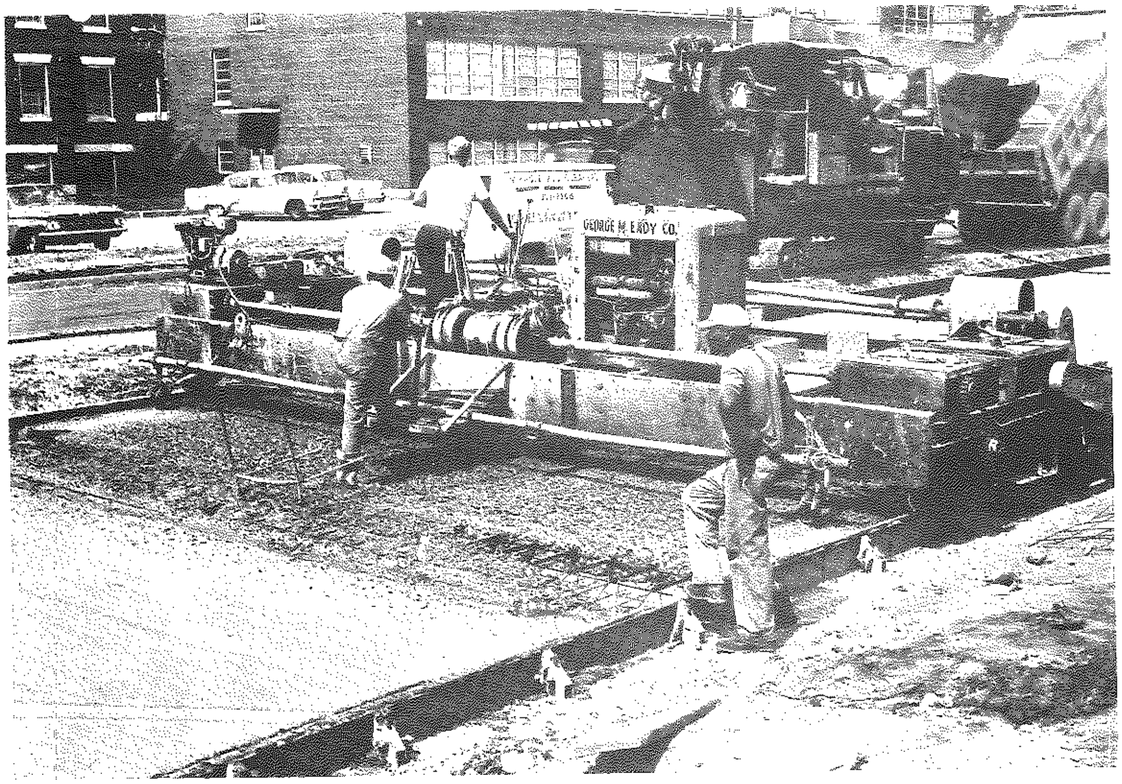


Fig. 7 - Tie Bars Installed at 30-inch Centers
Along Longitudinal Joint

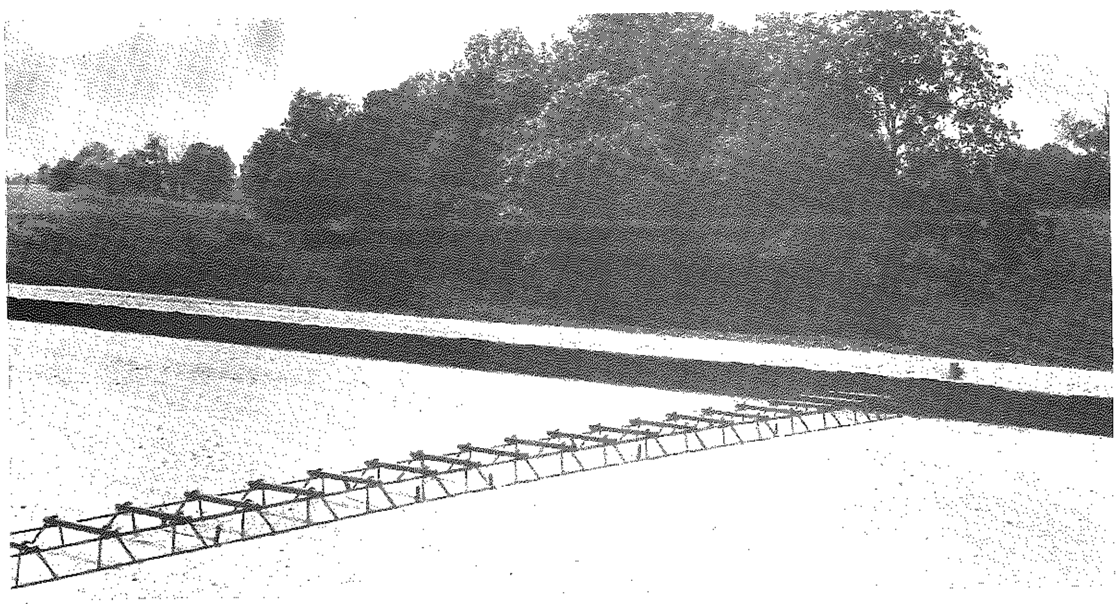


Fig. 8 - Load-Transfer Assembly, 50-foot Intervals
at Transverse Joints

specific gravities of the fine aggregate and fly ash were approximately the same, and the deduction of 14 and 60 pounds of sand from sections A and B did not affect the yield. In effect, the fine aggregate to total aggregate ratio was maintained at 37 percent for the experimental mixtures.

Materials were dry-batched at the plant (Fig. 3) located near the center of the project. Trucks were loaded at the plant in the following order: (1) coarse aggregate, (2) cement, (3) fly ash, and (4) sand. Considerable difficulty was encountered in dispensing the correct quantity of fly ash from the hopper. The problem was corrected through installation of new rollers in that hopper. Dusting of the fly ash was also a problem, and a longer boot was installed in an effort to minimize loss during loading. The boot aided but did not completely eliminate dusting. Materials were mixed at the site of placement in a Koehring Paver, 34 E, Twin batch mixer (Fig. 4) for a period of one minute. The mixer had a rated capacity of 34 cubic feet and was operated at a 10-percent overload.

The major portion of concrete used in each of the three sections was placed and finished by conventional mechanical methods (Figs. 5 and 6). Concrete was placed in two lifts to facilitate installation of wire mesh (No. 4 gage steel wire at 12-inch centers) at a plane below the final surface elevation of one-third the pavement depth. No. 4(1/2-inch diameter), deformed tie bars (Fig. 7) were installed at 30-inch intervals along the center line of each dual-lane pavement, and smooth dowel assemblies (Fig. 8) were placed at 50-foot intervals at transverse joints.

All bars were placed at a depth below the surface of one-half the slab thickness. The surface was screeded and float finished (Fig. 9) and then belted and final finished with a burlap drag (Fig. 10). Joints were sawed to a depth of one-fourth the slab thickness and sawing commenced approximately 8 hours after placement of the concrete. The pavement was initially cured (min. period of 6 hours) with wet burlap and then final cured (min. period of 3 days) with Kraft-paper (Fig. 11).

Construction supervision and inspection were in accordance with standard procedures. Division of Materials personnel initially sampled materials, performed quality tests, and supplied tentative mixture proportions for the three sections. Division of Construction personnel made necessary adjustments in mixture proportions, sampled materials, supervised construction and provided necessary inspectors. Beams and cylinders were cast independently by Division of Research personnel for flexural- and compressive-strength testing at ages of 3, 7 and 28 days and 6 and 12 months. Specimens were also cast for freeze-thaw tests and 3-month compressive strength tests. Four sets of specimens (18 beams and 18 cylinders) were cast from concrete placed within each of the three sections and all tests were in triplicate.

All beams and cylinders were cast and cured in accordance with procedures outlined under ASTM Designation: C 31, Making and Curing Concrete Compression and Flexure Test Specimens in the Field. Compressive-test specimens were 6 inches in diameter and 12 inches in length. The specifications designate that coarse aggregate for specimens of the size cast shall not exceed 2-inches in nominal size. In order to comply with that requirement, the fresh concrete for casting cylinders was passed through a 2-inch screen. Flexural-test specimens of 3-inch by 4-inch by 16-inches were cast and the fresh concrete

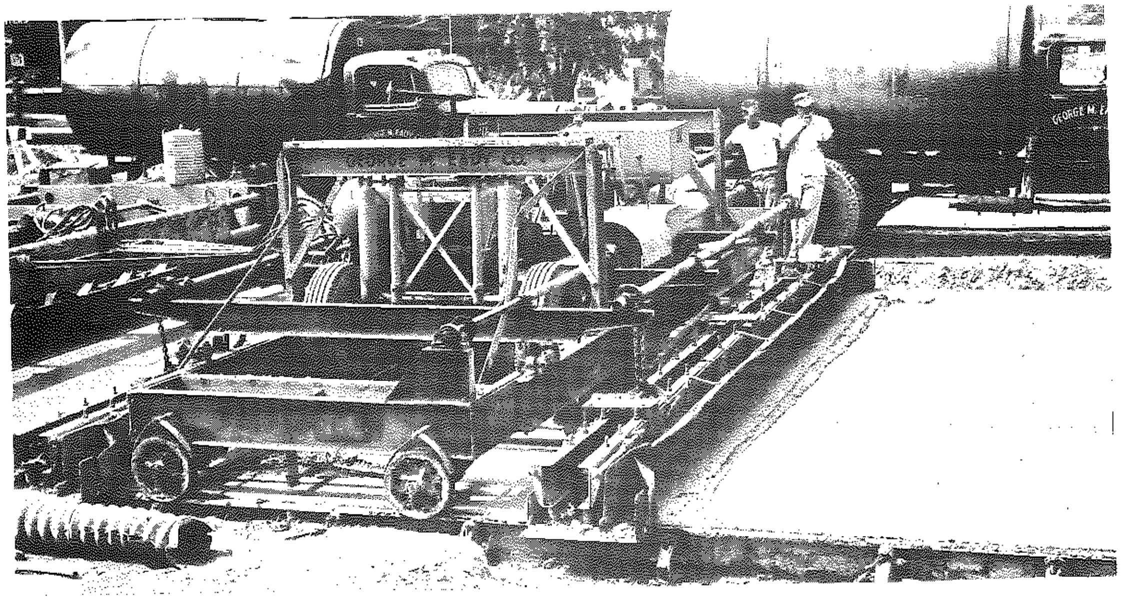


Fig. 9 - Float Finishing

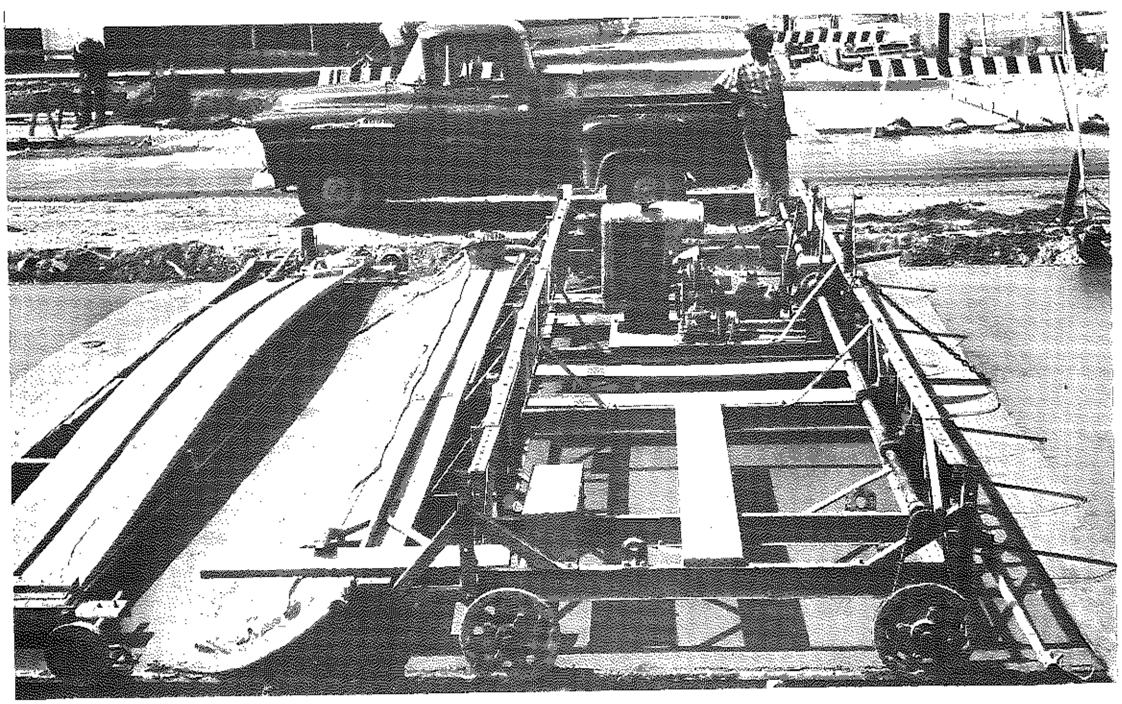


Fig 10 - Belting and Finishing Surface
with Burlap Drag

Fig. 11 - Pavement Initally Cured with Wetted Burlap; Final Cure with Kraft Paper.

for these specimens was passed through a 1-inch screen to meet specification requirements.

Concreting operations began on December 5, 1962, and concrete was placed between stations 161 + 45 and 166 + 00 in Experimental Section A. The air temperature was between 35° and 40° F during time of placement and dropped below freezing that night. The temperature remained below freezing for several days thereafter, and operations were deferred until the following Spring. Specimens were cast from the concrete placed in 1962, and test results for those specimens are included in tables in the following chapter. Paving operations were again started on May 31, 1963; and the project was completed on September 5, 1963. A special provision for this project is included in the Appendix.

TEST RESULTS AND PERFORMANCE SURVEYS

No particular difficulties were encountered in placement or finishing the experimental sections other than the fact that finishers reported occasional gumminess or stickiness of the mixtures unless finished immediately after placement. The quantity of air-entraining agent required to maintain the desired air content varied considerably for the various mixtures placed within a particular section, and no definite effect upon air-entraining agent requirement could be established for the experimental sections versus the control section. Four to five air-content and slump tests were performed daily during the course of the project, and values of the tests made upon mixtures from which specimens were cast are listed in Table I.

Samples of materials collected and tested by Division of Research personnel were representative of materials utilized in production of mixtures from which test specimens were cast. All tests were made in accordance with appropriate ASTM designation requirements, and average test values for these samples were as follows. The coarse aggregate had a specific gravity (S. S. D.) of 2.75, and absorption of 1.04 percent, percent ware by Los Angeles abrasion of 24.7 and contained 11.5 percent elongated pieces. The fine aggregate had fineness modulus of 2.99, a specific gravity (S. S. D.) of 2.65, absorption of 1.07, and percent coal and lignite of 0.015. Mortar cubes cast using the fine aggregate had 7-day compressive strengths averaging 2692 psi. or 97 percent of that for control specimens cast utilizing graded Ottawa sand, and tensile strengths averaged 480 psi. or 135 percent of that for control specimens.

Cement utilized throughout the project had a specific gravity of 3.15 and a Blaine fineness of 3352 square centimeters per gram. Specimens cast with the cement had an Autoclave expansion and volume change at 28 days of -0.0133 and -0.0180 percent respectively. The cement mortar had an air content of 8.28 percent, normal consistency of 26 percent and a final time of set by the Vicat needle of 2 hours and 35 minutes. Average 7-and 28-day compressive strengths for mortar cubes were 3220 and 4559 psi. respectively. The fly ash had a specific gravity of 2.63, a Blaine fineness of 2844 square centimeters per gram and 94.4 percent passing the No. 325 sieve. Specimens cast using the fly ash had an Autoclave expansion and volume change at 28 days of -0.029 and -0.020 respectively. Normal consistency with the fly ash was 26 percent and the air content was 5.40 percent. Average 7-and 28-day mortar cube compressive strengths were 5419 and 6846 psi.

The fine aggregate was dredged river sand and was somewhat deficient in fines. It was anticipated that the addition of fly ash in the experimental sections might result in a reduction in the free-water requirement of those mixtures below that of the control mixtures. Laboratory mixtures proportioned prior to start of the project indicated such a reduction and the water requirements were: 31, 29, and 28.5 gallons per cubic yard for the Control, Experimental A and B mixtures respectively. Significant differences in water requirements were not obtained in actual production of mixtures on the project, and the average water requirements of four mixtures (those from which test specimens were cast) per section were: 31.00, 30.01 and 31.24 gallons per cubic yard for the Control, Experimental A and B sections respectively. Mix quantities, dates and locations of placement of these mixtures are contained in Table I.

TABLE I

MIXTURE WEIGHTS PER CUBIC YARD - SLUMP AND AIR TEST RESULTS

	Date Placed	Location			Material Weights-Lbs*			Slump-In.	Air Content-Percent
		Sta.	to Sta.	Lane	Free Water	S.S.D. Sand	S.S.D. Stone		
Control	6-13-63	111+80	120+20	SBL	252.7	1167	1987	2, 2.5, 2, 2.5	5.2, 4.7, 4.8, 4.6
Control	7-17-63	107+86	116+50	NBL	264.2	1156	1970	2.5, 2.5, 2.25, 2.25	4.3, 4.5, 4.5, 4.6
Control	7-24-63	102+85	106+00	SBL	255.6	1164	1983	3, 2.5, 3, 3	4.7, 5.0, 4.8, 4.6
Control	8- 8-63	Dixon & Mayer Aves.		-	260.6	1158	1973	3, 3, 2.5, 3	2.3, 6.2, 6.2, 5.4
				Avg.	258.3	1161	1978	2.6	4.7
Expr. A	12- 5-62	161+45	166+00	SBL	238.9	1175	2012	2.5, 2.75, 2.5, 2.5	3.7, 4.3, 4.1, 4.7
Expr. A	6- 3-63	157+50	161+00	SBL	261.3	1146	1973	2, 2.5, 2.5, 2	6.3, 6.1, 5.0, 4.7, 4.9
Expr. A	6-11-63	130+00	138+00	SBL	253.4	1138	1983	3, 3, 2, 2.25, 2.25	5.2, 4.8, 4.9, 4.7, 4.6
Expr. A	8-21-63	Fincastle Ave.		-	250.5	1157	1992	3, 3, 3, 2.75, 3	
				Avg.	251.0	1161	1978	2.6	4.8
Expr. B	7- 1-63	188+71	195+78	NBL	259.9	1104	1976	2, 2.25, 2.5, 2.25, 2.5	4.5, 4.9, 5.1, 4.7, 4.6
Expr. B	7- 3-63	206+14	216+50	NBL	264.2	1097	1965	2.5, 2.75, 2, 2.25, 2.25	4.8, 4.5, 4.7, 5.0, 4.8
Expr. B	7-15-63	157+00	165+00	NBL	259.9	1104	1974	3, 3, 2.5, 3	4.0, 6.5, 4.4, 4.7
Expr. B	8- 1-63	138+00	146+00	NBL	257.0	1107	1978	3, 2.5, 2.25, 2.5, 2.5	2.8, 6.0, 4.9, 5.4, 5.6
				Avg.	260.2	1103	1973	2.5	4.8

*Control - 564 Lbs. Cement
Expr. A - 470 Lbs. Cement and 94 Lbs. Fly Ash
Expr. B - 470 Lbs. Cement and 140 Lbs. Fly Ash

TABLE II
STRENGTH-TEST DATA

	Date Placed	COMPRESSIVE STRENGTH Avg. of 3 Specimens-psi. 3 Day	7 Day	28 Day	3 Mo.	6 Mo.	1 Yr.	FLEXURAL STRENGTH Avg. of 3 Specimens-psi. (third-point loading) 3 Day	7 Day	28 Day	6 Mo.	1 Yr.
Control	6-13-63	3249	3806	4914	4955	5902	6999	806	850	1050	1250	1200
	7-17-63	2882	4089	4562	5491	6493	7679	813	938	1125	1338	1337
	7-24-63	2963	4073	5453	5856	6208	7042	725	956	1075	1413	1350
	8- 8-63	3447	3776	4949	5813	6289	6794	735	1062	1263	1425	1287
	Avg.	3135	3936	4970	5529	6223	7129	770	952	1128	1357	1294
Expr. A	12-5-62	1958	3872	5868	7159	6455	7094	385	811	1106	1349	1413
	6- 3-63	2952	3579	4619	6354	6170	7777	738	988	1188	1500	1388
	6-11-63	2330	3270	4572	5282	6428	7238	550	700	1015	1400	1263
	8-21-63	2896	3759	4551	5744	7014	7616	738	900	1012	1450	1550
	Avg.	2534	3620	4903	6135	6519	7431	603	850	1080	1425	1403
Expr. B	7- 1-63	2855	3349	5208	6817	6656	7962	719	863	1138	1163	1262
	7- 3-63	2445	4124	5496	6463	7502	7989	687	925	1275	1338	1337
	7-15-63	2480	3420	4622	5505	6515	7015	756	731	1038	1200	1399
	8- 1-63	3129	3414	3788	5638	6198	7431	773	963	1250	1287	1387
	Avg.	2727	3577	4779	6106	6718	7600	734	871	1175	1247	1346

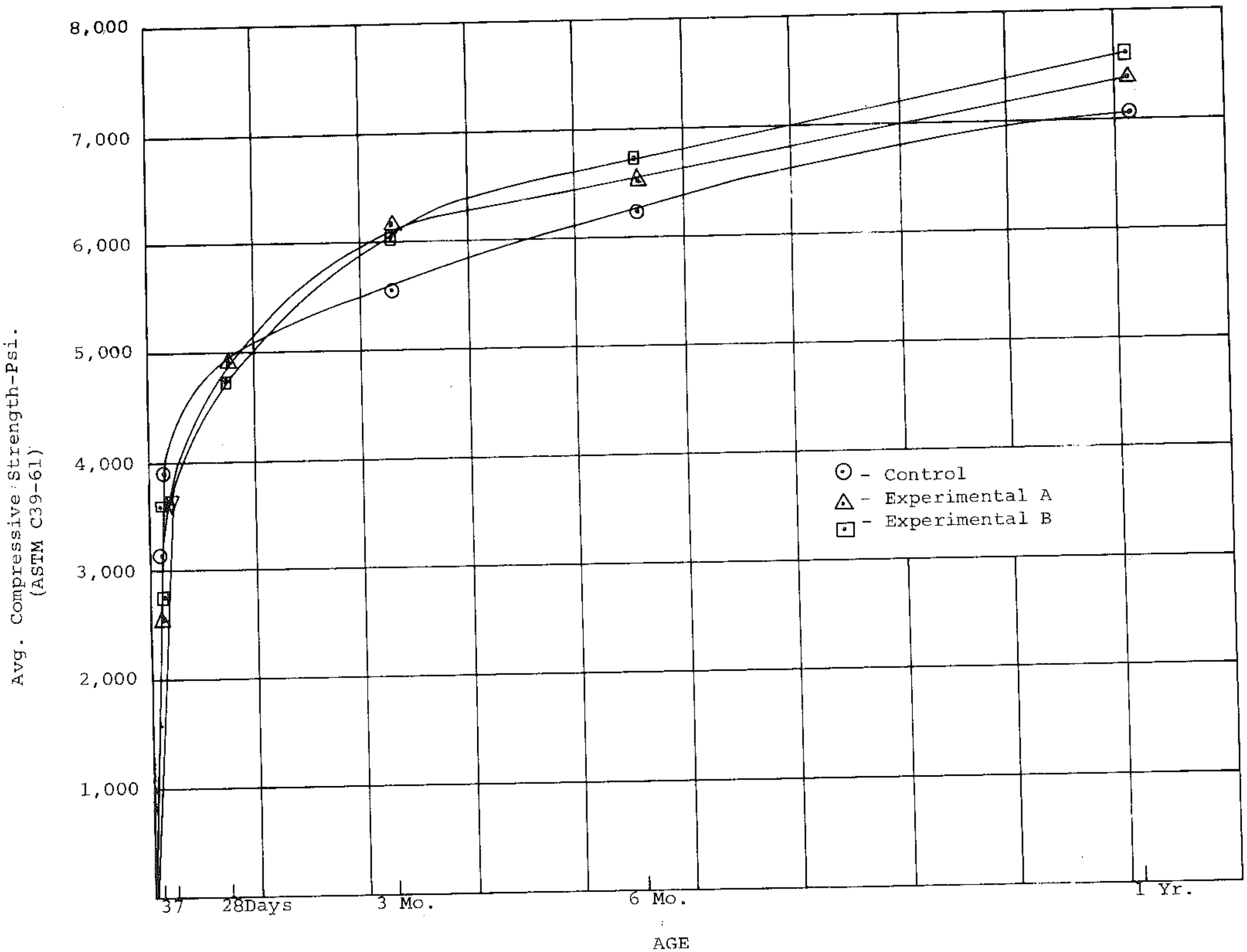


Fig. 12 - Average Compressive Strengths Versus Age

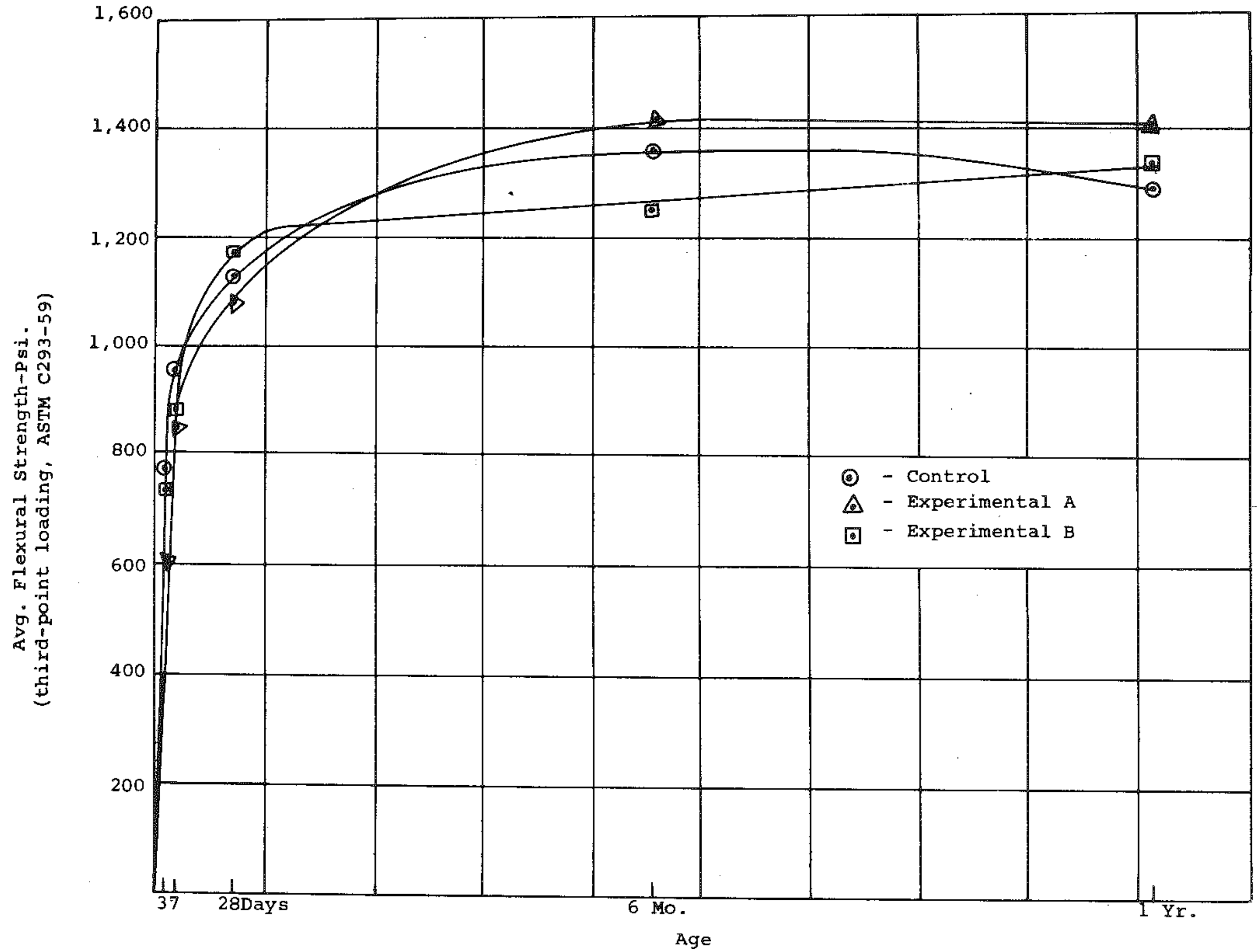


Figure 13 - Average Flexural Strengths Versus Age

Table II contains values for the compressive - and flexural -strength test results. Figure 12 is a plot of average compressive strengths versus age for specimens from the three sections. As may be noted in Table II or Figure 12, average compressive strengths for the experimental mixtures were less than those for the control mixtures at 3, 7 and 28 days and exceeded control mixture strengths at ages of 3 and 6 months and one year. Compressive strengths for Control and Experimental A specimens were equal at approximately 36 days, and the age of equal strength for Control and Experimental B specimens were of approximately equal strengths at 3 months. The relations of Control specimen strengths versus Experimental specimen strengths are in accordance with the general conception that pozzolanic benefits develop slowly and do not develop within the first month.

Average flexural strengths versus age for the three sections are plotted in Figure 13. The one-year strengths for the Control and Experimental A specimens were slightly less than their 6-month strengths. Each set of specimens from each section for tests at all ages were cast from concrete contained within one batch; thereby, the mixture proportions for sets of specimens were identical. The fact that one-year strengths for Experimental B specimens were greater than the 6-month strengths more or less eliminates the possibility of a fault within the testing machine for one-year strength tests. Specimens for all age tests were stored in one moist room maintained at a constant humidity and temperature. A similar reduction in one-year compressive strengths for the Control and Experimental A specimens was not experienced and the erratic flexural strengths are somewhat preplexing. The ratio of average compressive strengths to average flexural strengths increased with age for specimens from all sections. These ratios were fairly constant for specimens from all sections at a given age and ranged from approximately 4 at 3-day tests to 5.5 at one-year tests. These ratios are probably not of any real significance but do indicate that the addition of fly ash to concrete does not have an appreciable effect upon the compressive strength - flexural strength relationship.

Freeze-thaw test specimens were moist cured for a period of 14-days prior to initiation of the tests. These tests were conducted in a manner similar to that outlined under ASTM Designation: C291-61T. Durability factors for 300 cycles of freezing and thawing are listed for all specimens in Table III. The specimens performed quite well and no apparent differences in performance were observed for specimens cast for the three sections. The over-all averages of durability factors were: 98.9, 100.5 and 97.4 for the Control, Experimental A and Experimental B sections respectively. Testing was continued to 1600 cycles and durability factors from these tests data are listed in Table IV. Several of the specimens disintegrated at some point prior to 1600 cycles of freezing and thawing and were removed from the test chamber. Durability factors were computed for these specimens in reference to 1600 cycles on the basis of their dynamic modulus of elasticity prior to disintegration. Average durability factors were: 91.9, 95.2 and 66.0 for the Control, Experimental A and Experimental B sections respectively. As may be noted, the Control and Experimental A specimens were decidedly superior to the specimens from Experimental Section B, and the A specimens were slightly better than the Control specimens.

Five performance surveys have been made to date, and observations noted during these surveys are plotted on the strip maps contained in the Appendix. The surveys did not include that portion of the Control Section between stations 93 + 50 and 102 + 85 due to heavy volumes of traffic in the

TABLE III

DURABILITY FACTORS OF FREEZE-THAW SPECIMENS FOR 300 CYCLES

Date	Durability Factor 1	2	3	Avg.
CONTROL				
6-13-63	102.3	103.5	100.0	101.9
7-17-63	96.7	97.2	97.8	97.2
7-24-63	97.8	97.8	95.7	97.1
8- 8-63	100.0	98.9	98.9	99.3
EXPERIMENTAL A				
12- 5-62	98.9	98.9	98.9	98.9
6- 3-63	104.0	102.8	101.6	102.8
6-11-63	100.5	104.0	104.6	103.0
8-21-63	98.9	97.2	96.2	97.4
EXPERIMENTAL B				
7- 1-63	92.3	93.8	95.0	93.7
7- 3-63	96.1	97.8	98.9	97.6
7-15-63	98.3	99.4	101.7	99.8
8- 1-63	98.9	98.9	97.8	98.5

TABLE IV
DURABILITY OF FREEZE-THAW SPECIMENS
FOR 1600 CYCLES

Date Cast	Durability Factor			
	1	2	3	Avg**
CONTROL				
6-13-63	83.0	107.0	101.0	97.0
7-17-63	88.7	72.1	86.6	82.5
7-24-63	99.4	98.6	1238*	81.1
8- 8-63	96.2	102.2	92.4	96.9
EXPERIMENTAL A				
12- 5-62	79.8	100.5	102.1	94.1
6- 3-63	97.2	105.0	99.4	100.5
6-11-63	102.8	101.7	106.4	100.4
8-21-63	79.5	87.2	90.9	85.9
EXPERIMENTAL B				
7- 1-63	1031*	1385*	1523*	49.8
7- 3-63	1561*	906*	1377*	51.1
7-15-63	76.2	1458*	98.2	78.0
8- 1-63	99.4	72.7	83.2	85.1

*Specimen disintegrated and removed at cycle No. listed.

**Averages listed are for all 3 specimens (durability factors for beams removed before 1600 cycles were computed in reference to 1600 cycles and used in averaging).

vicinity of the Eastern Parkway. Cracks, spalls, pop-outs, etc. are color coded to denote the time defects were first observed. Table V is a listing of lineal feet of new cracks observed per section per survey. For comparative purposes, the column headed "Ft. of Cracks per Ft. Pave" is included. Numerous cracks were above underground conduits or originated at manholes and curb drains. The footages of cracks not associated with conduits, manholes, or drains are listed in the right column of Table V. Table VI is a listing of accumulative totals per survey for items contained in Table V. Table VII is a listing of new spalls and pop-outs observed per survey per section and also contains accumulative totals of said defects per survey.

The minimum expected 28-day strength of portland cement concrete as required by the Department is 3500 pounds per square inch in compression and 600 pounds per square inch modulus of rupture. Specimens cast from mixtures placed in all sections exceeded the required strengths by a substantial amount. The present condition of all sections is essentially the same, and no major variations in performance are evident. Major variations in future performance may be anticipated for Experimental Section B on basis of the average durability factor at 1600 cycles. To date, no adverse effects or superlative properties attributable to the fly ash are in evidence from this project.

TABLE VII
CRACK-SURVEY DATA

Date	Ft. of Cracks*	Ft. Cracks* Per Ft. Pave.	Ft. Cracks Omitted**	Ft. Cracks Per Ft. Pave.
CONTROL (6430 Ft.)				
12-63	148	0.023	32	0.018
3-64	134	0.021	48	0.013
11-64	786	0.122	372	0.064
5-65	597	0.093	175	0.066
5-66	305	0.047	56	0.039
EXPERIMENTAL A (8460 Ft.)				
12-63	278	0.033	60	0.026
3-64	60	0.007	25	0.004
11-64	1421	0.168	390	0.120
5-65	310	0.037	68	0.029
5-66	856	0.101	152	0.083
EXPERIMENTAL B (8460 Ft.)				
12-63	67	0.008	46	0.002
3-64	83	0.010	36	0.006
11-64	1400	0.165	348	0.124
5-65	780	0.092	152	0.074
5-66	672	0.079	143	0.062

* Footages of new cracks noted at time of survey
**Conduit -, manhole-or-drain-associated cracks

TABLE VI

ACCUMULATIVE TOTAL FEET OF CRACKS PER SURVEY

Date	Ft. of Cracks	Ft. Cracks Per Ft. Pave.	Ft. Cracks* Omitted	Ft. Cracks Per Ft. Pave.
CONTROL (6430 Ft.)				
12-63	148	0.023	32	0.018
3-64	282	0.044	80	0.032
11-64	1068	0.166	452	0.096
5-65	1665	0.259	627	0.162
5-66	1970	0.306	683	0.200
EXPERIMENTAL A (8460 Ft.)				
12-63	278	0.033	60	0.026
3-64	338	0.040	85	0.030
11-64	1759	0.208	475	0.152
5-65	2069	0.244	543	0.180
5-66	2925	0.345	695	0.263
EXPERIMENTAL B (8460 Ft.)				
12-63	67	0.008	46	0.002
3-64	150	0.018	82	0.008
11-64	1550	0.183	430	0.132
5-65	2330	0.275	582	0.207
5-66	3002	0.355	725	0.269

*Conduit -, manhole - and drain - associated cracks

TABLE VII

SPALL AND POP-OUT DATA

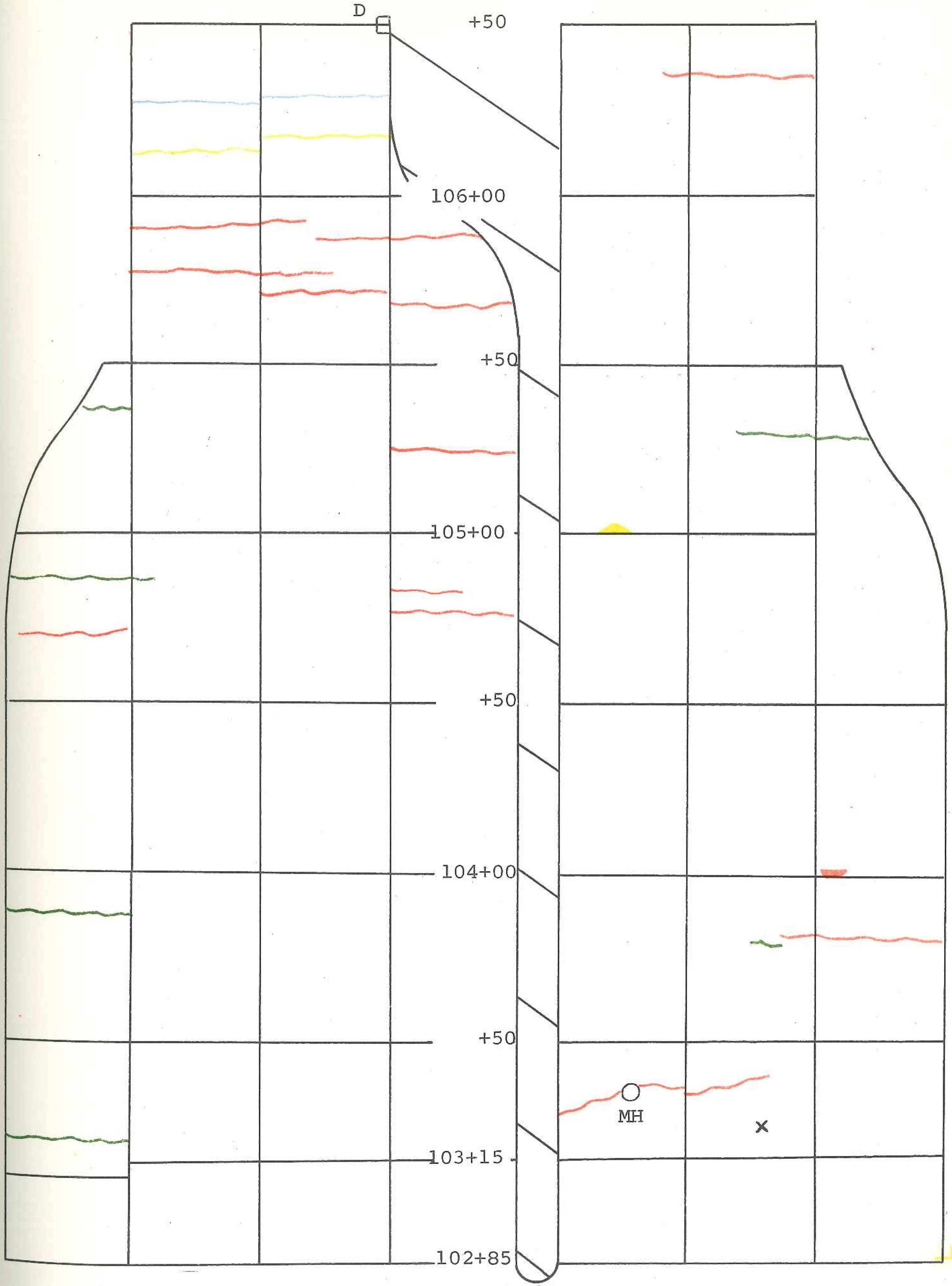
Date	New Per Survey		Accumulative Totals	
	Spalls	Pop-Outs	Spalls	Pop-Outs
CONTROL				
12-63	0	2	0	2
3-64	0	8	0	10
11-64	0	0	0	10
5-65	0	4	0	14
5-66	6	0	6	14
EXPERIMENTAL A				
12-63	0	11	0	11
3-64	0	10	0	21
11-64	4	1	4	22
5-65	14	4	18	26
5-66	18	3	36	29
EXPERIMENTAL B				
12-63	0	10	0	10
3-64	0	2	0	12
11-64	2	0	2	12
5-65	7	4	9	16
5-66	16	1	25	17

APPENDIX

LEGEND

Crack --------------------	
Spall --------------------	
Pop-Out-------------------	X
Drain --------------------	□ D
Culvert-------------------	▭ C
Manhole-------------------	○ MH
Meter --------------------	○ M
Rained on Fresh Concrete--	

Black	- Dec. 1963
Yellow	- Mar. 1964
Blue	- Nov. 1964
Red	- May 1965
Green	- May 1966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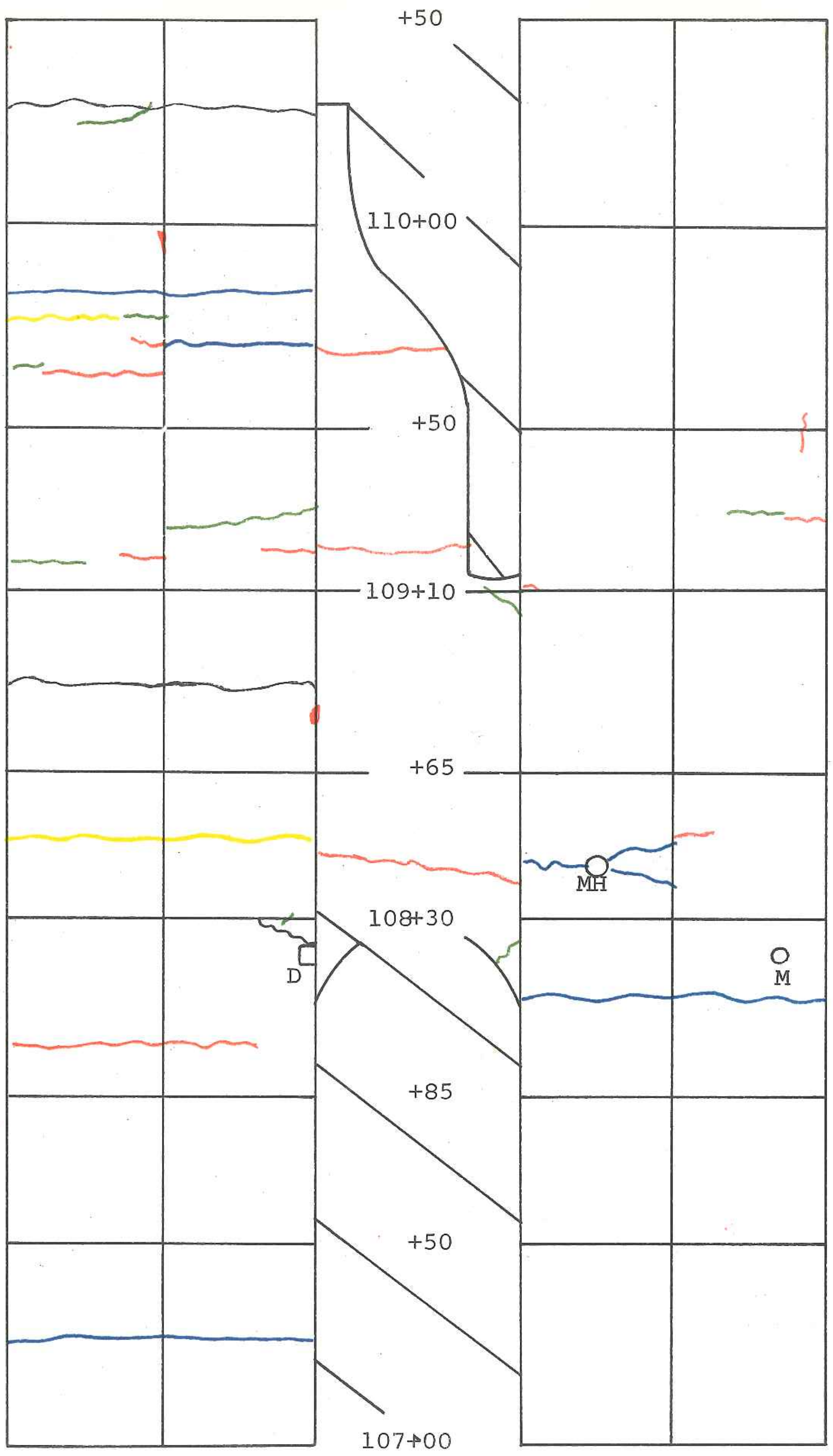
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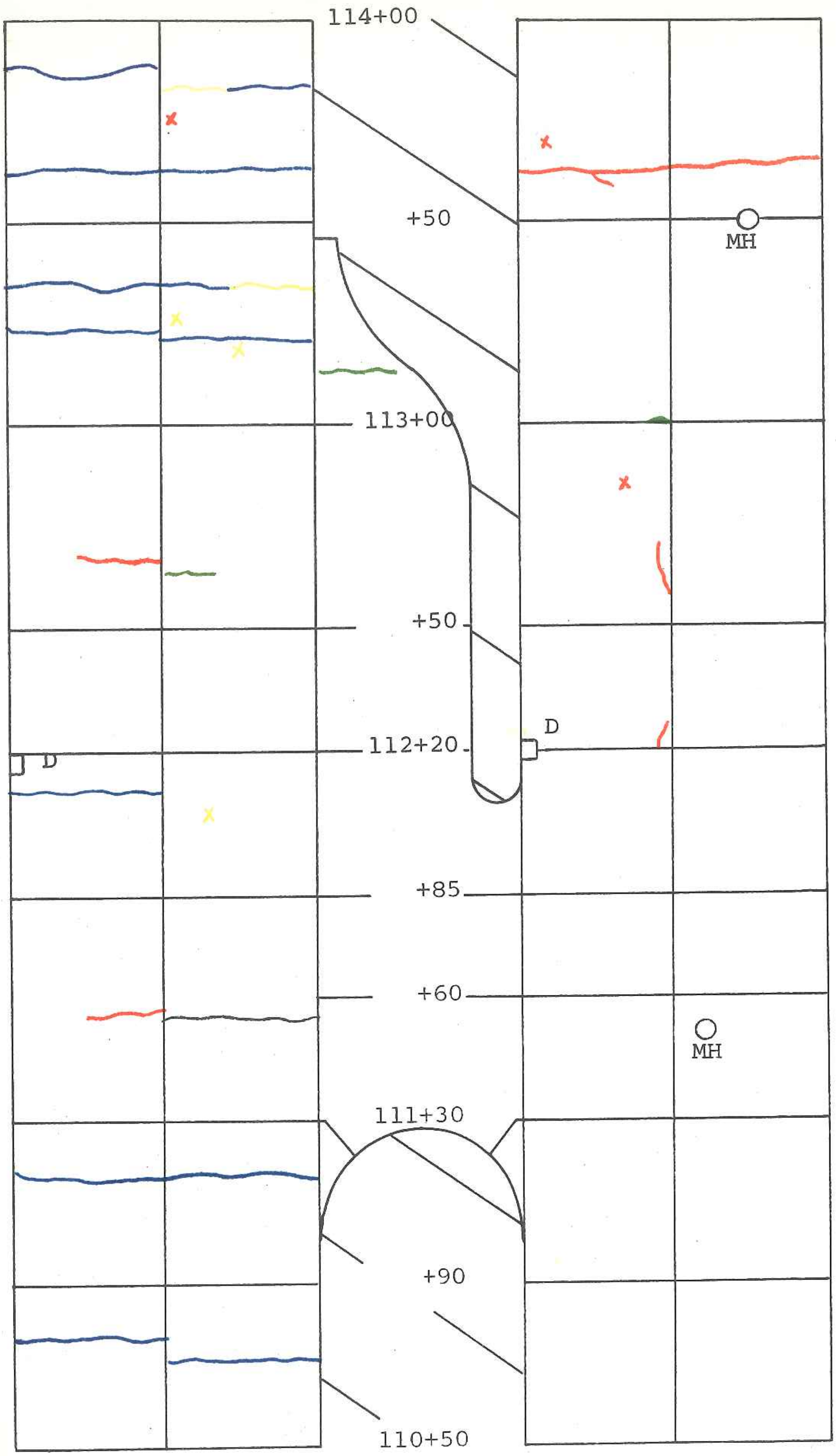
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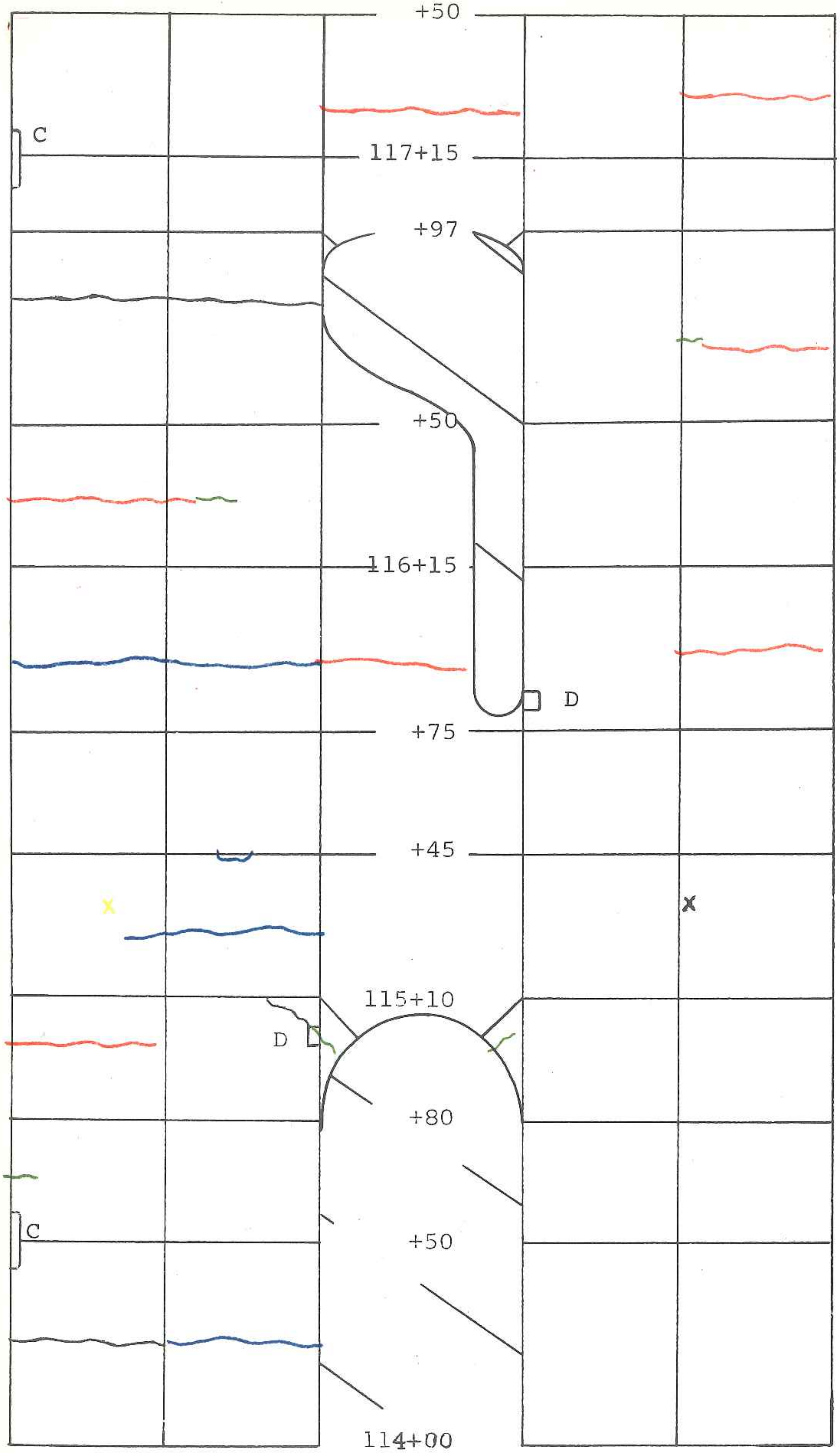
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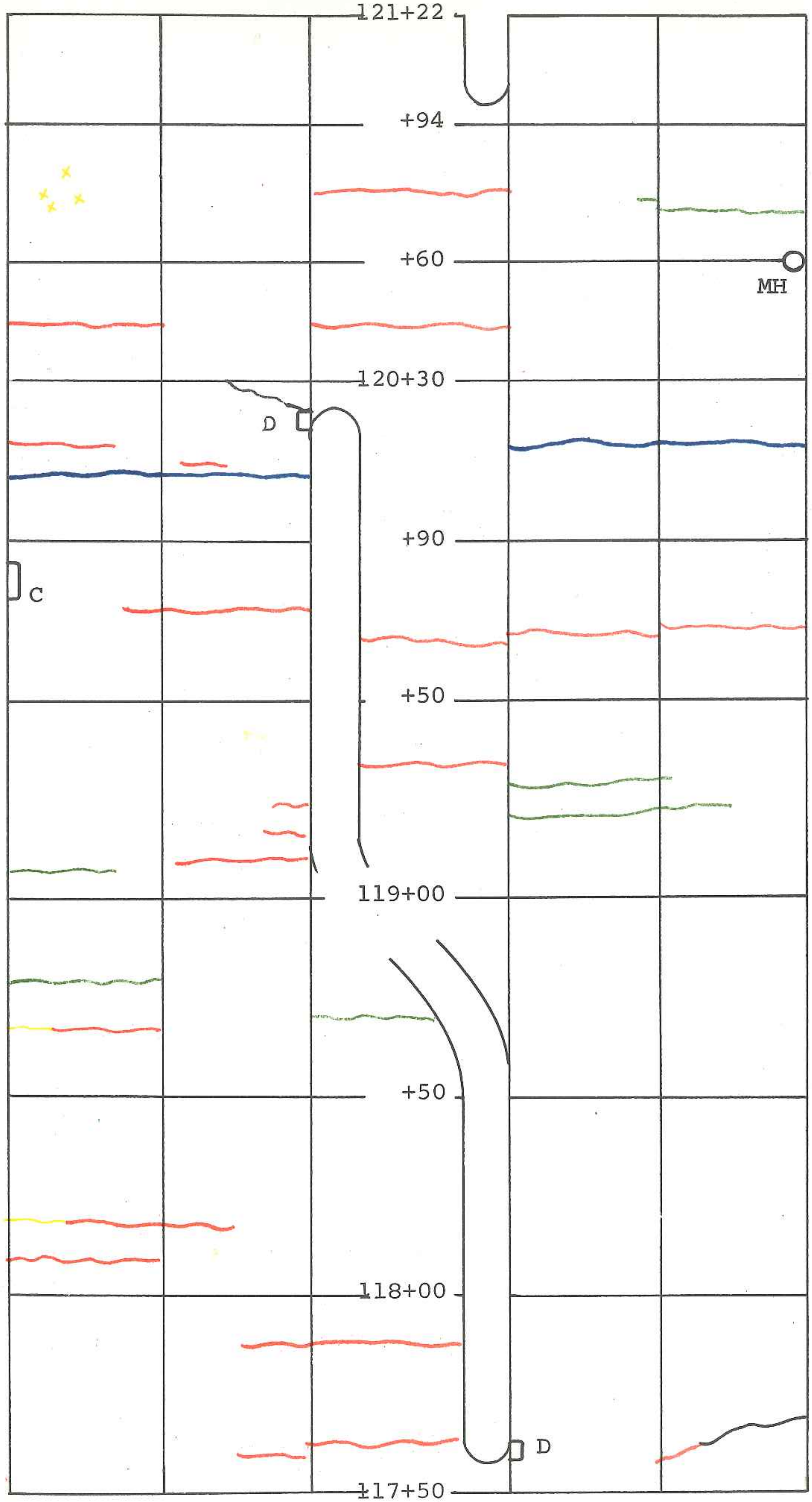
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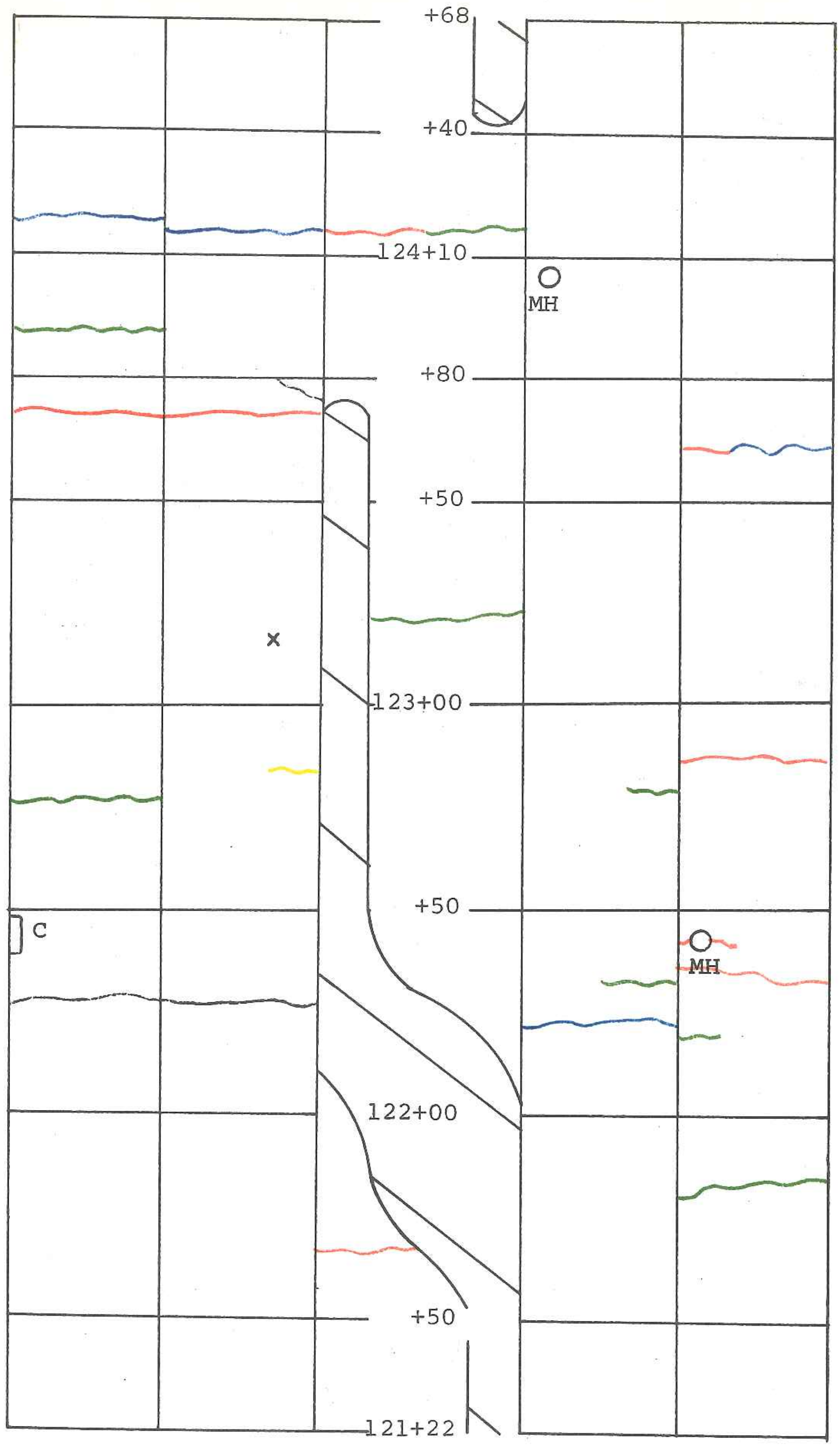
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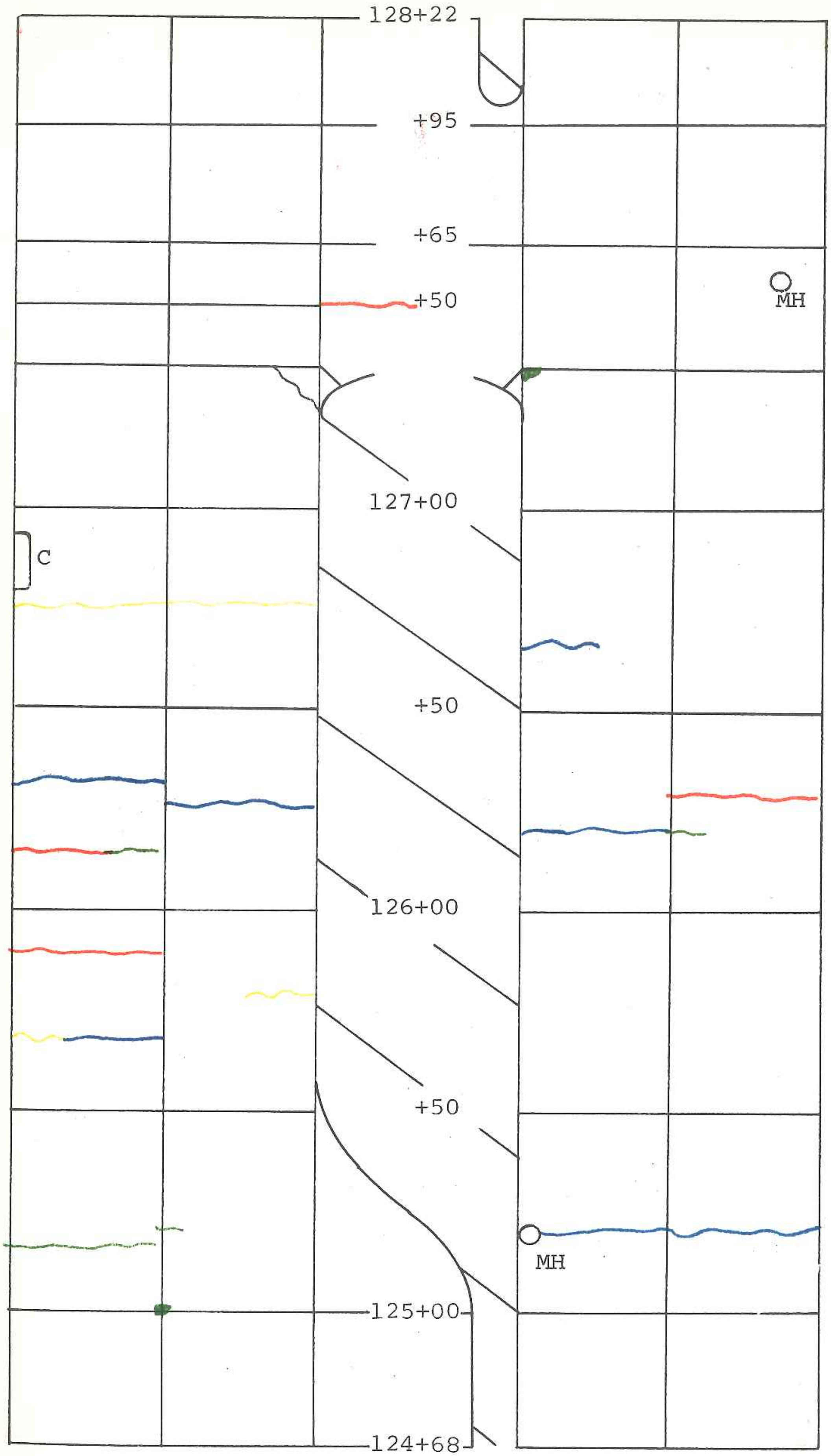
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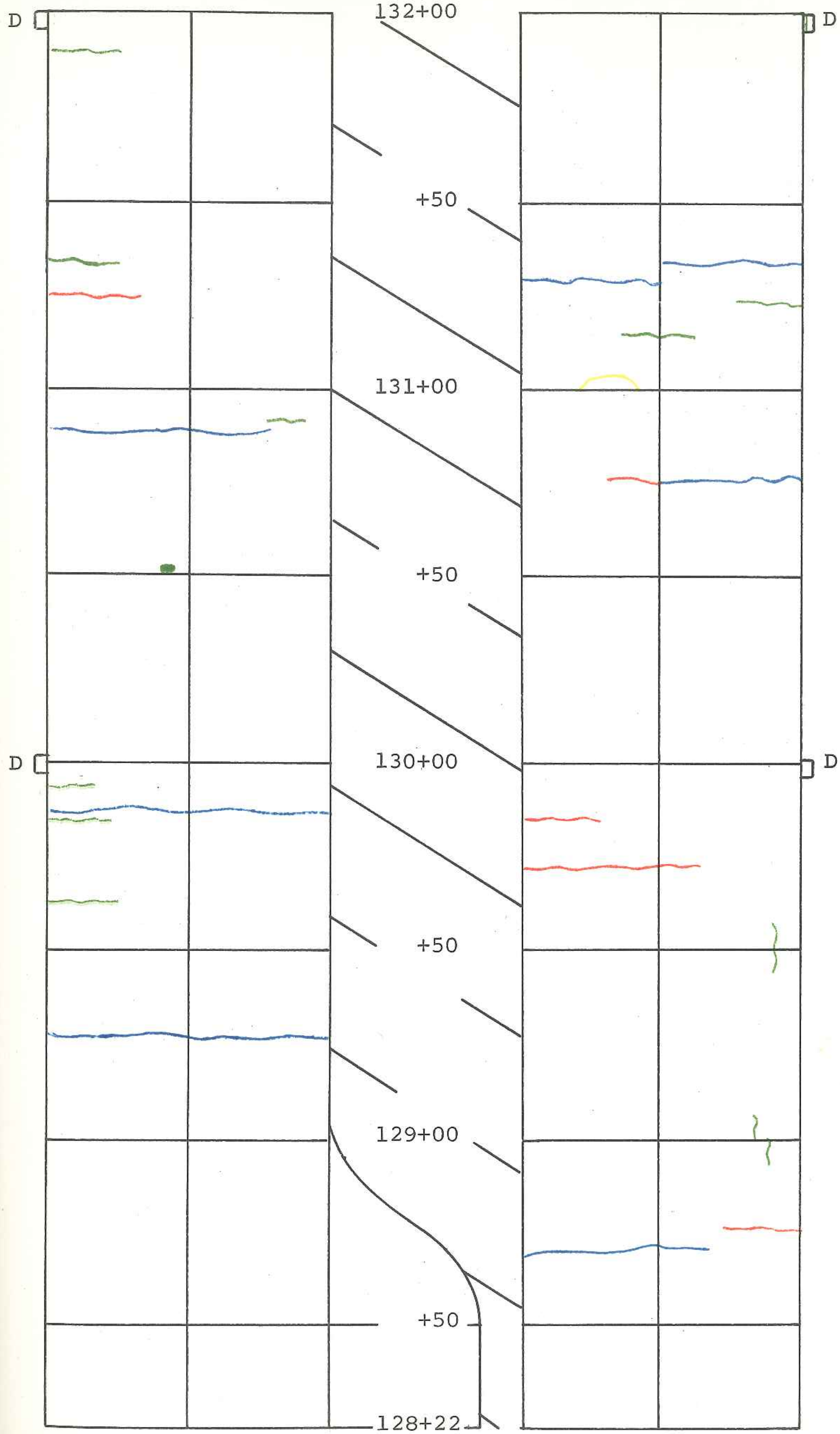

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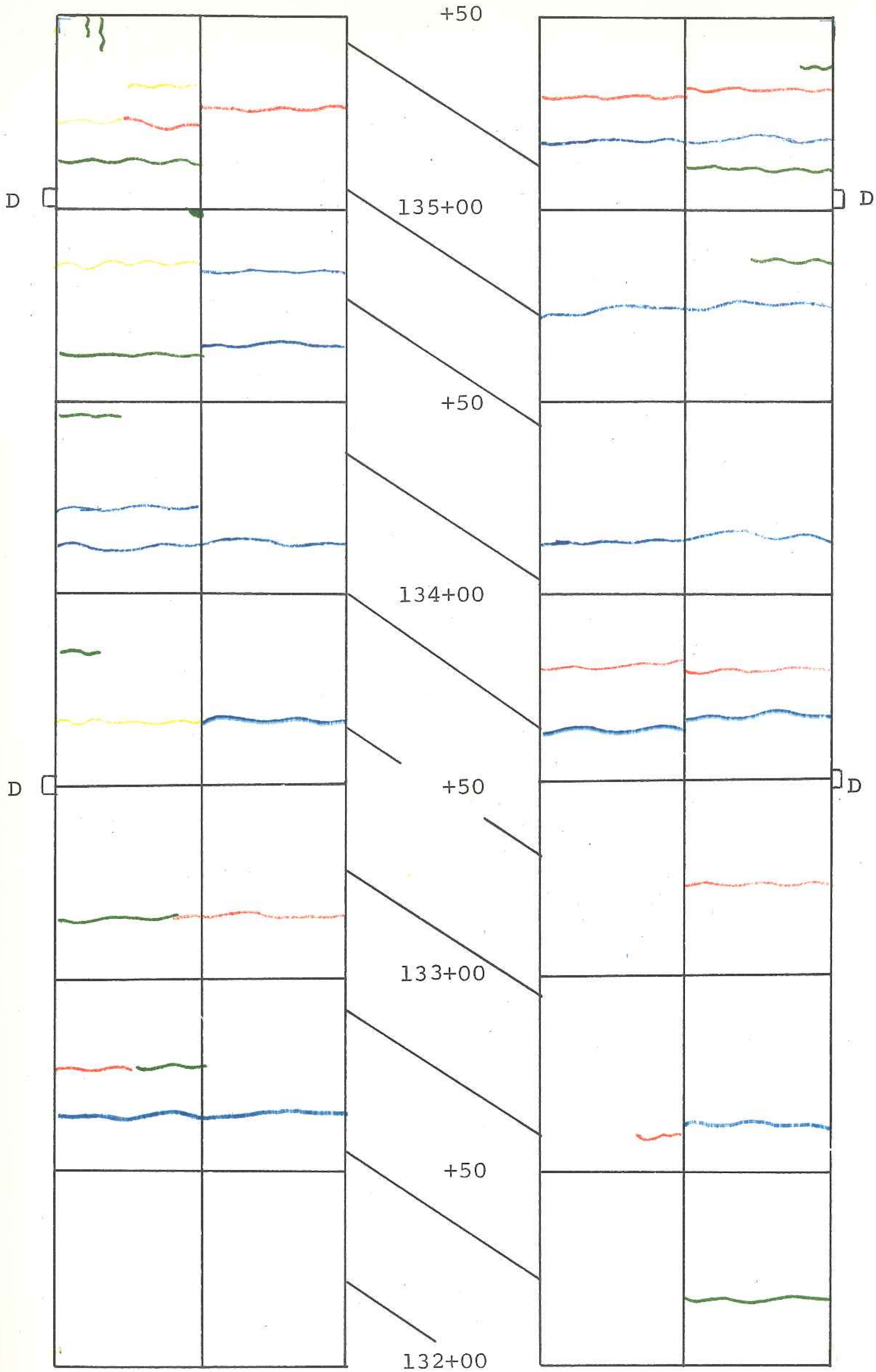
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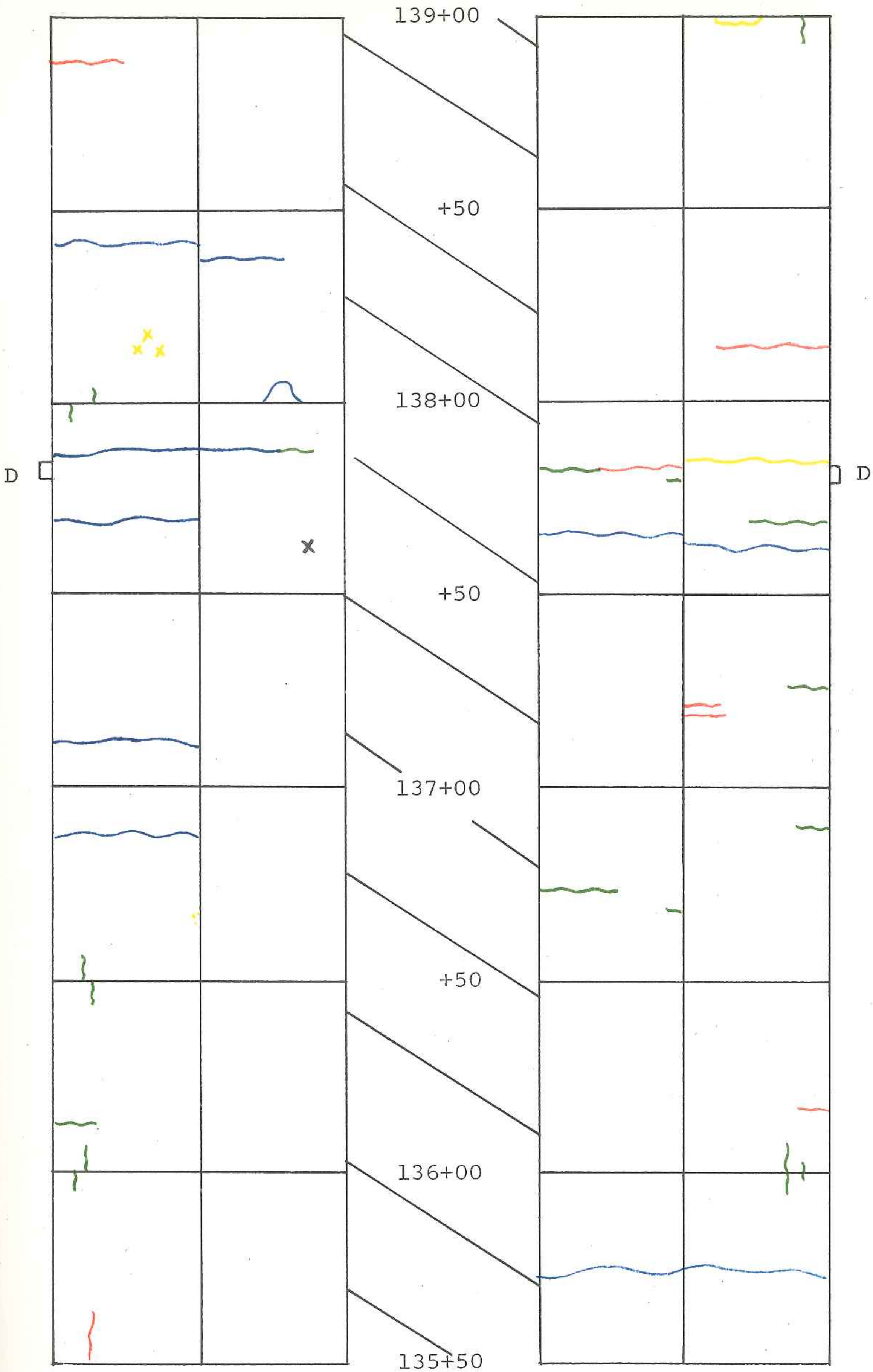

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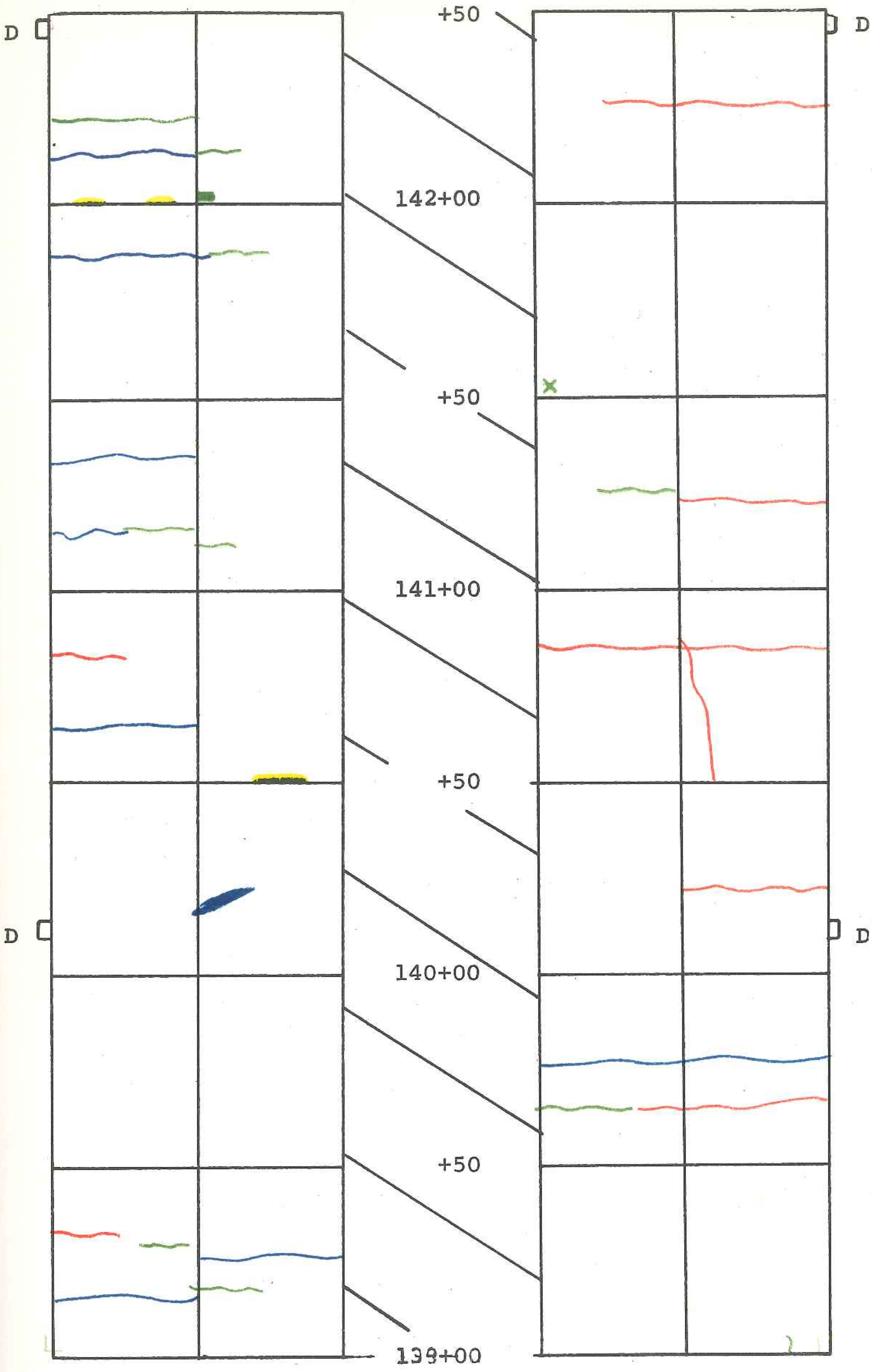
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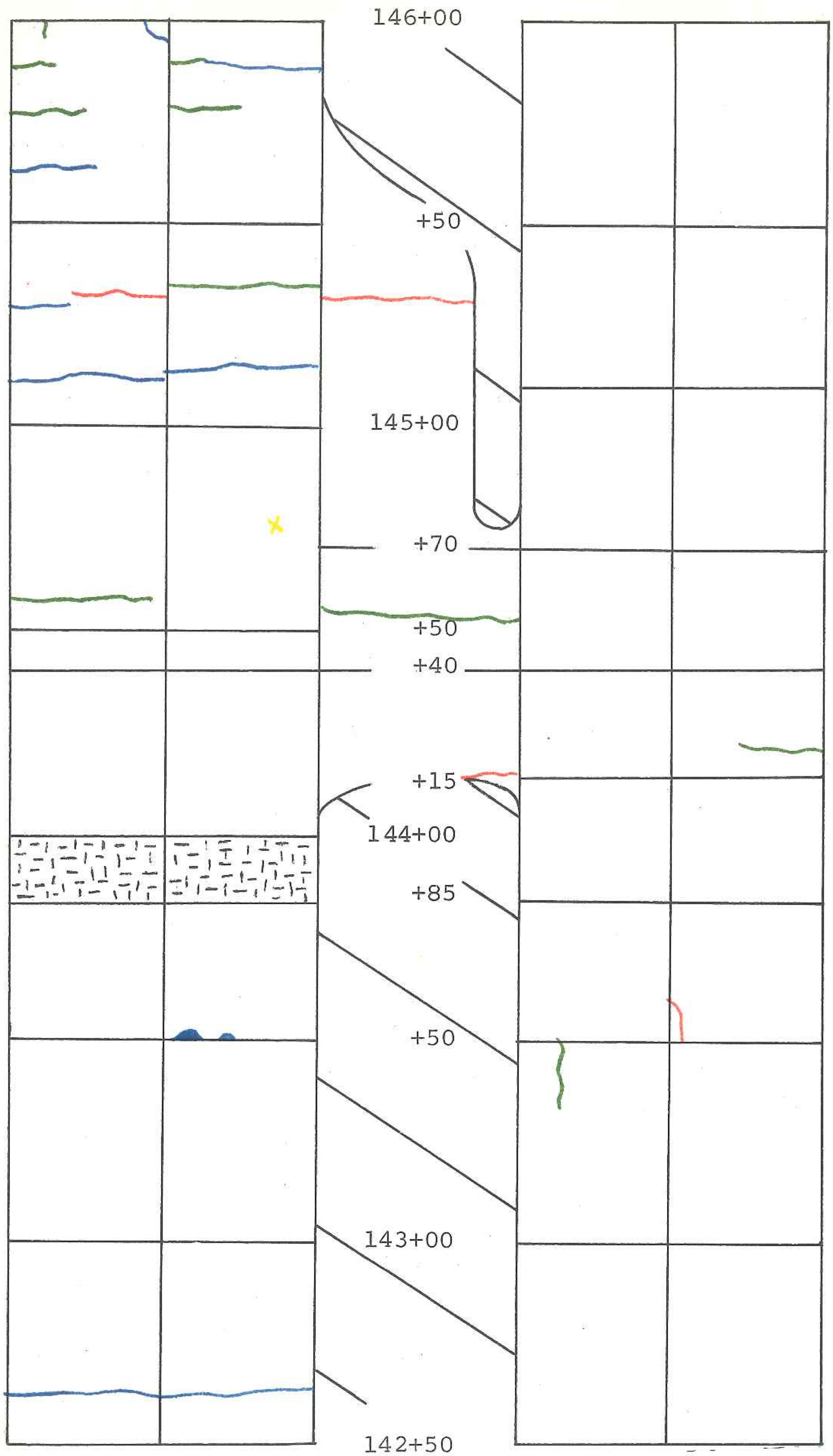
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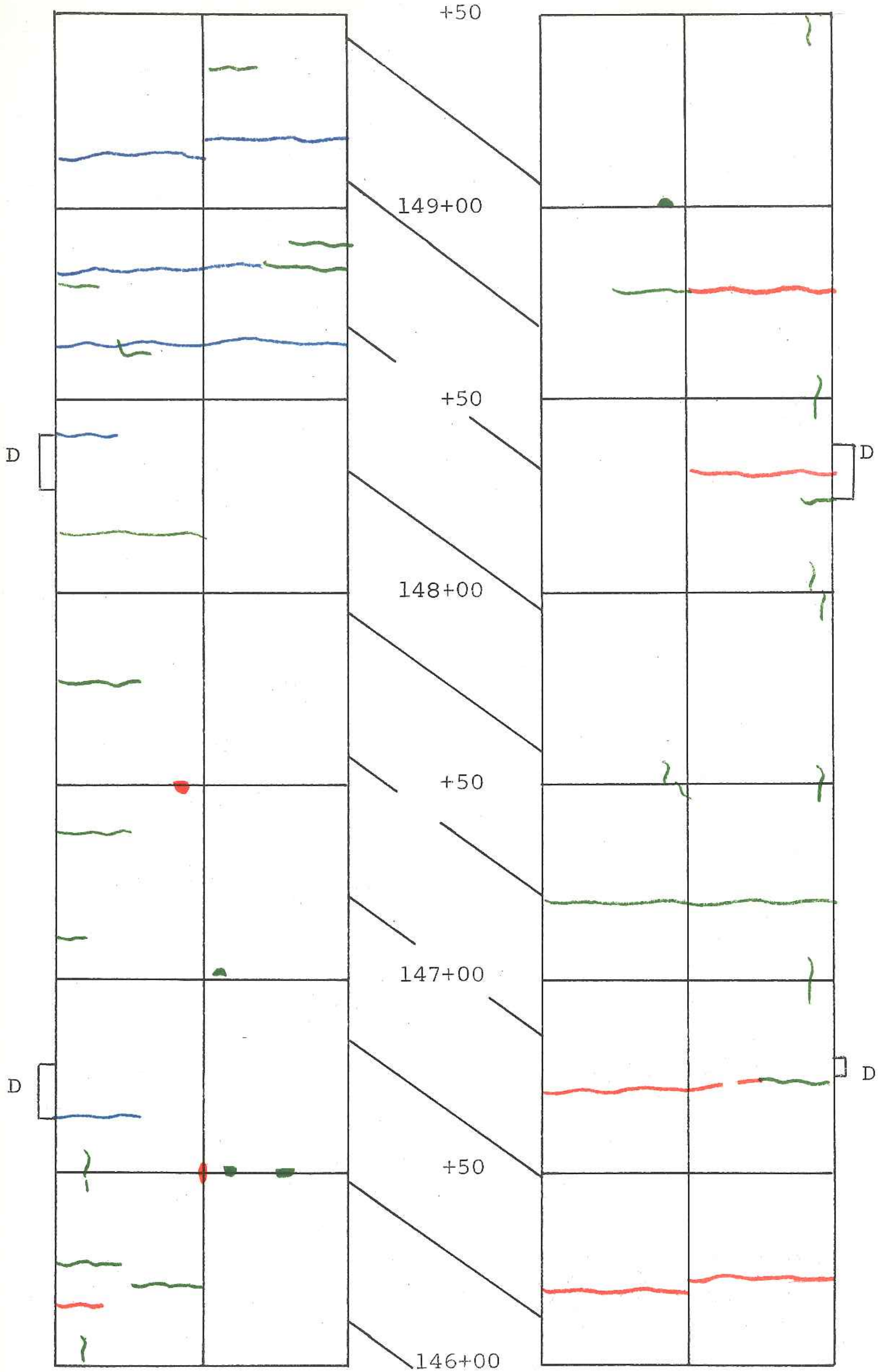
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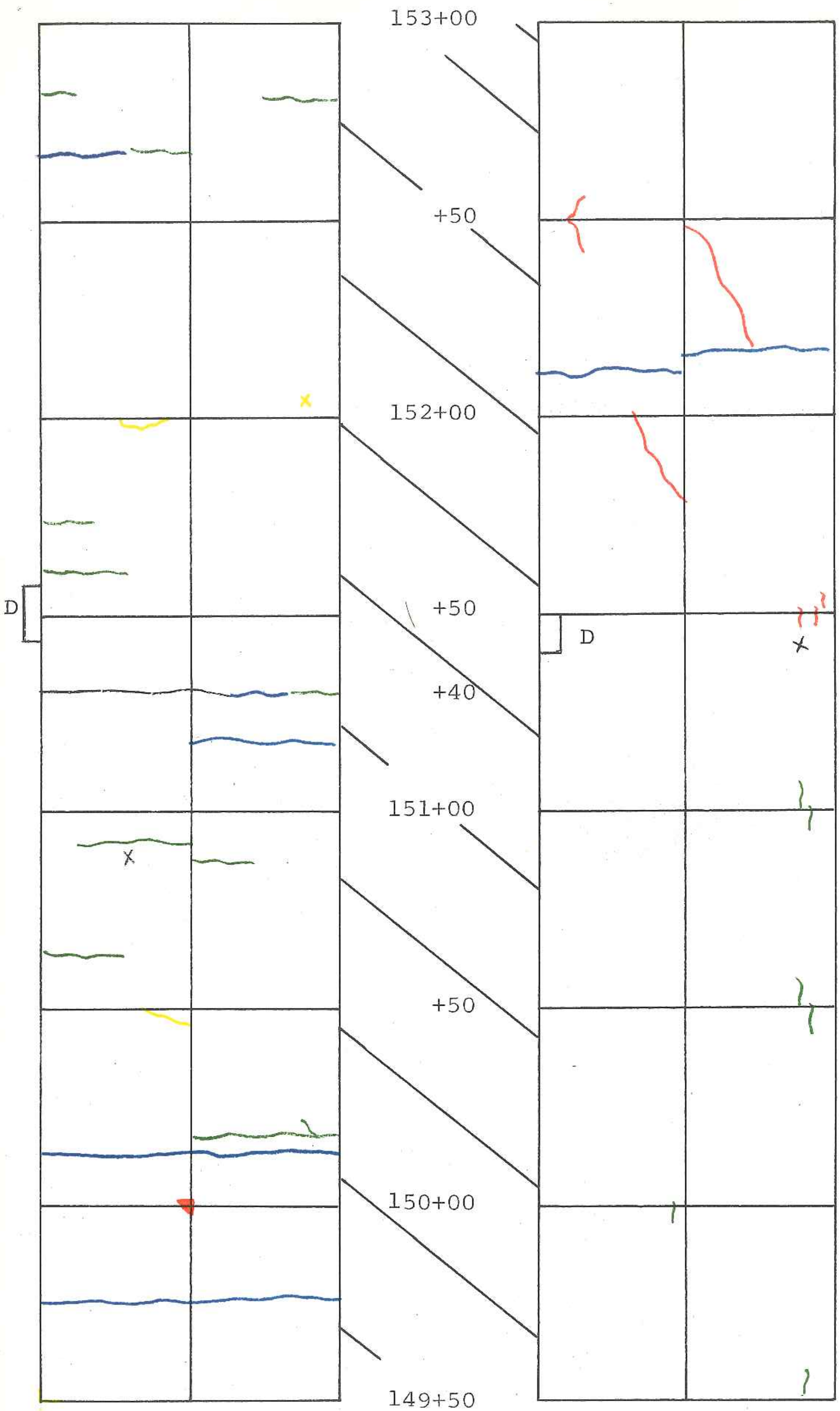
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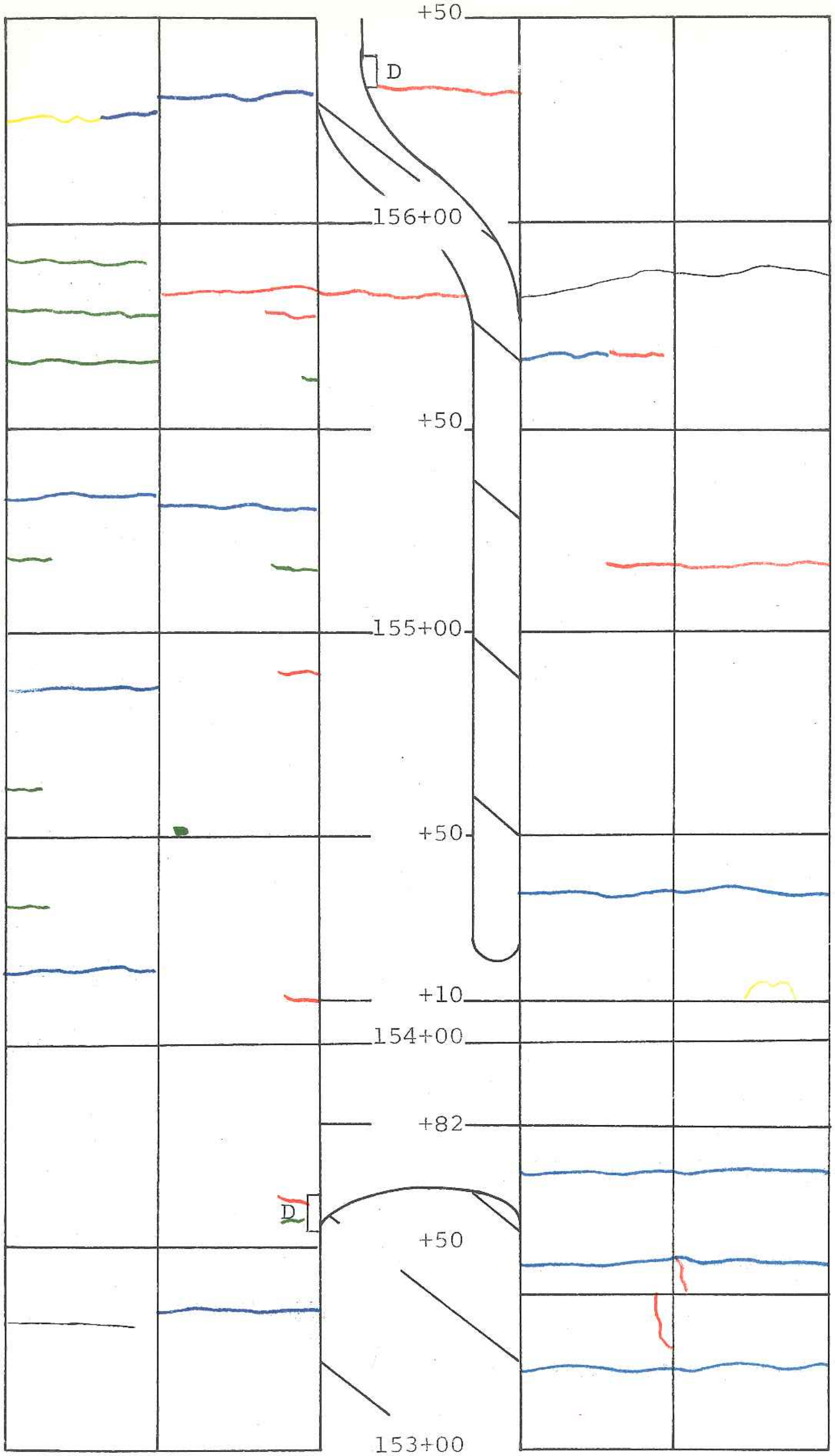
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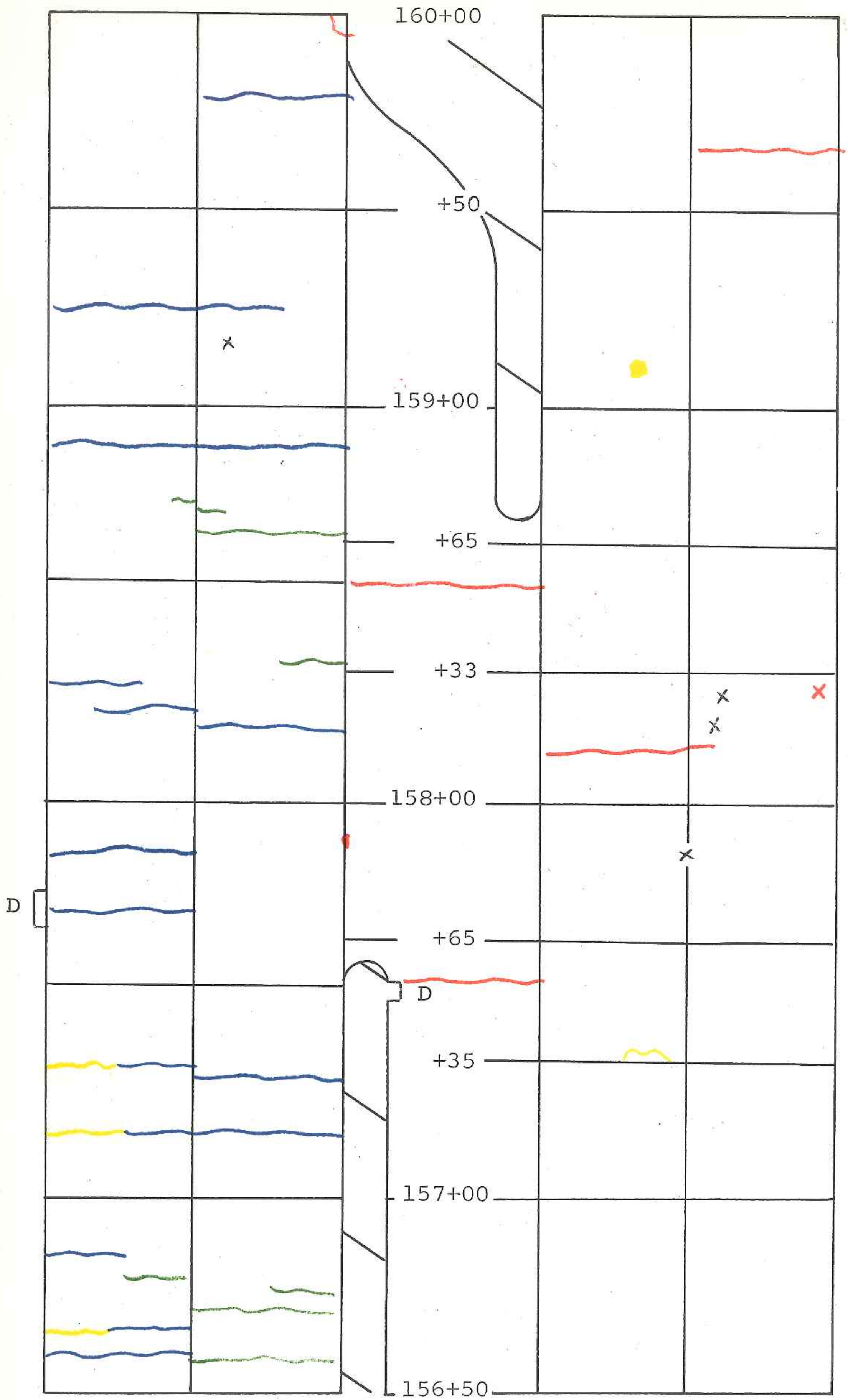
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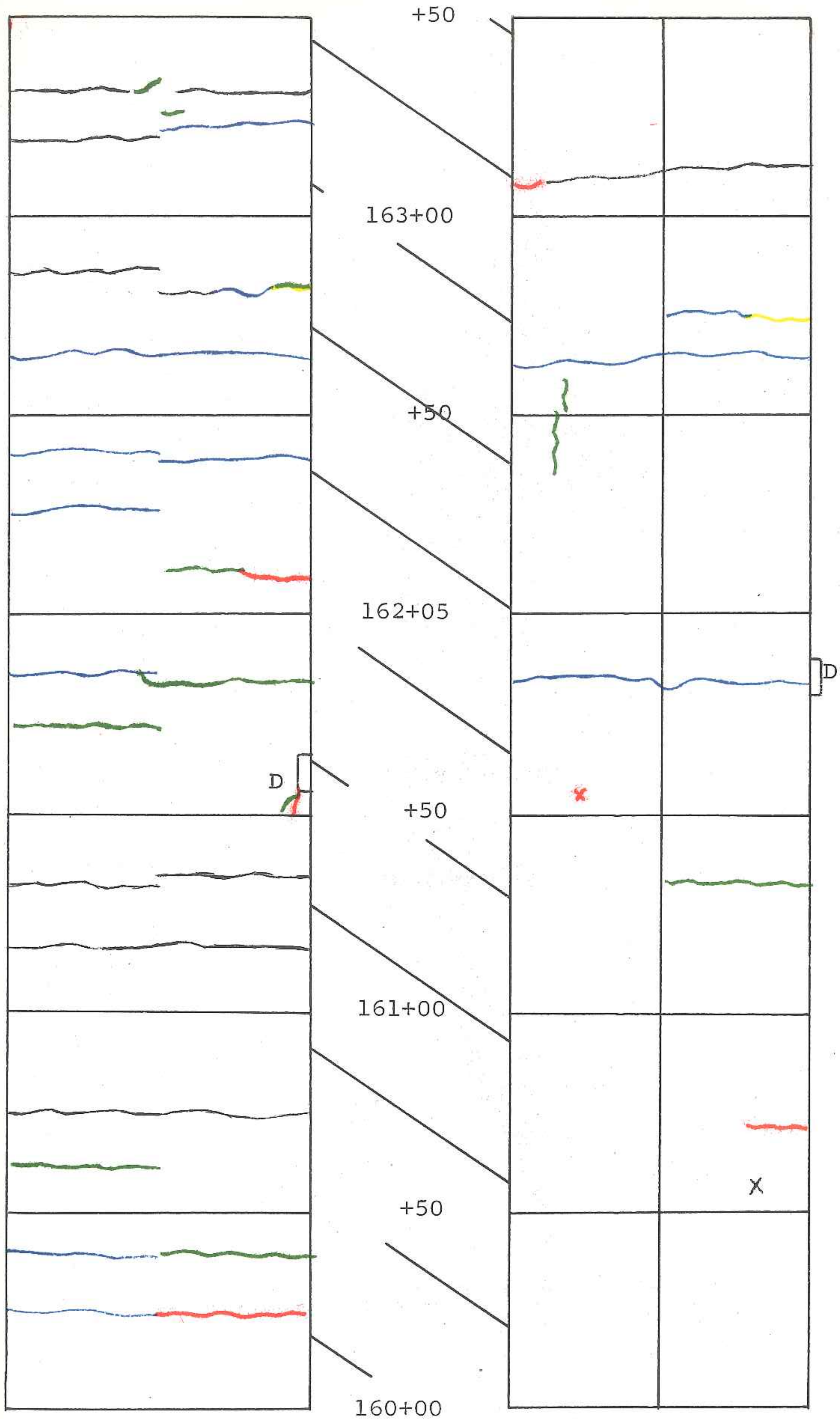
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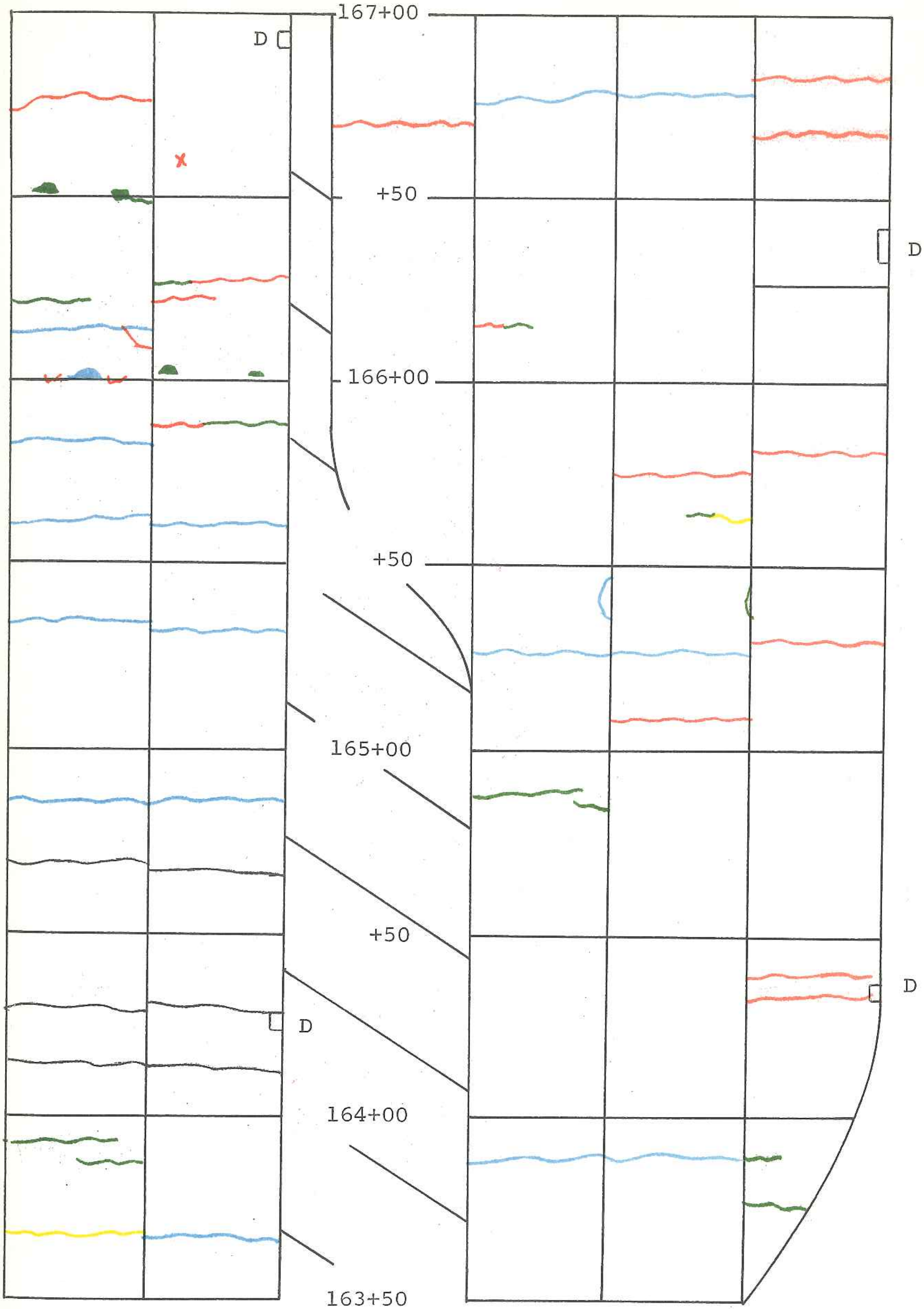
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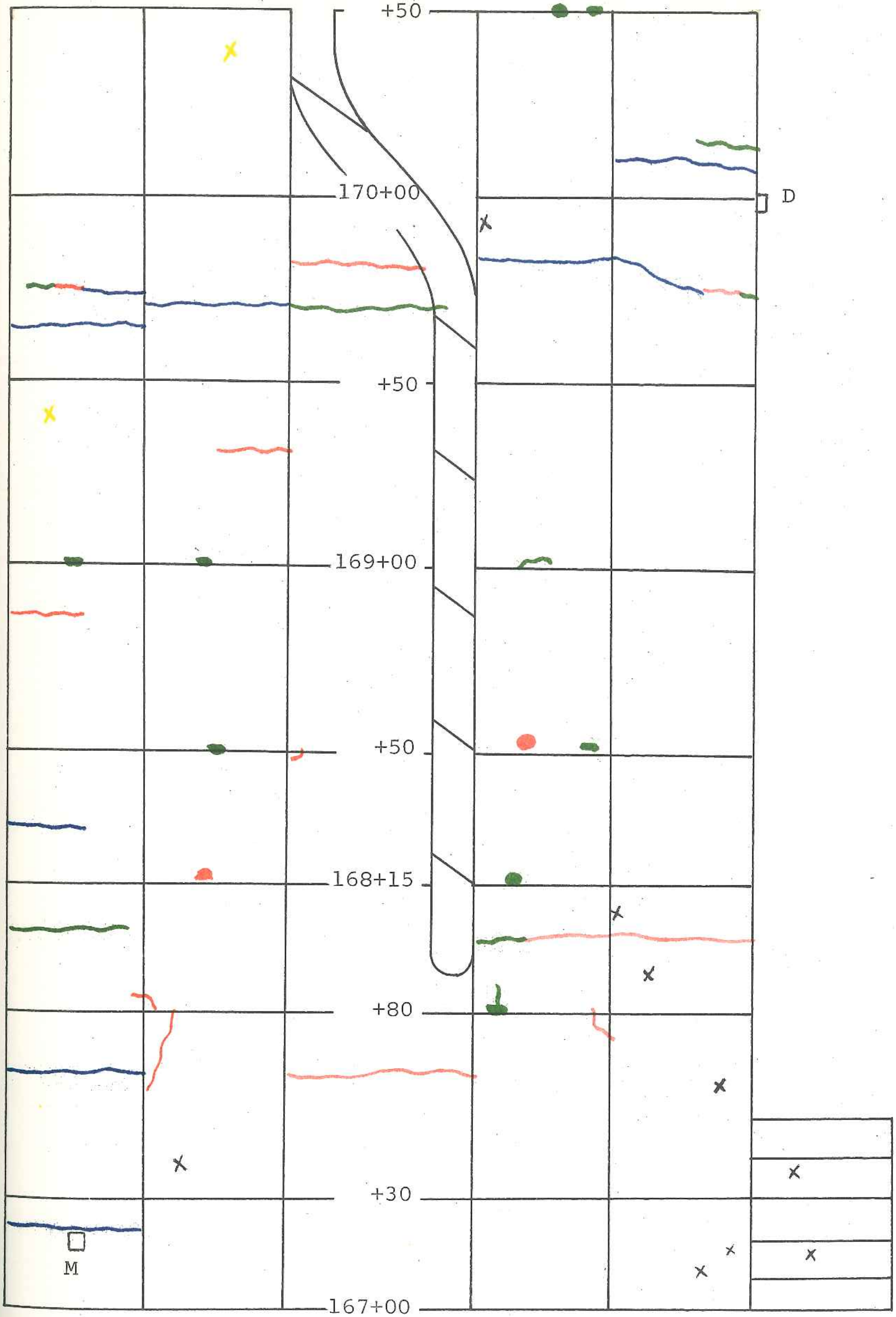

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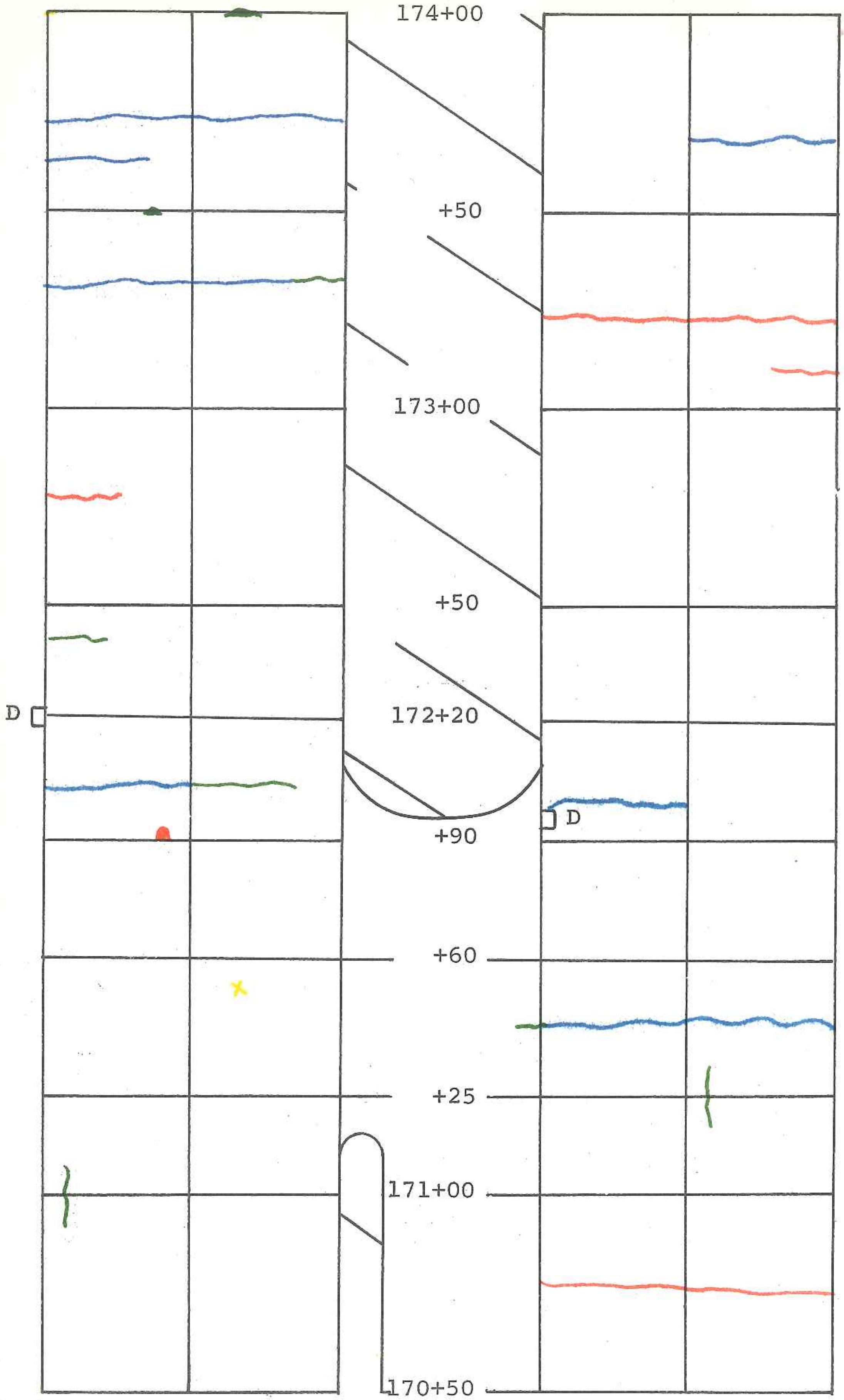
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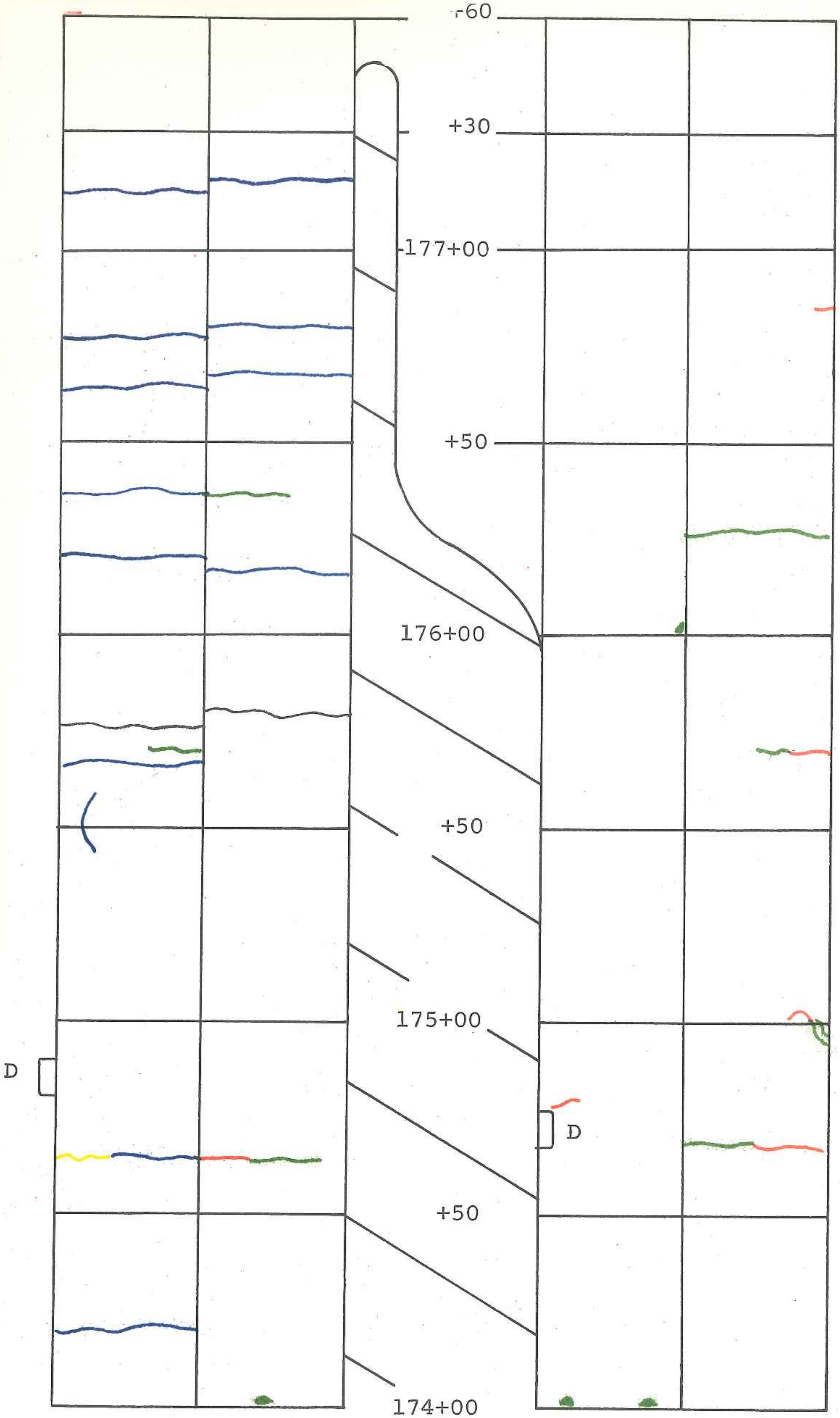
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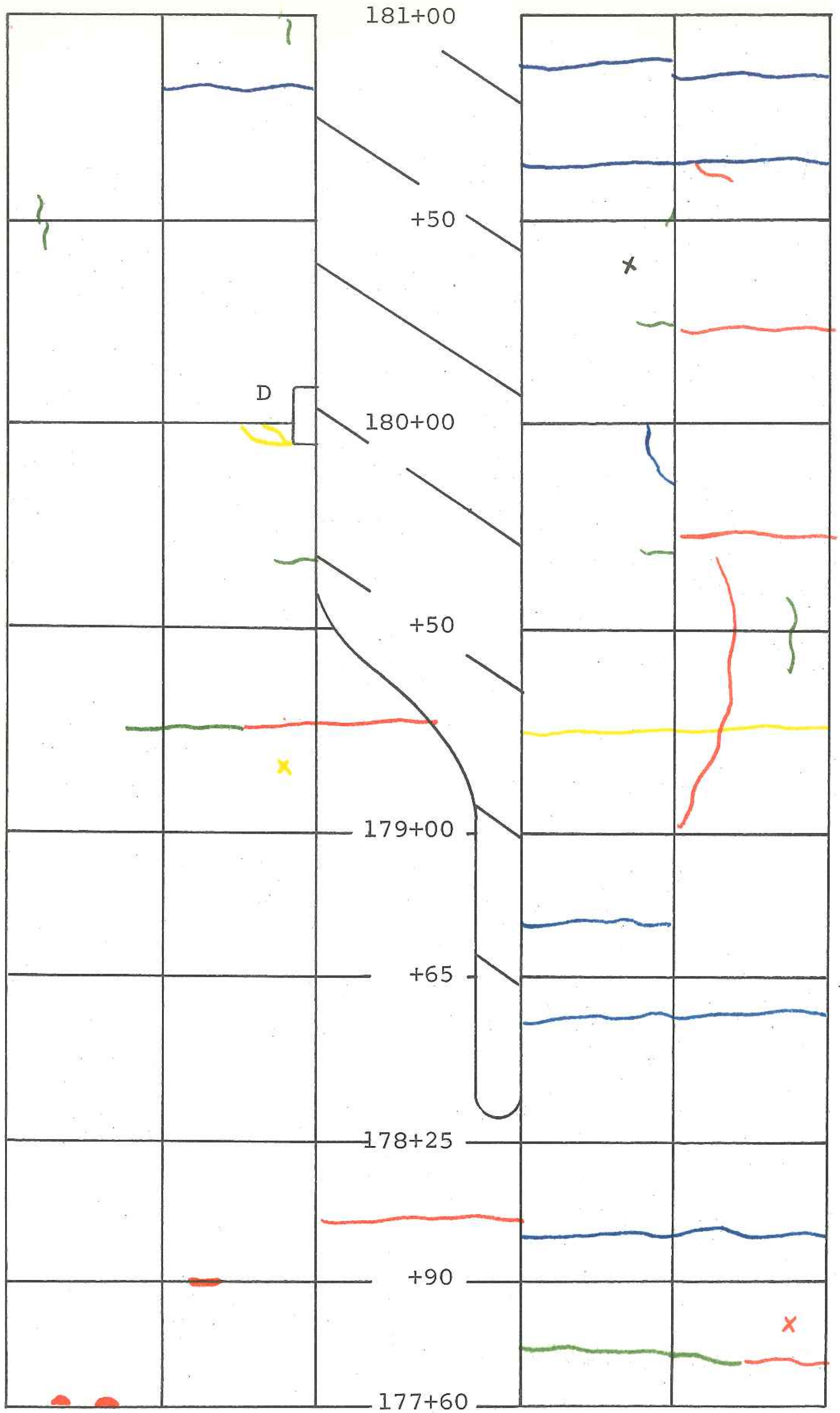
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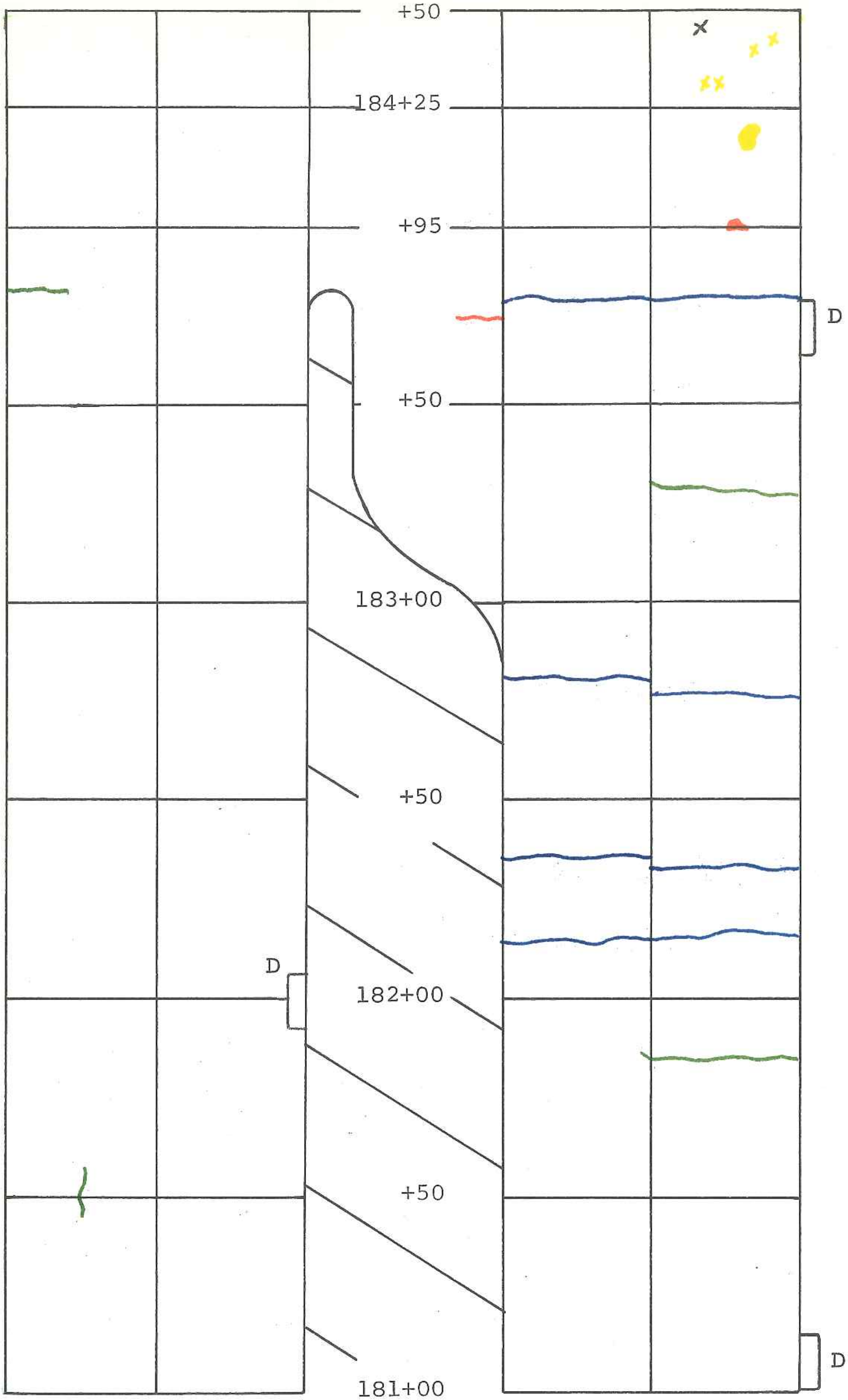
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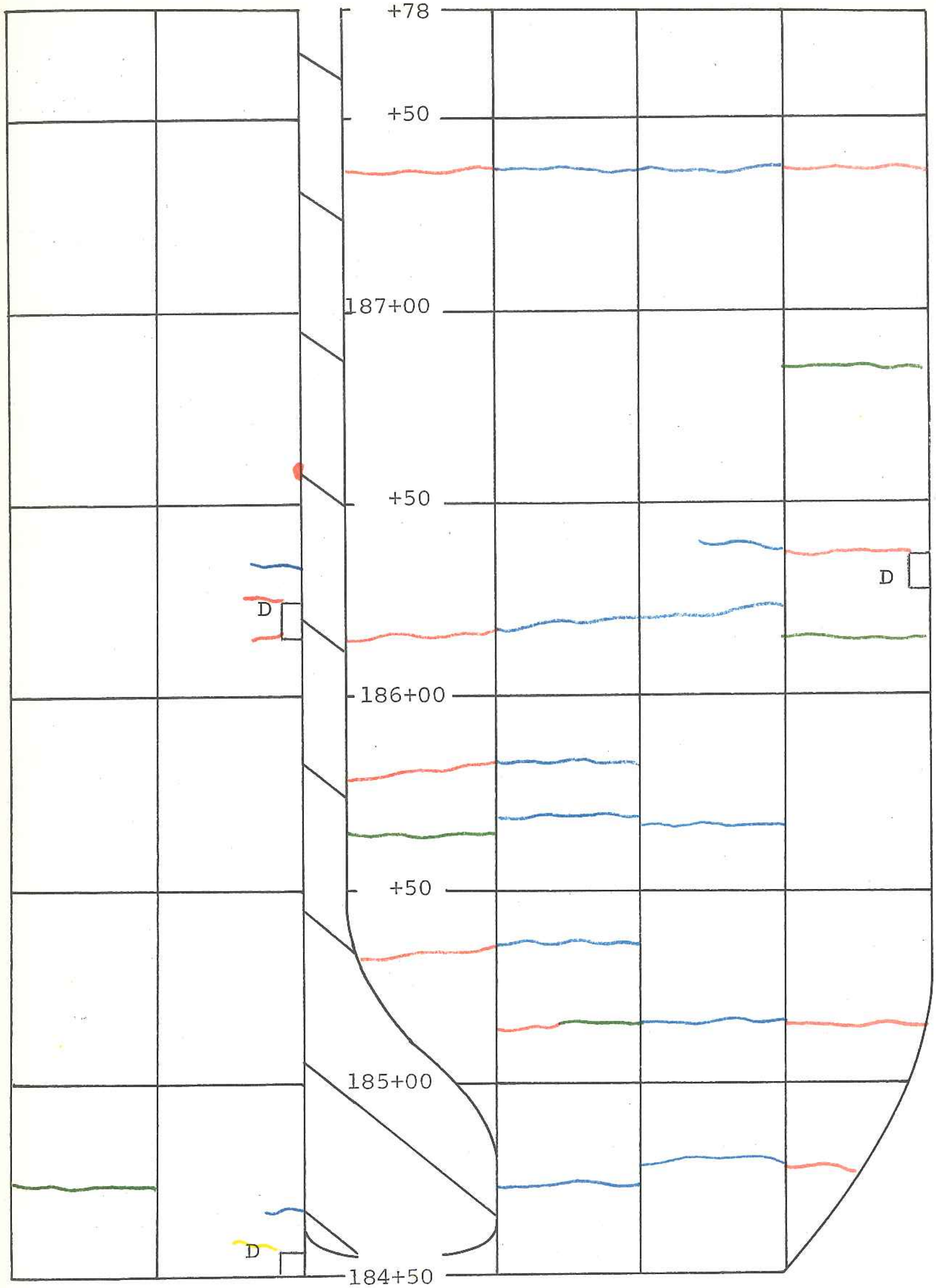
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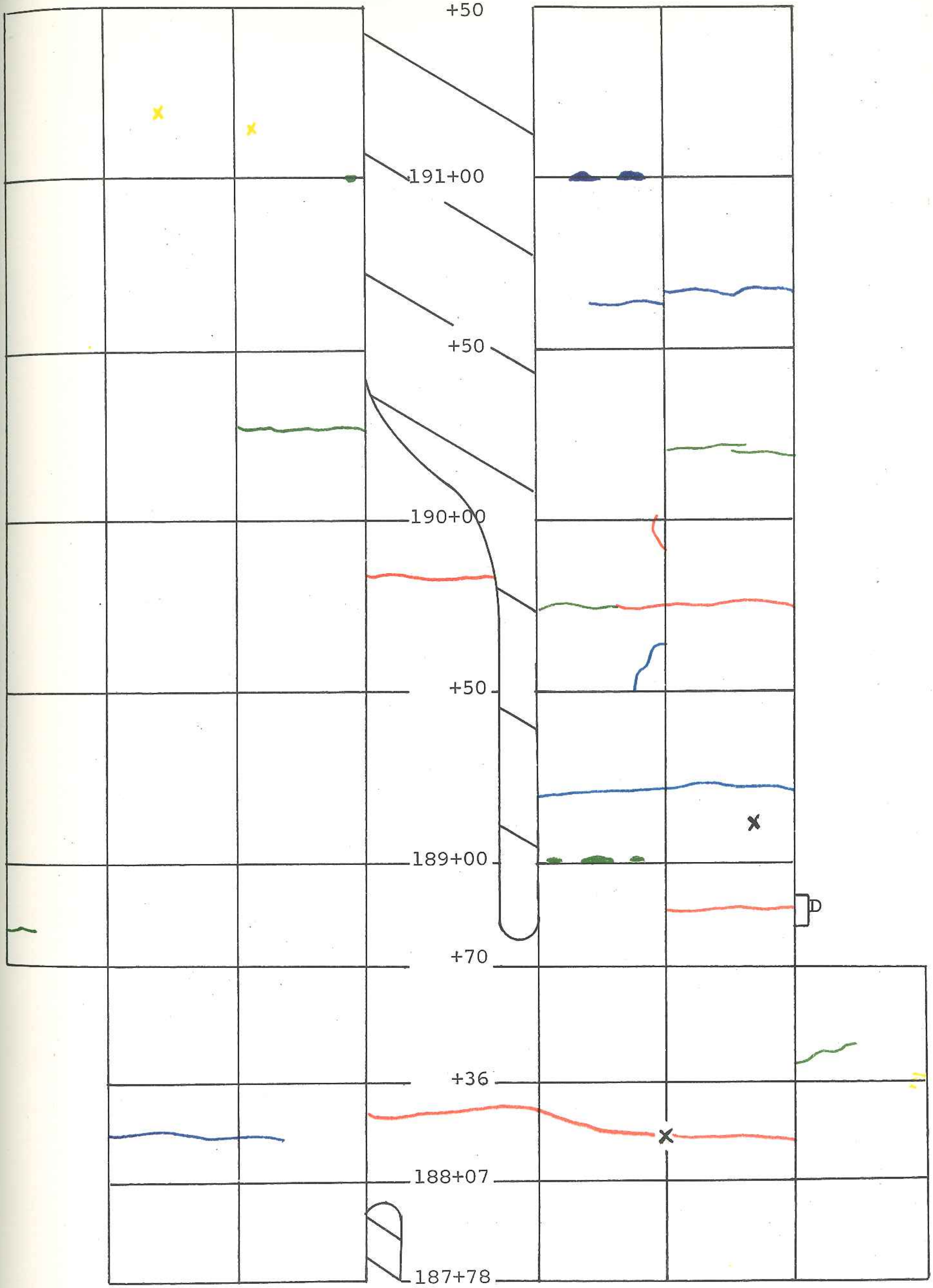
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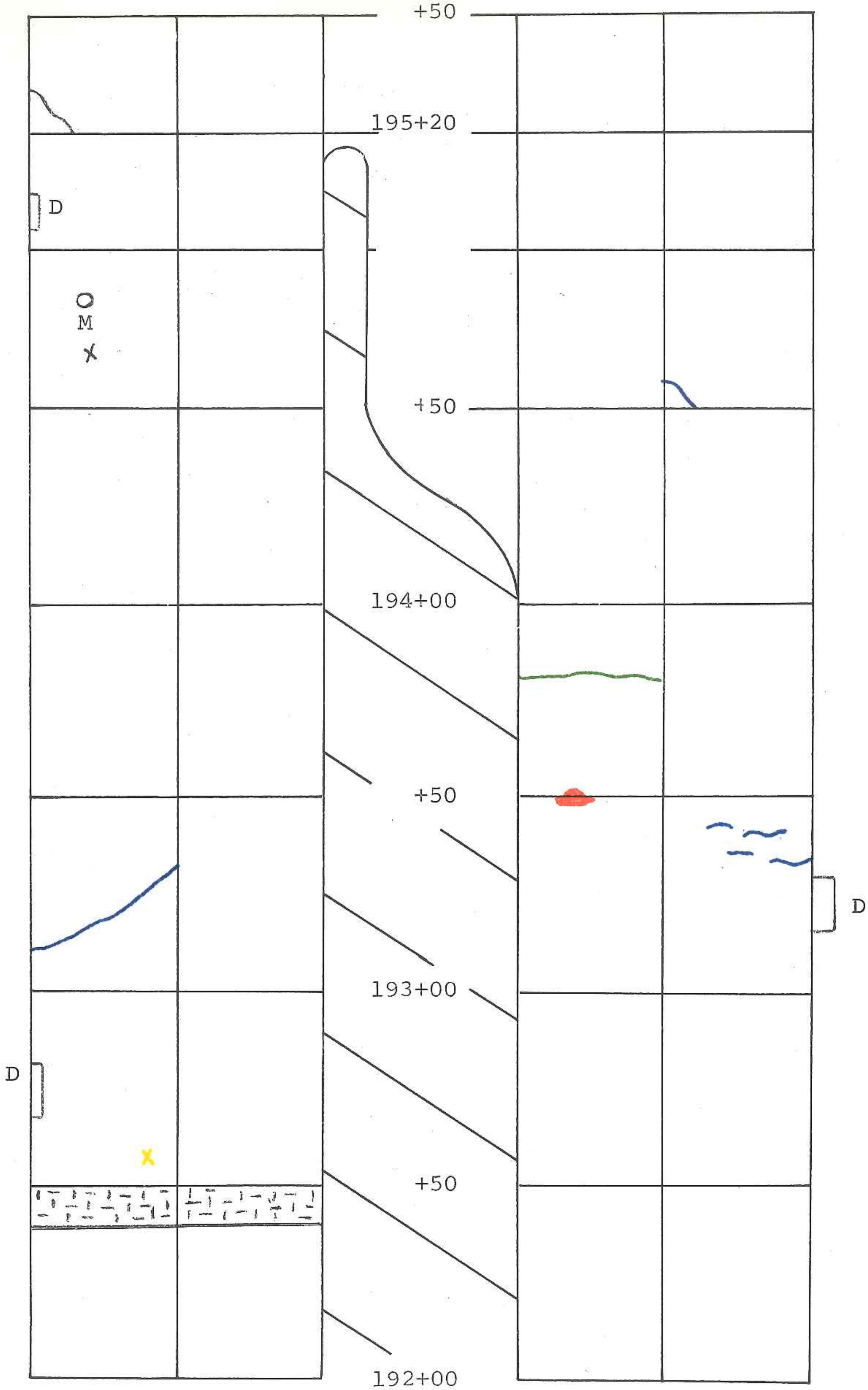
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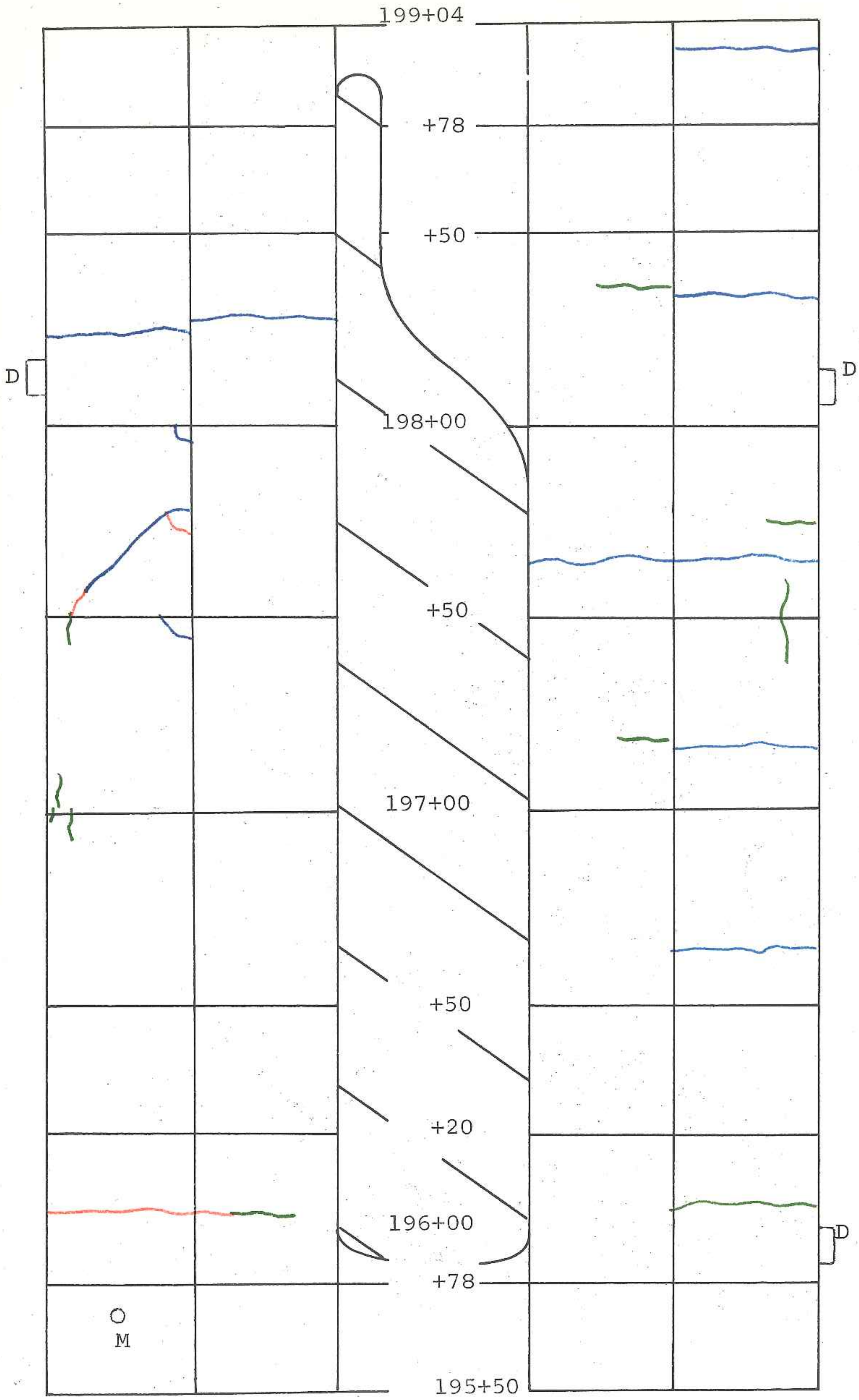
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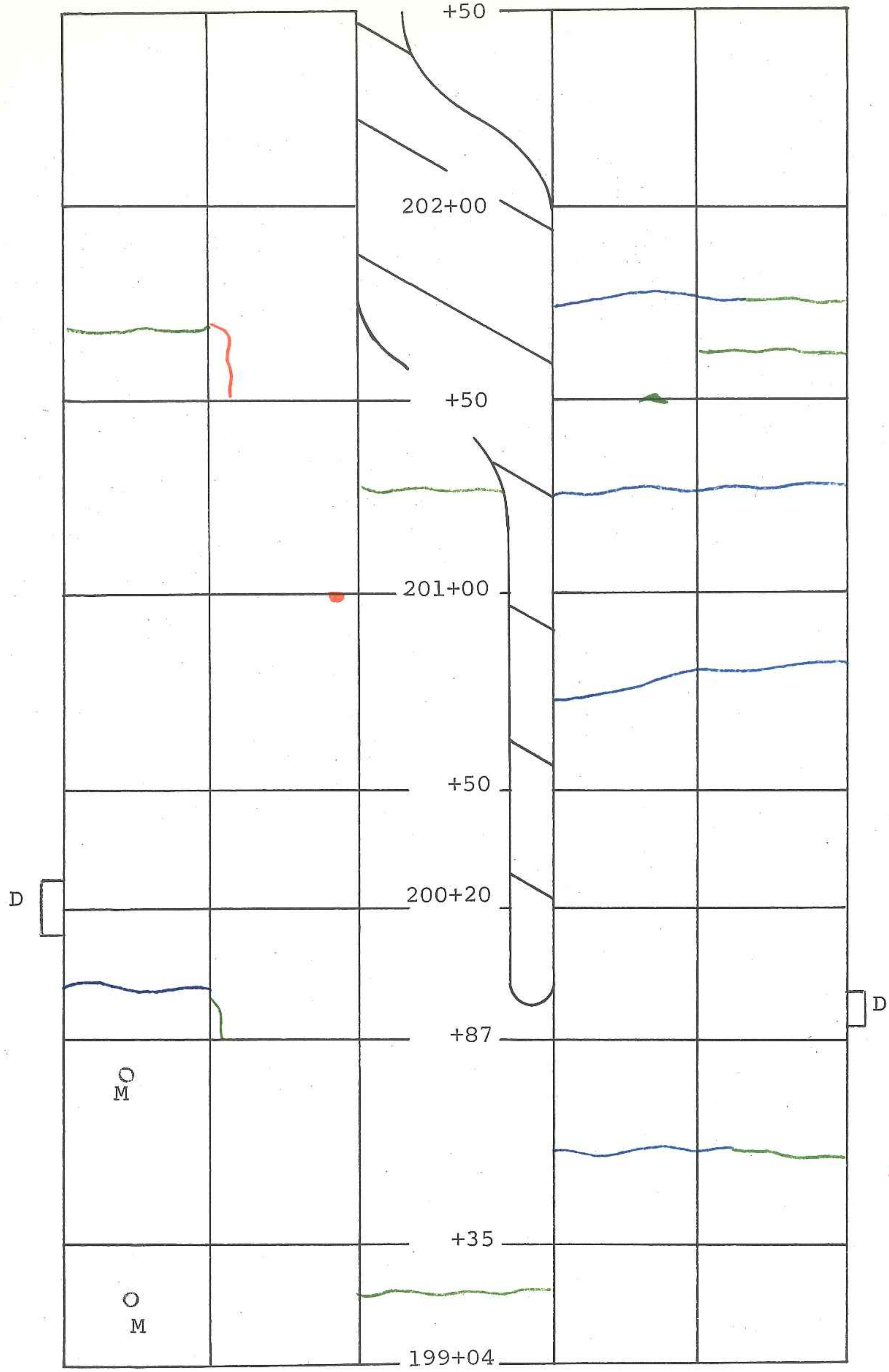
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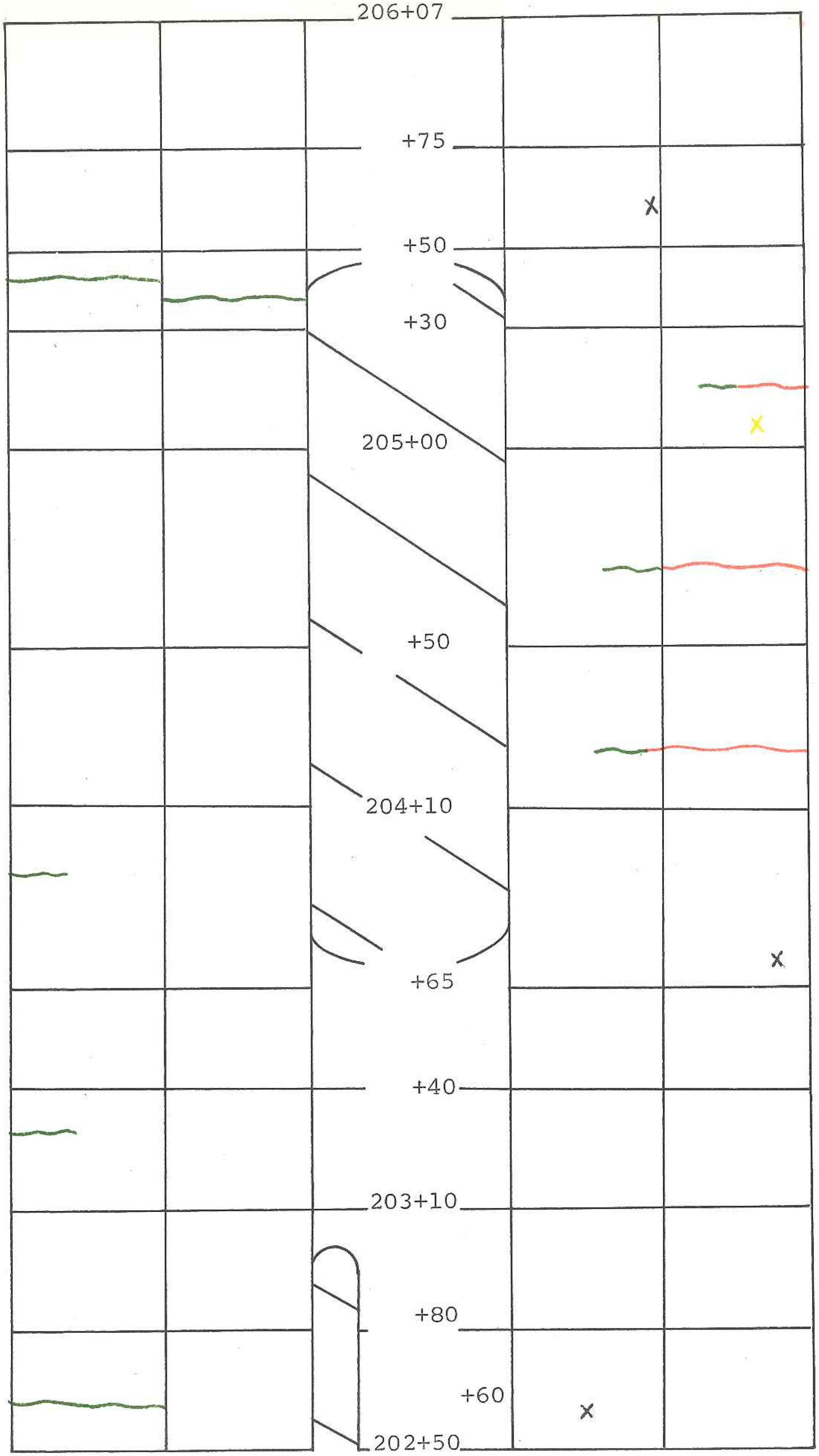
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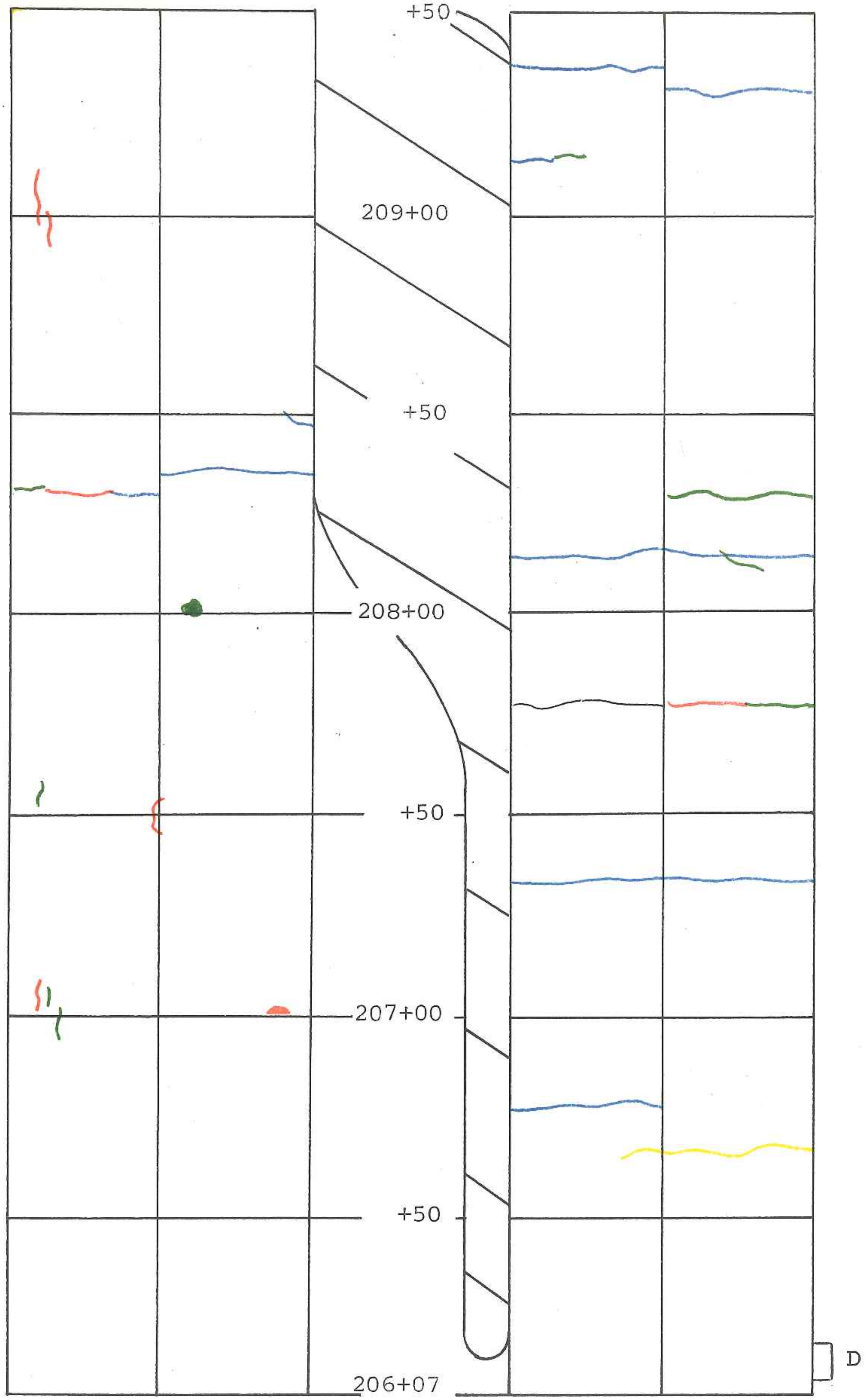
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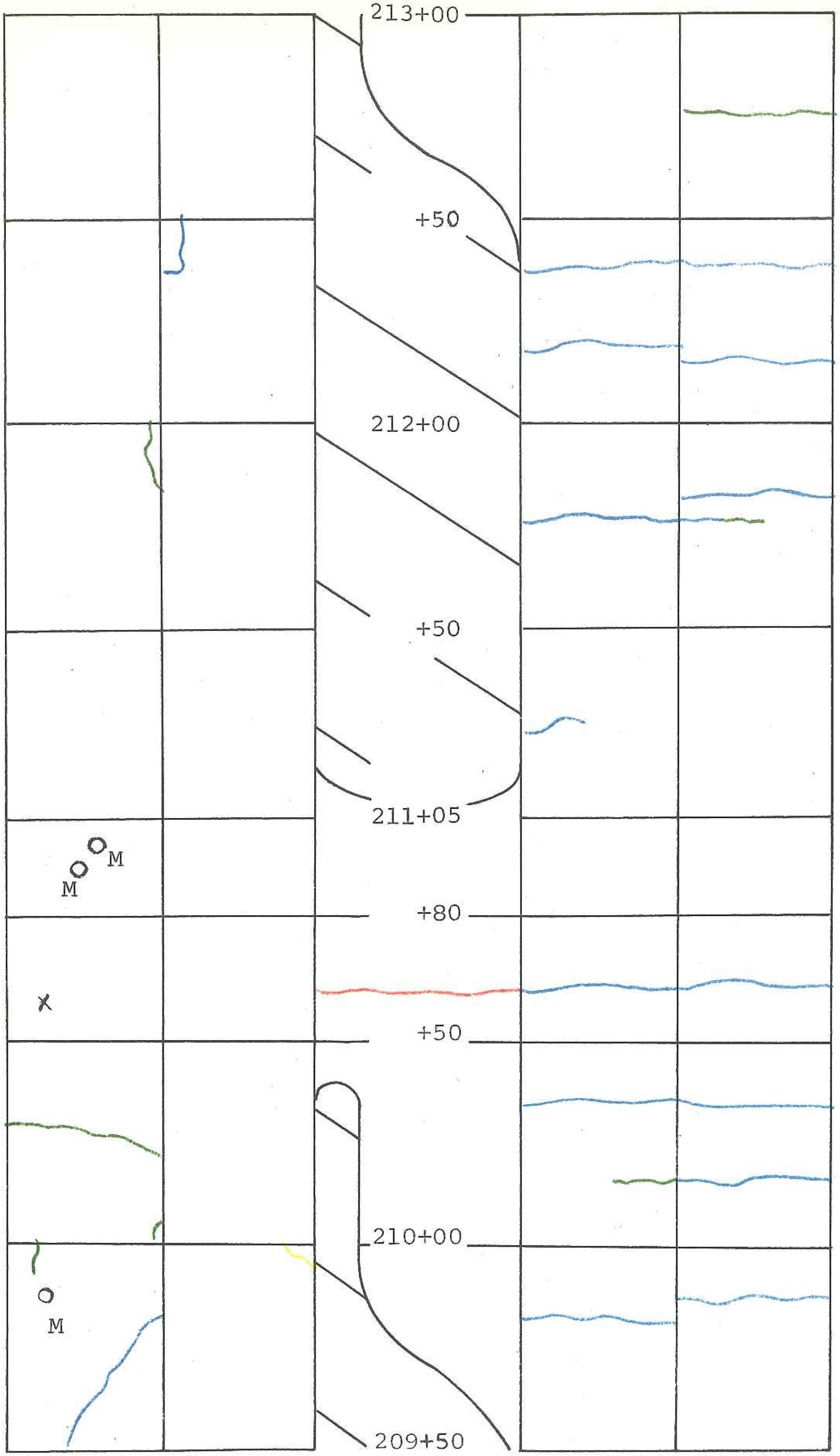
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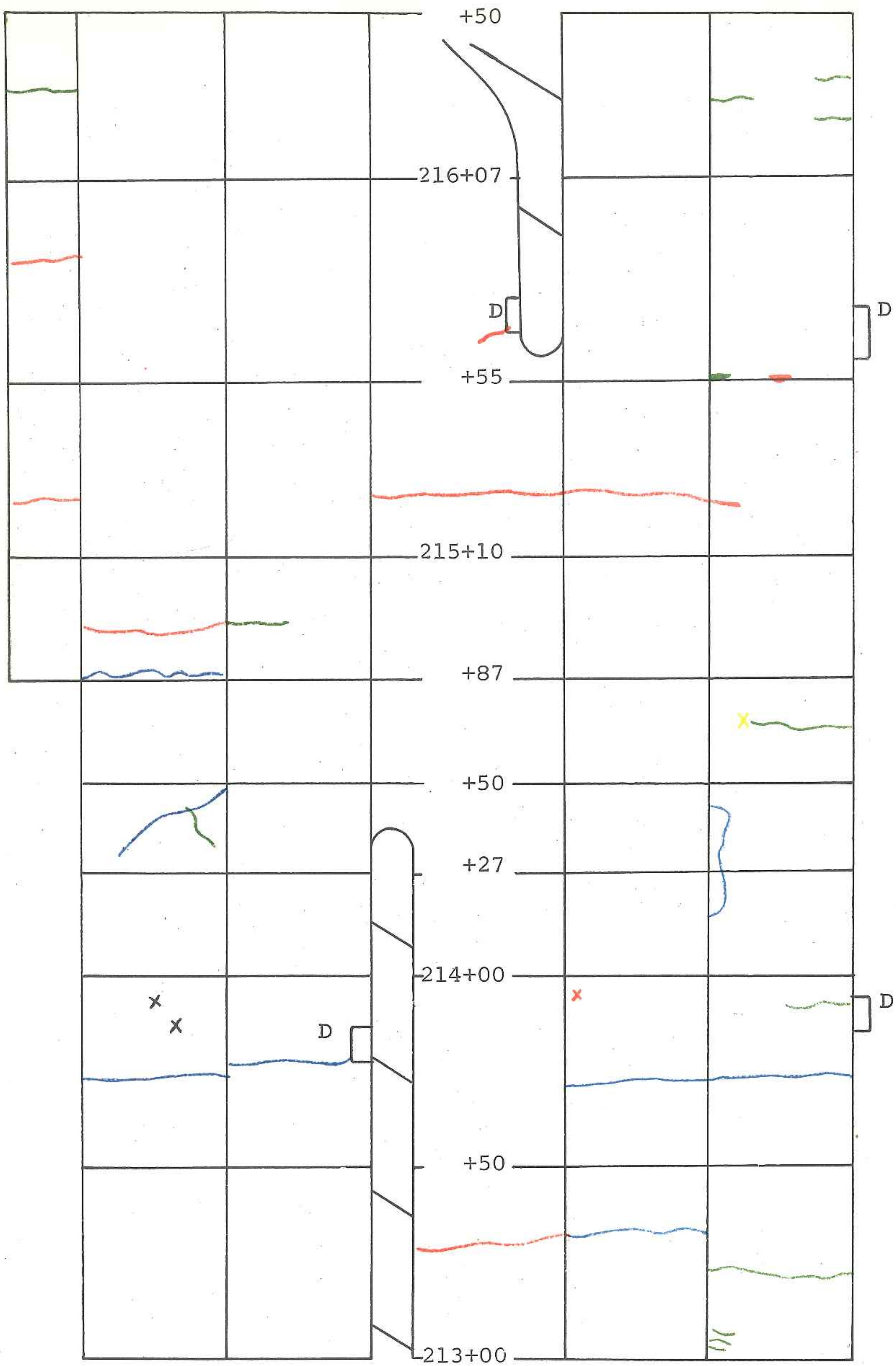
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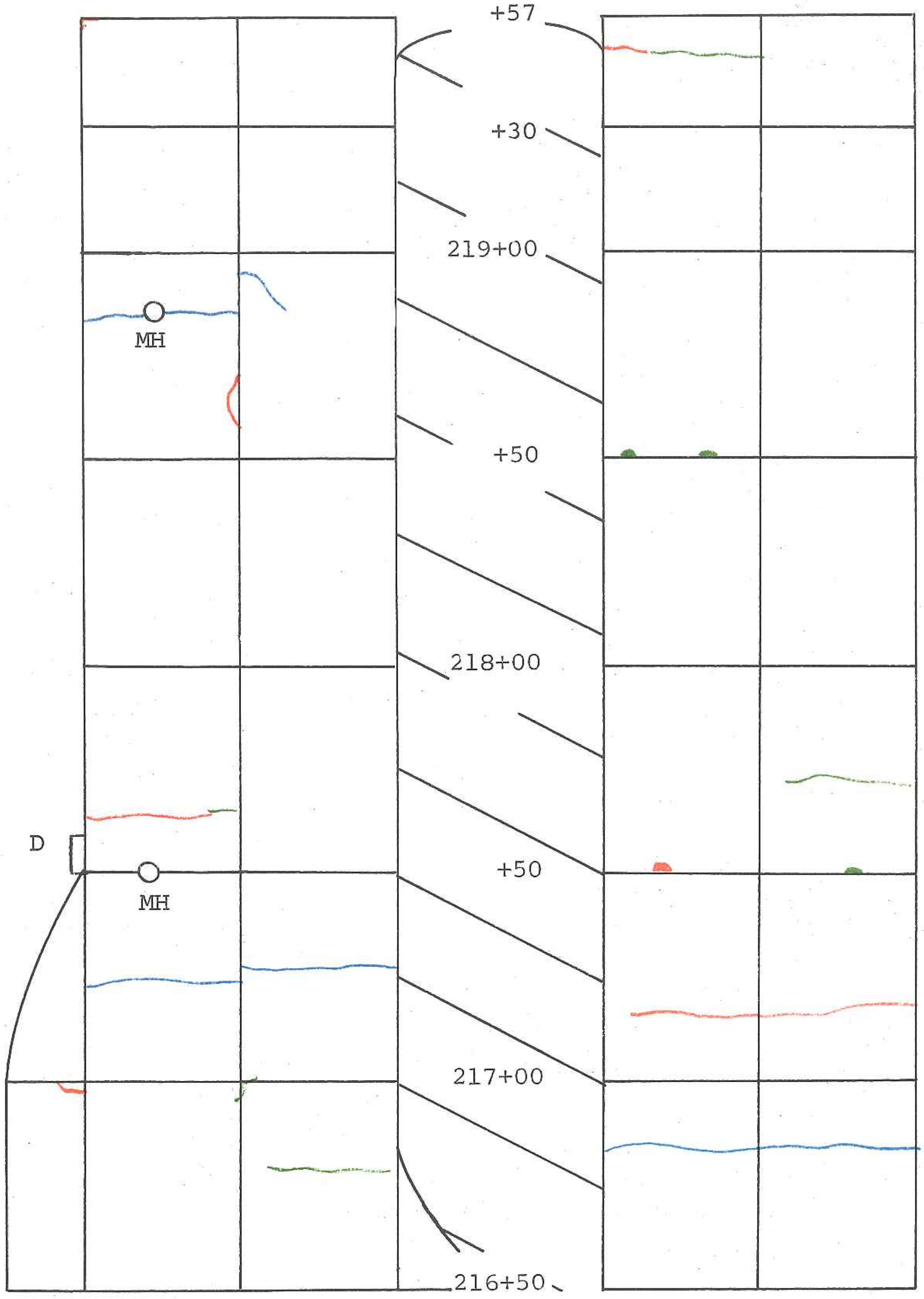

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COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

Special Provisions
for

Experimental Cement Concrete Pavement Containing Fly-Ash Admixtures, Jefferson County, Project No. U 553 (1), Poplar Level Road.

These special provisions cover the requirements for the experimental sections of concrete pavement on Project No. U 553 (1), Poplar Level Road in Jefferson County between Station 135 + 00 and Station 219 + 60. These special provisions amend only those portions of Article 4.1.0 of the Department's 1956 Standard Specifications ... which are concerned with the proportioning of ingredients in the concrete and only insofar as they pertain to modification occasioned by the use of fly-ash as a concrete admixture.

I. DESCRIPTION

A. All concrete pavement in the northbound lanes between stations 135 + 00 and 219 + 60 shall consist of Type D concrete in which 0.25 barrel (1 sack) of the cement requirement per cubic yard as specified in Article 4.1.5 shall be omitted and an equal weight (94 lbs.) of fly-ash substituted therefor.

B. All concrete pavement in the southbound lanes between stations 135 + 00 and 219 + 60 shall consist of Type D concrete in which 0.25 barrel (1 sack) of the cement requirement per cubic yard as specified in Article 4.1.5 shall be omitted and 140 pounds of fly-ash substituted therefor.

II. MATERIALS

The fly ash shall meet the requirements of ASTM Designation C350-60T. Fly-ash from different sources shall not be mixed or used alternatively without the permission of the Engineer.

III. EQUIPMENT

Dispensing and weighing equipment for the fly-ash shall conform to the same requirements as specified for cement, Article 4.1.3-B.

IV. STORING AND HANDLING MATERIALS

Storage and handling of fly-ash shall be in accordance with Article 4.1.4-B and as specified for cement.

V. PREPARATION AND CONTROL OF EXPERIMENTAL MIXES CONTAINING FLY-ASH ADMIXTURES

A. Proportioning Experimental Section A

The Engineer shall fix the proportions for the aggregates and water to obtain a satisfactory mix having the required cement content and fly-ash content, and no subsequent changes shall be permitted except as directed by the Engineer. The concrete mix shall be designed to contain 1.25 barrels of cement and 94 pounds of fly-ash for each cubic yard of concrete produced, and the proportions shall be maintained withing the tolerances of not less than 1.24 and not more than 1.26 barrels of cement per cubic yard and not less than 93 pounds and not more than 95 pounds of fly-ash per cubic yard. The volume of fly-ash (in excess of that required to replace an equal solid volume of one bag of cement) shall be considered to be a portion of the fine aggregate. The maximum free-water content in the mix shall not exceed 34.5 gallons of water per cubic yard of concrete produced. The actual quantity of water used shall be controlled by the Engineer in accordance with Article 4.1.5. Air-content, consistency (slump), and quantities of coarse and fine aggregate shall be otherwise standard and in accordance with Article 4.1.5.

B. Proportioning Experimental Section B

The concrete mix shall be designed to contain 1.25 barrels of cement and 140 pounds of fly-ash for each cubic yard of concrete produced, and the proportions shall be maintained within the tolerances of not less than 1.24 and not more than 1.26 barrels of cement per cubic yard and not less than 139 pounds and not more than 141 pounds of fly-ash per cubic yard. Except for these modifications, the concrete shall comply with the provisions set forth under Para. A (above).

IV. STORING AND HANDLING MATERIALS

Storage and handling of fly-ash shall be in accordance with Article 4.1.4-B and as specified for cement.

V. PREPARATION AND CONTROL OF EXPERIMENTAL MIXES CONTAINING FLY-ASH ADMIXTURES

A. Proportioning Experimental Section A

The Engineer shall fix the proportions for the aggregates and water to obtain a satisfactory mix having the required cement content and fly-ash content, and no subsequent changes shall be permitted except as directed by the Engineer. The concrete mix shall be designed to contain 1.25 barrels of cement and 94 pounds of fly-ash for each cubic yard of concrete produced, and the proportions shall be maintained withing the tolerances of not less than 1.24 and not more than 1.26 barrels of cement per cubic yard and not less than 93 pounds and not more than 95 pounds of fly-ash per cubic yard. The volume of fly-ash (in excess of that required to replace an equal solid volume of one bag of cement) shall be considered to be a portion of the fine aggregate. The maximum free-water content in the mix shall not exceed 34.5 gallons of water per cubic yard of concrete produced. The actual quantity of water used shall be controlled by the Engineer in accordance with Article 4.1.5. Air-content, consistency (slump), and quantities of coarse and fine aggregate shall be otherwise standard and in accordance with Article 4.1.5.

B. Proportioning Experimental Section B

The concrete mix shall be designed to contain 1.25 barrels of cement and 140 pounds of fly-ash for each cubic yard of concrete produced, and the proportions shall be maintained within the tolerances of not less than 1.24 and not more than 1.26 barrels of cement per cubic yard and not less than 139 pounds and not more than 141 pounds of fly-ash per cubic yard. Except for these modifications, the concrete shall comply with the provisions set forth under Para. A (above).