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REPORT TITLE/ TITTEL

Total Organic Carbon and Kerogen Analysis of Samples from Well 6407/2-1.

CLIENT/ OPPDRAGSGIVER

Saga Petroleum A/S

BA 83-2323-1

RESPONSIBLE SCIENTIST/ PROSJEKTANSVARLIG

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AUTHORS/ FORFATTERE

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SUMMARY/ SAMMENDRAG

A total of fourty samples were subjected to TOC, Rock-Eval and Pyrolysis-gas chromatography (Py-GC) analysis.

The TOC values vary from extremely low (0.01%) to extremely high (35.09%). There is an overall good correlation between the Py-GC and Rock-Eval results. The results suggest that samples M-9047 (2231.5m) to M-9060 (2810m) contain immature and marginal mature mixed type III/IV kerogens. Sample M-9061 (2828m) contains an immature type III kerogen. Samples M-9063 (2848m) to M-9069 (2885m) contain immature type I or mixed type I/II kerogens. Samples M-9070 (2907m) and M-9071 (2913m) contain immature mixed type II/III and type III kerogens respectively. Samples M-9072 (2920m) and M-9073 (2930m) contain immature type III/IV kerogens. Samples M-9074 (3089m) to M-9076 (3165m) contain marginal mature type III and mixed type III/II kerogens. M-9077 (3357m) contains a marginal mature mixed type II/III kerogen. Samples M-9078 (3407m) and M-9079 (3439m) contain marginal mature to mature type III or mixed III/IV kerogens. M-9080 (3551m) and M-9081 (3694m) contain mature type III and III/II respectively. Samples M-9082 (3718m) and M-9084 (3743m) contain mature mixed type III/IV kerogens and M-9083 (3725.5m) a mature mixed type II/III kerogen.

KEY WORDS/ STIKKORD

Kerogen | Pyrolysis | Analysis

EXPERIMENTAL

Total Organic Carbon (TOC)

The samples were crushed and aliquots were weighed into Leco crucibles, treated with hot 2N HCl to remove carbonate, and washed twice with destilled water to remove traces of HCl. The crucibles were then placed in a vacuum oven at 50°C and evacuated to 20mm Hg for 12 hrs. The total organic carbon (TOC) content of the dried samples was determined using a Leco EC12 carbon analyser. Results are given in Table 1.

Rock-Eval Pyrolysis

100mg crushed sample was weighed into a platinum crucible the base and cover of which are made of sintered steel, and analysed on a Rock-Eval pyrolyser. Results are given in Table 1.

Pyrolysis-Gas Chromatography (Py-GC)

Two Py-GC methods were used in this study. A temperature programmed pyrolysis technique, Py-GC (Progr.), was applied for samples with TOC values of ca. 1% and lower. Flash pyrolysis at 600°C, Py-GC (600°C), was used for samples with TOC values higher than 1%.

Thermal Extraction

20-30mg of fine ground whole rock sample was placed in a boat shaped sample probe and heated in a stream of helium at 300°C for five minutes.

Py-GC (600°C)

A chemical Data Systems (CDS) Pyroprobe 120 interfaced to a Varian 3700 gas chromatograph was used for flash pyrolysis. Fine ground thermally extracted whole rock sample was suspended in methanol and added to the platinum ribbon sample probe with a disposable Pasteur pipette. The sample was flash pyrolysed and flushed directly onto a capillary column via a laboratory built interface/splitter and analysed under the GC conditions given below.

Instrumental conditions:
Pyrolysis: 600°C for 5 sec.. in nitrogen
Column: 25m OV-1 fused silica capillary; ID 0.3mm
Carrier gas: Nitrogen with inlet pressure 6 psi; Flow ca. 1.5ml/min.
Split ratio: 1:30.
Oven programme: 40°C/1 min. to 270°C at 4°C/min.

Py-GC (Progr.)

20-30mg of thermally extracted whole rock sample was pyrolysed in a stream helium (300°C to 550°C at 35°C/min.) using a tube furnace type pyrolyzer interfaced to a Varian 3700 gas chromatograph. The outlet of the pyrolyzer was connected to a fused silica capillary column via an interface/splitter (sample/split ratio; 1:30). The pyrolysis product was trapped in a cooled (liquid nitrogen) U-shaped part at the front of the column.

The outlet of the splitter was connected to a flame ionisation detector (FID) and the course of the pyrolysis could be followed by the detector response of the bulk pyrolysis product which was recorded as a broad peak. At the end of the pyrolysis, the trapped pyrolysis product was injected by removing the liquid nitrogen bath at ambient temperature and analysed under the GC conditions given below.

Instrumental conditions:
Pyrolysis: 300°C to 550°C at 35°C/min.
Column: 25m OV-1 fused silica capillary; ID 0.3mm.
Carrier gas: Helium with inlet pressure 10 psi; Flow ca. 1.5 ml/min.
Split ratio: 1:30.
Oven program: 40°C/1 min. to 270°C at 4°C/min.

RESULTS AND DISCUSSION

A total of fourty samples were subjected to TOC, Rock-Eval and Py-GC analysis.

Total Organic Carbon (TOC)

The TOC values are listed in Table 1 varying from extremely low (0.01%) to very high (35.09%).

Rock-Eval Pyrolysis

M-9047 (2231.5m), M-9048 (2251.5m), M-9049 (2257m), M-9050 (2302m), M-9051 (2348m), M-9052 (2453m), M-9053 (2511m) and M-9054 (2541m).
The low T_{max} values indicate immaturity. M-9050 has very low T_{max} value and are misleading. The low hydrogen and oxygen indices are typical for type III/IV and IV kerogens. Type IV kerogen is used to describe the inertinite group of macerals or reworked material with a poor potential for hydrocarbons (mainly gas).

M-9055 (2592m), M-9056 (2640m), M-9057 (2730m), M-9058 (2755m), M-9059 (2785m) and M-9060 (2810m).
Hydrogen and oxygen indices are representative of III/IV and IV kerogens. The T_{max} values indicate marginal mature to mature samples. M-9056 and M-9059 have very low anomalous T_{max} values probably due to measurements on bitumen rather than kerogen.

M-9061 (2828m)
The hydrogen index and T_{max} value suggest an immature type III kerogen.

M-9062 (2832m)
Due to very low TOC value the Rock-Eval data are misleading.

M-9063 (2848m), M-9064 (2854m), M-9065 (2859m), M-9066 (2866m), M-9067 (2874.5m), M-9068 (2880m) and M-9069 (2885m)
The very high hydrogen and low oxygen indices are typical of type I kerogens. T_{max} values are low indicating immaturity.

M-9070 (2907m)
The hydrogen index and T_{max} value suggest an immature mixed type II/III kerogen.

M-9071 (2913m)
The hydrogen index and T_{max} value suggest an immature type III kerogen.

M-9072 (2920m) and M-9073 (2930m)
The T_{max} values indicate immaturity. The low hydrogen and oxygen indices are typical for type III/IV kerogens.

M-9074 (3089m) and M-9075 (3135m) The hydrogen and oxygen indices are typical for type III kerogens. The T_{max} values indicate marginal maturity.

M-9076 (3165m)
The hydrogen index and T_{max} value suggest a marginal mature mixed type III/II kerogen.

M-9077 (3357m)
The hydrogen index and T_{max} value suggest a marginal mature mixed type II/III kerogen.

M-9078 (3407m)
The low hydrogen and oxygen indices are typical for a type III/IV or IV kerogen. The T_{max} value suggest marginal maturity.

M-9079 (3439m)
The hydrogen index and T_{max} value suggest a mature type III/IV or IV kerogen.

M-9080 (3551m)
The hydrogen index and T_{max} value suggest a mature type III kerogen.

M-9081 (3694m)
The hydrogen index and T_{max} value suggest a mature mixed type III/II.

M-9082 (3718m)

The hydrogen and oxygen indices are typical for a type III/IV or IV kerogen. T_{max} suggest maturity.

M-9083 (3725.50m)

The hydrogen index and T_{max} value suggest a mature mixed type II/III kerogen.

M-9084 (3743m)

The hydrogen and oxygen indices are typical for a type III/IV or IV kerogen. T_{max} suggests maturity.

M-9085 (3847m) and M-9086 (3864)

Due to very low TOC values the Rock-Eval data are misleading.

Pyrolysis-Gas Chromatography

The instrumental conditions are described in the experimental section. Based on retention and mass spectrometric data from other kerogens, the peaks in the pyrograms are tentatively identified: The numbered peaks are n-alkene/n-alkane doublets of the corresponding carbon number. The alkenes have the shorter retention time. T=toluene; X=m/p-xylenes and Pr=pristenes.

M-9062 (2832m), M-9085 (3847m) and M-9086 (3864)

No pyrograms were obtained for these three samples due to very low TOC values.

M-9047 (2231.5m), M-9048 (2251.5m), M-9049 (2257m), M-9050 (2302m), M-9051 (2348m), M-9052 (2453m), M-9053 (2511m) and M-9054 (2541m)

The pyrograms of these eight samples are overall very similar showing a high abundance of aromatics relative to the short range, C_7 to ca. C_{17}, aliphatic homology. The abundance of the alkanes is much higher than of the alkenes. The pyrograms show a type III or mixed type III/IV kerogen fingerprint.

M-9055 (2592m), M-9056 (2640m), M-9057 (2730m), M-9058 (2755m), M-9059 (2785m) and M-9060 (2810m)

The pyrograms of these six samples are overall very similar showing a short range, C_7 to C_{19}, aliphatic homology. The hydrocarbons in the C_{15} to C_{20} range are probably not generated from the kerogen pyrolysis. It is likely that these hydrocarbons have been trapped in the kerogen/-mineral matrix and were released during pyrolysis. The pyrograms are quite similar to M-9047 - M-9054 showing a type III or mixed type III/IV kerogen fingerprint.

M-9061 (2828m)

The pyrogram shows an n-alkene/n-alkane homology ranging from C_7 to C_{25}. The abundance of aromatics is high relative to the aliphatics. The pyrogram shows a mixed type III/II kerogen fingerprint.

M-9063 (2848m), M-9064 (2854m), M-9065 (2859m), M-9066 (2866m), M-9067 (2874.5m), M-9068 (2880m) and M-9069 (2885m)

The pyrograms of these seven samples are almost identical showing a strong aliphatic homology ranging from C_7 to ca C_{27}. The pyrograms show a typical type I or mixed type I/II kerogen fingerprint.

M-9070 (2907)

The pyrogram shows an aliphatic homology ranging from C_7 to C_{25}. The abundance of aromatics is higher than in M-9063 - M-9069. Generally the pyrogram shows a mixed type II/III kerogen fingerprint.

M-9071 (2913m), M-9072 (2920m) and M-9073 (2930m)

The pyrograms of these three samples are very similar showing a short range n-alkene/n-alkane homology ranging from C_7 to C_{21}. The abundance of aromatics is higher than in M-9070. The pyrogram shows a type III kerogen fingerprint.

M-9074 (3089m), M-9075 (3135m) and M-9076 (3165m)

The pyrograms of these three samples are very similar showing an aliphatic homology ranging from C_7 to C_{25}. The pyrograms are very similar to M-9070, i.e. a mixed type II/III kerogen.

M-9077 (3357m)

The pyrogram shows an n-alkene/n-alkane homology ranging from C_7 to C_{27} with a high abundance in the C_{15}-C_{25} range. This indicates a plant derived kerogen with a high input of lipid rich material (spores, cuticles, resins etc.), i.e. a mixed type II/III kerogen fingerprint.

M-9078 (3407m)

The pyrogram shows an aliphatic homology ranging from C_7 to C_{27}. The abundance of aromatics is higher than in M-9077. The pyrogram shows a type III kerogen fingerprint.

M-9079 (3439m) and M-9080 (3551m)

The pyrograms of these two samples are almost identical and they are very similar to M-9078, i.e. a type III kerogen fingerprint.

M-9081 (3694m)

The pyrogram shows an n-alkene/n-alkane homology ranging from C_7 to C_{25}. The abundance of aromatics is lower than in M-9079 and M-9080. Generally the pyrogram shows a mixed type III/II kerogen fingerprint.

M-9082 (3718m)

The pyrogram shows a very high abundance of aromatics relative to the short range (C_7 to C_{23}) weak aliphatic homology. The pyrogram shows a type III or mixed type III/IV kerogen finerprint.

M-9083 (3725.5m)

The pyrogram is very similar to M-9077, i.e. a mixed type II/III kerogen.

M-9084 (3743m)

The pyrogram shows an aliphatic homology ranging from C_7 to C_{25}. The abundance of aromatics is high. Generally the pyrogram shows a type III kerogen fingerprint.

CONCLUSION

A total of fourty samples were subjected to TOC, Rock-Eval and Pyrolysis-gas chromatography (Py-GC) analysis.

The TOC values vary from extremely low (0.01%) to extremely high (35.09%).

There is an overall good correlation between the Py-GC and Rock-Eval results. However, until more Py-GC results for type III/IV and IV kerogens are available, it is difficult to discriminate between type III and type III/IV and IV kerogens on the basis of Py-GC results alone.

Due to the complexity of kerogens, kerogen studies should therefore ideally include both microscopic and physico chemical methods in order to more completely understand the nature and interrelationships of the contributing material.

The Rock-Eval and Py-GC results suggest that samples M-9047 (2231.5m) to M-9060 (2810m) contain immature and marginal mature mixed type III/IV kerogens. Sample M-9061 (2828m) contains an immature type III kerogen. Samples M-9063 (2848m) to M-9069 (2885m) contain immature type I or mixed type I/II kerogens. Samples M-9070 (2907m) and M-9071 (2913m) contain immature mixed type II/III and type III kerogens respectively. Samples M-9072 (2920m) and M-9073 (2930m) contain immature type III/IV kerogens. Samples M-9074 (3089m) to M-9076 (3165m) contain marginal mature type III and mixed type III/II kerogens. M-9077 (3357m) contains a marginal mature mixed type II/III kerogen. Samples M-9078 (3407m) and M-9079 (3439m) contain marginal mature to mature type III or mixed III/IV kerogens. M-9080 (3551m) and M-9081 (3694m) contain mature type III and III/II respectively. Samples M-9082 (3718m) and M-9084 (3743m) contain mature mixed type III/IV kerogens and M-9083 (3725.5m) a mature mixed type II/III kerogen.

TABLE 1.

ROCK EVAL PYROLYSES

IKU No.	DEPTH m	S1	S2	S3	TOC (%)	HYDR. INDEX	OXYGEN INDEX	OIL OF GAS CONTENT S1+S2	PROD. INDEX S1/(S1+S2)	TEMP. MAX (C)
6407/2-1										
M 9047	2231.50	0.23	0.44	0.43	0.83	52	52	0.67	0.34	405
M 9048	2251.50	0.44	0.73	0.21	0.95	77	22	1.17	0.38	412
M 9049	2257	0.40	0.54	0.35	1.01	53	35	0.94	0.43	426
M 9050	2302	0.30	0.30	0.20	0.70	43	29	0.60	0.50	361
M 9051	2348	0.28	0.59	0.15	0.95	62	16	0.87	0.32	427
M 9052	2453	0.19	0.72	0.33	0.90	80	37	0.91	0.21	426
M 9053	2511	0.31	0.48	0.19	0.85	56	22	0.79	0.39	414
M 9054	2541	0.25	0.52	0.12	1.00	52	12	0.77	0.32	429
M 9055	2592	0.16	0.06	0.61	0.81	7	75	0.22	0.73	440
M 9056	2640	0.21	0.04	0.51	0.49	8	104	0.25	0.84	319
M 9057	2730	0.18	0.30	0.16	1.32	23	12	0.48	0.37	462
M 9058	2755	0.23	0.34	0.18	1.14	30	16	0.57	0.40	437
M 9059	2785	0.23	0.25	0.76	1.28	20	59	0.48	0.48	367
M 9060	2810	0.17	0.36	0.15	0.50	72	30	0.53	0.32	444
M 9061	2828	0.84	7.45	0.89	6.05	123	15	8.29	0.10	433
M 9062	2832	0.15	0.07	0.50	0.08	88	625	0.22	0.68	436
M 9063	2848	5.53	52.97	0.58	6.12	866	9	58.50	0.09	419
M 9064	2854	6.94	65.39	0.52	7.97	820	7	72.33	0.10	420
M 9065	2859	7.02	70.53	0.46	8.97	786	5	77.55	0.09	421
M 9066	2866	7.64	62.72	0.55	8.50	738	6	70.36	0.11	420
M 9067	2874.50	9.52	74.44	0.74	9.27	803	8	83.96	0.11	422
M 9068	2880	8.09	61.15	0.61	7.16	854	9	69.24	0.12	423
M 9069	2885	7.97	70.19	0.70	7.17	979	10	78.16	0.10	425

IKU

TABLE 1.

R O C K E V A L P Y R O L Y S E S

IKU No.	DEPTH m	S1	S2	S3	TOC (%)	HYDR. INDEX	OXYGEN INDEX	OIL OF GAS CONTENT S1+S2	PROD. INDEX S1/(S1+S2)	TEMP. MAX (C)
M 9070	2907	5.48	20.06	0.53	6.53	307	8	25.54	0.21	421
M 9071	2913	0.25	1.99	0.24	1.81	110	13	2.24	0.11	427
M 9072	2920	0.20	0.74	0.28	1.29	57	22	0.94	0.21	434
M 9073	2930	0.20	0.49	0.20	1.17	42	17	0.69	0.29	425
M 9074	3089	0.14	0.64	0.34	0.61	105	56	0.78	0.18	434
M 9075	3135	0.19	1.00	0.29	0.90	111	32	1.19	0.16	433
M 9076	3165	0.15	1.66	1.00	0.71	234	141	1.81	0.08	437
M 9077	3357	9.07	103.24	1.31	35.09	294	4	112.31	0.08	434
M 9078	3407	0.49	1.68	1.02	4.02	42	25	2.17	0.23	436
M 9079	3439	0.11	0.59	1.32	0.95	62	139	0.70	0.16	445
M 9080	3551	0.17	1.51	0.25	1.30	116	19	1.68	0.10	441
M 9081	3694	0.36	6.91	0.17	3.01	230	6	7.27	0.05	439
M 9082	3718	0.06	0.26	0.16	0.62	42	26	0.32	0.19	454
M 9083	3725.50	1.73	31.91	0.59	13.06	244	5	33.64	0.05	439
M 9084	3743	0.22	0.84	0.42	1.16	72	36	1.06	0.21	445
M 9085	3847	0.06	0.06	0.49	0.01	600	4900	0.12	0.50	442
M 9086	3864	0.06	0.11	0.24	0.03	367	800	0.17	0.35	347

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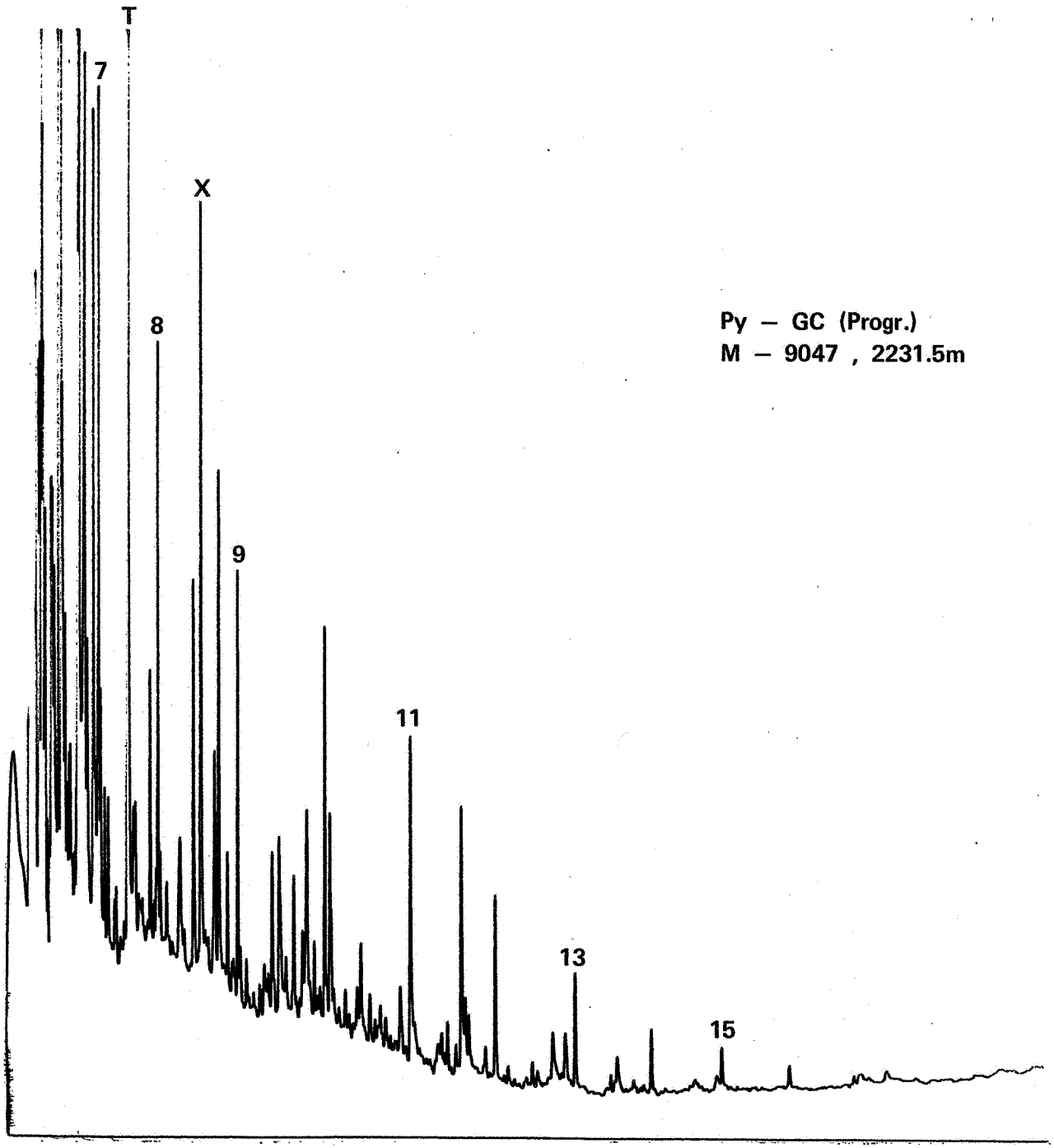
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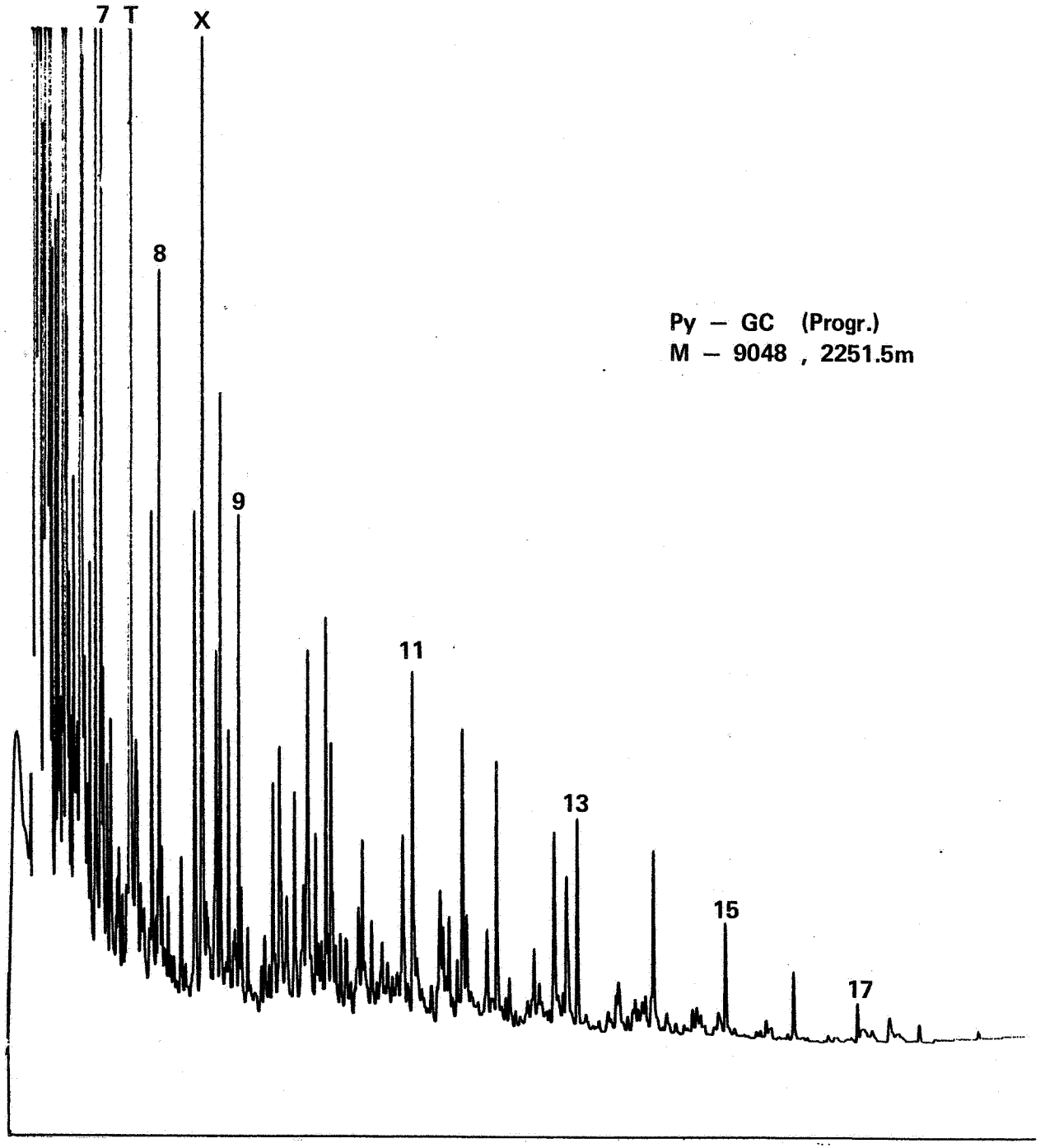
M – 9047 , 2231.5m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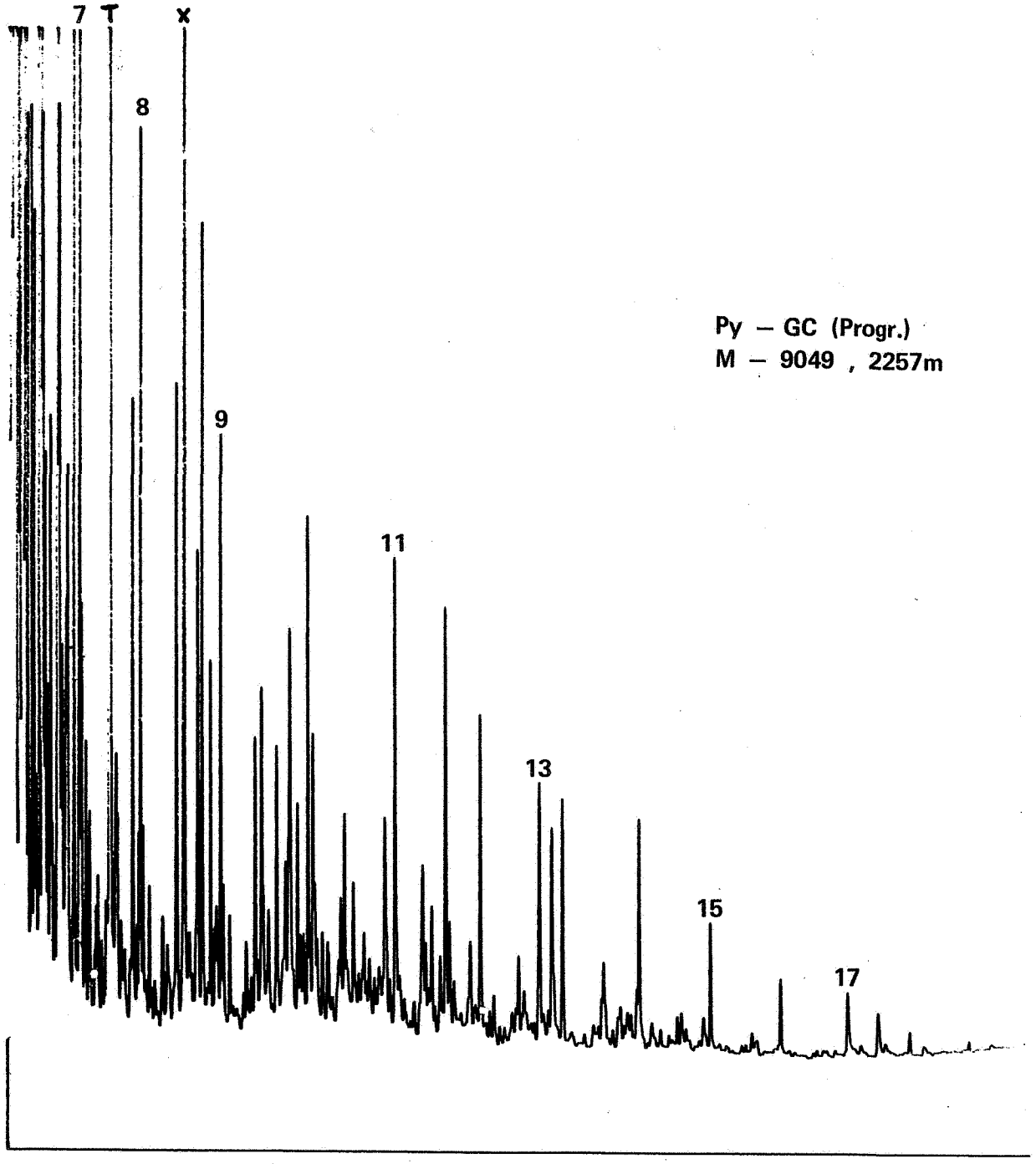
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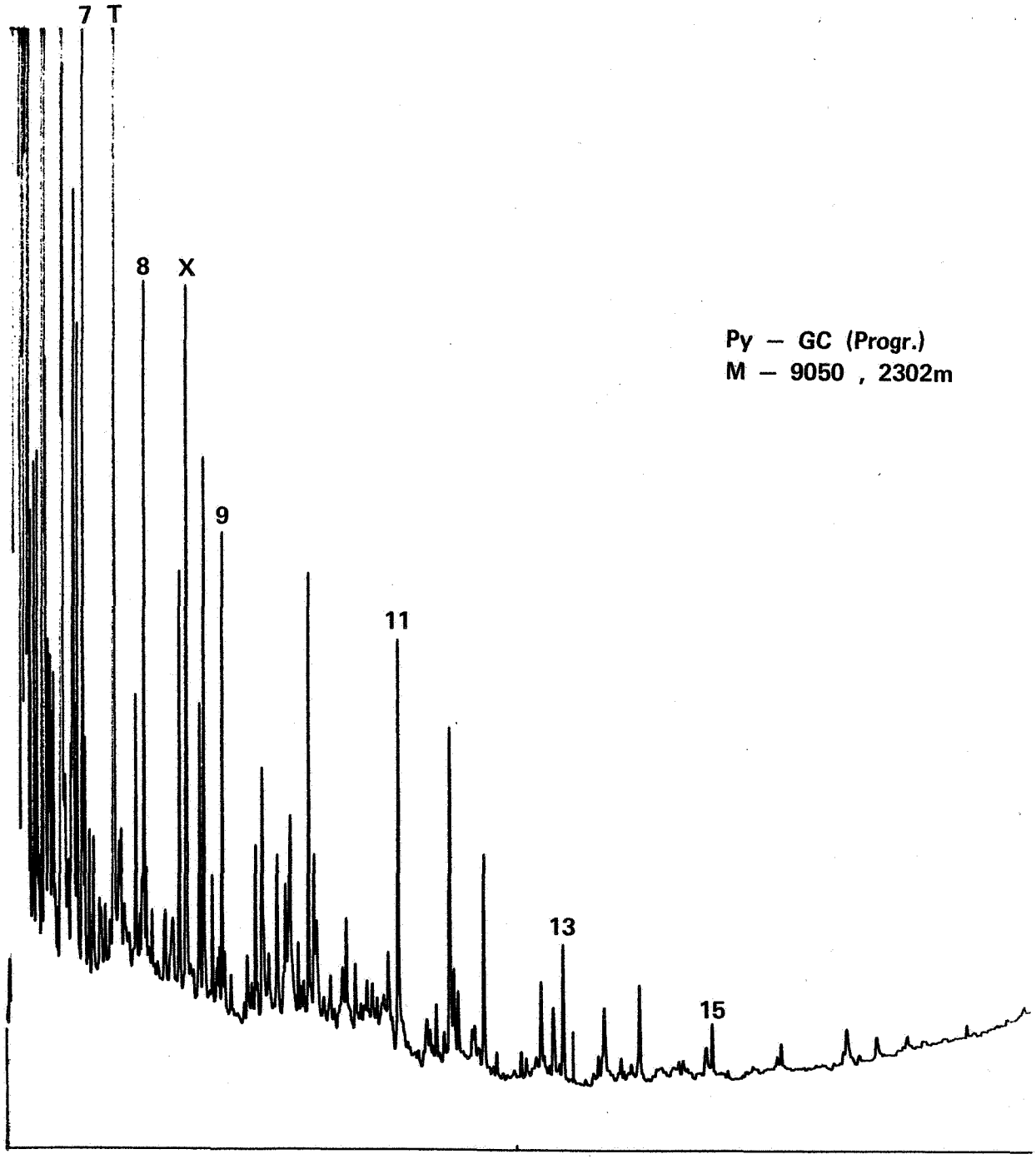
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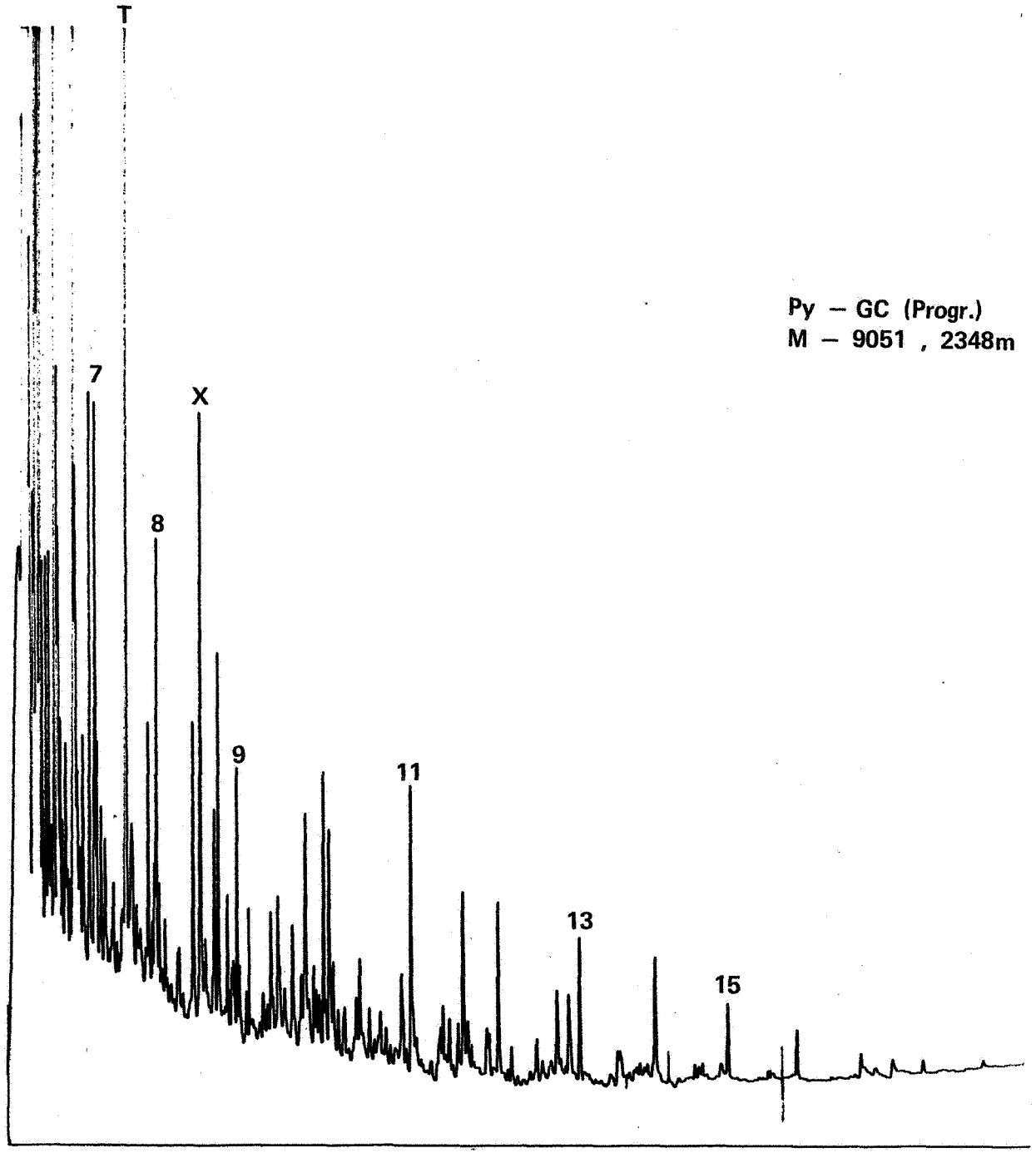
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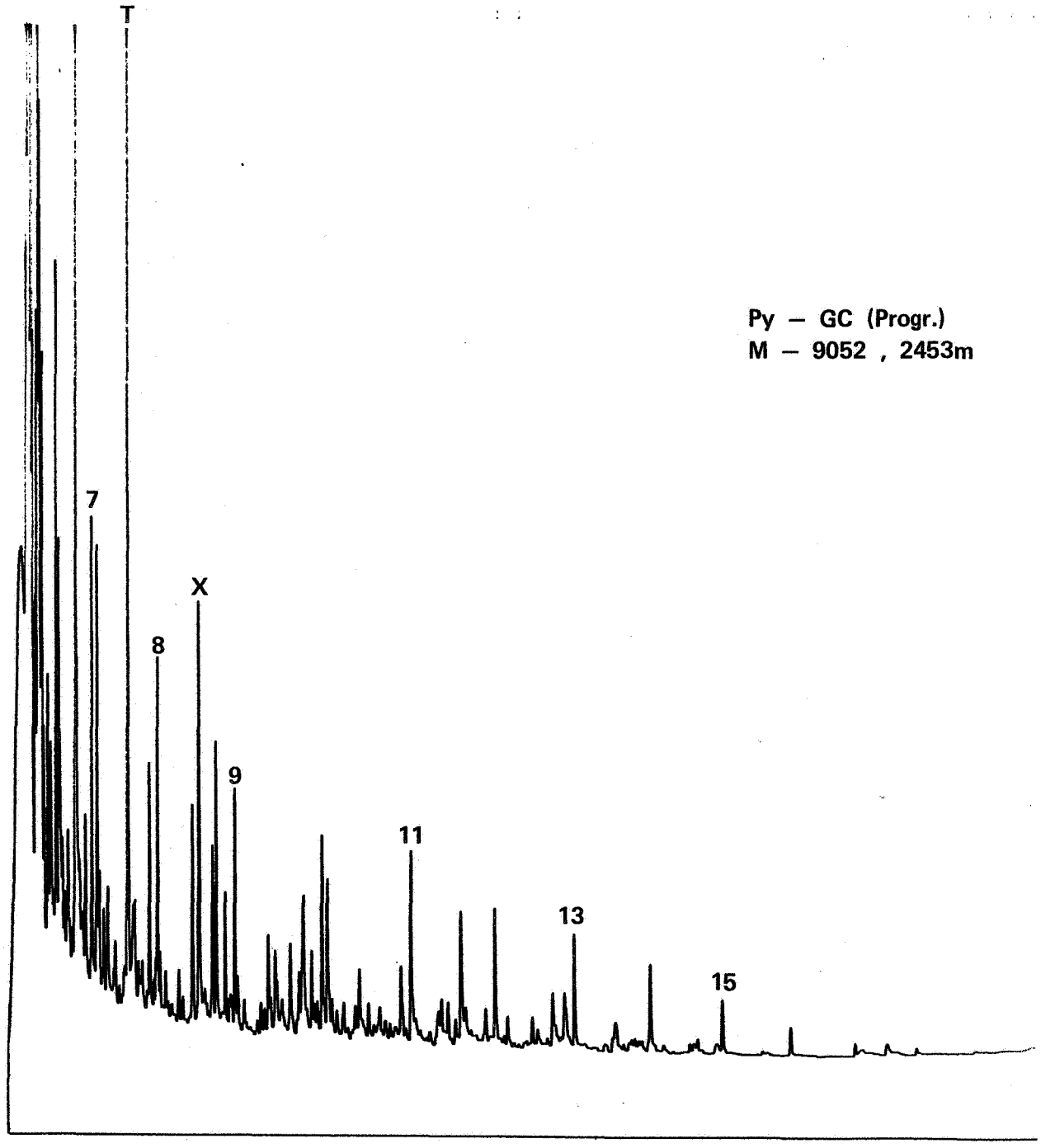
M – 9051 , 2348m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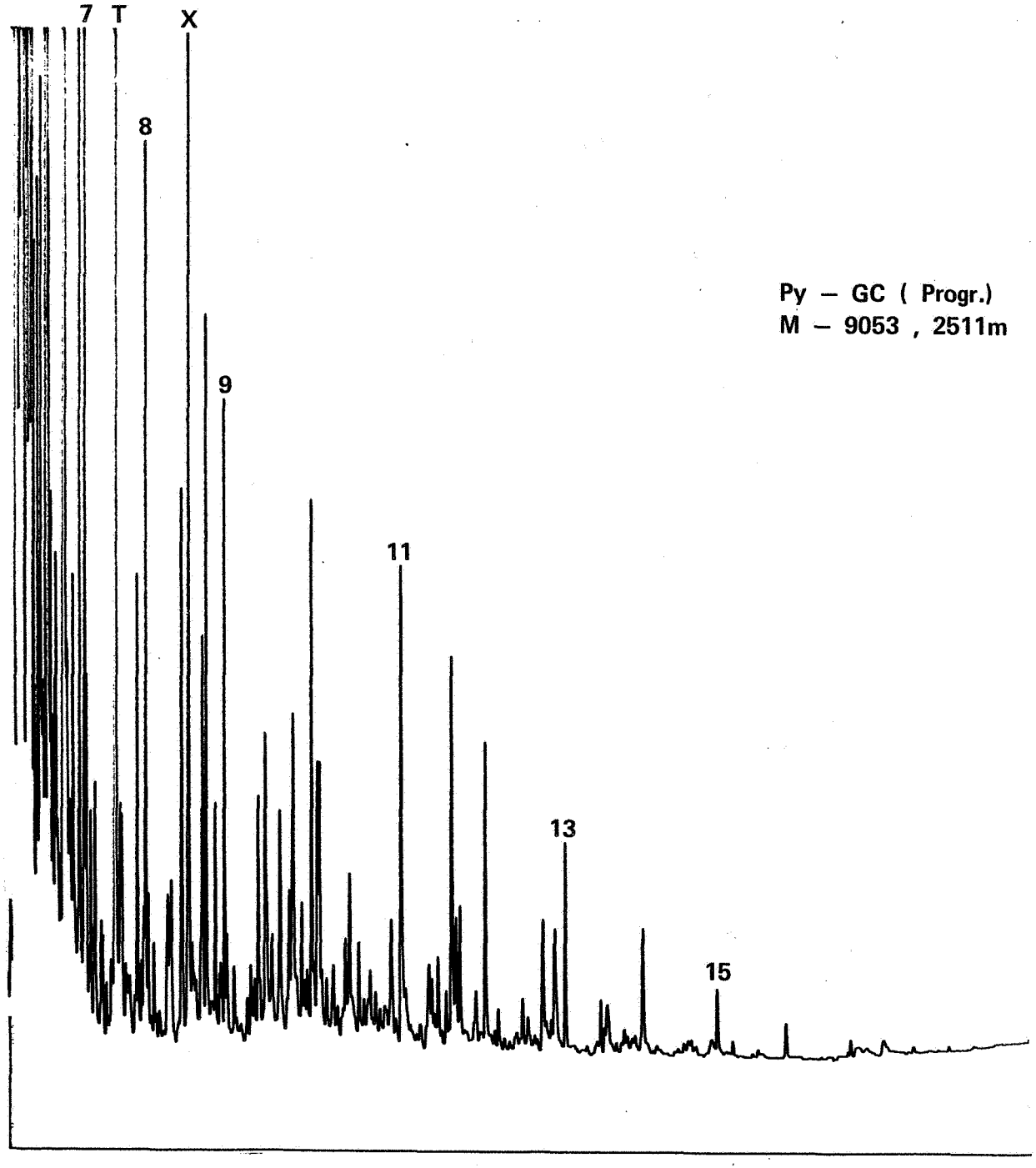
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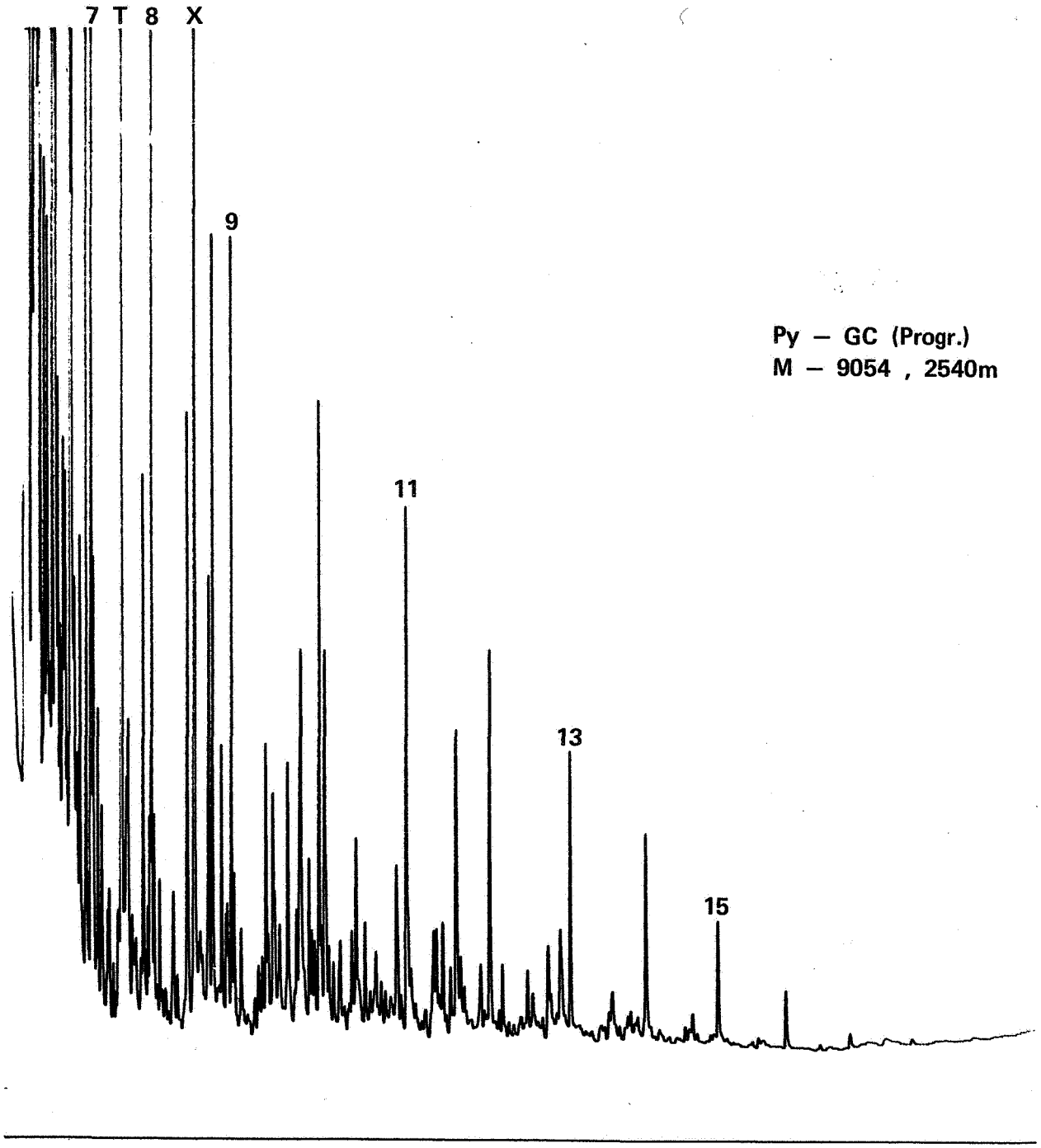
M – 9053 , 2511m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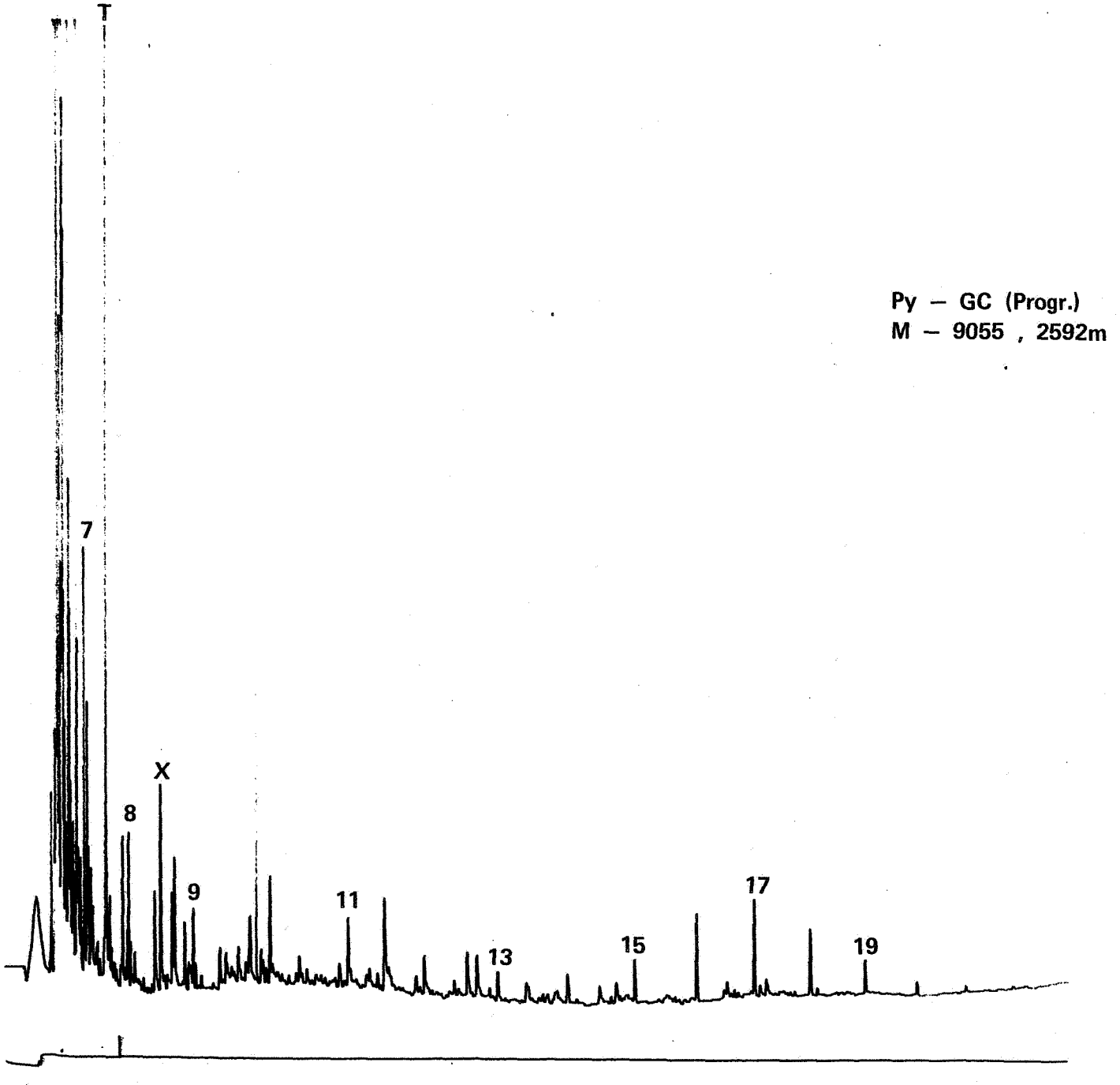

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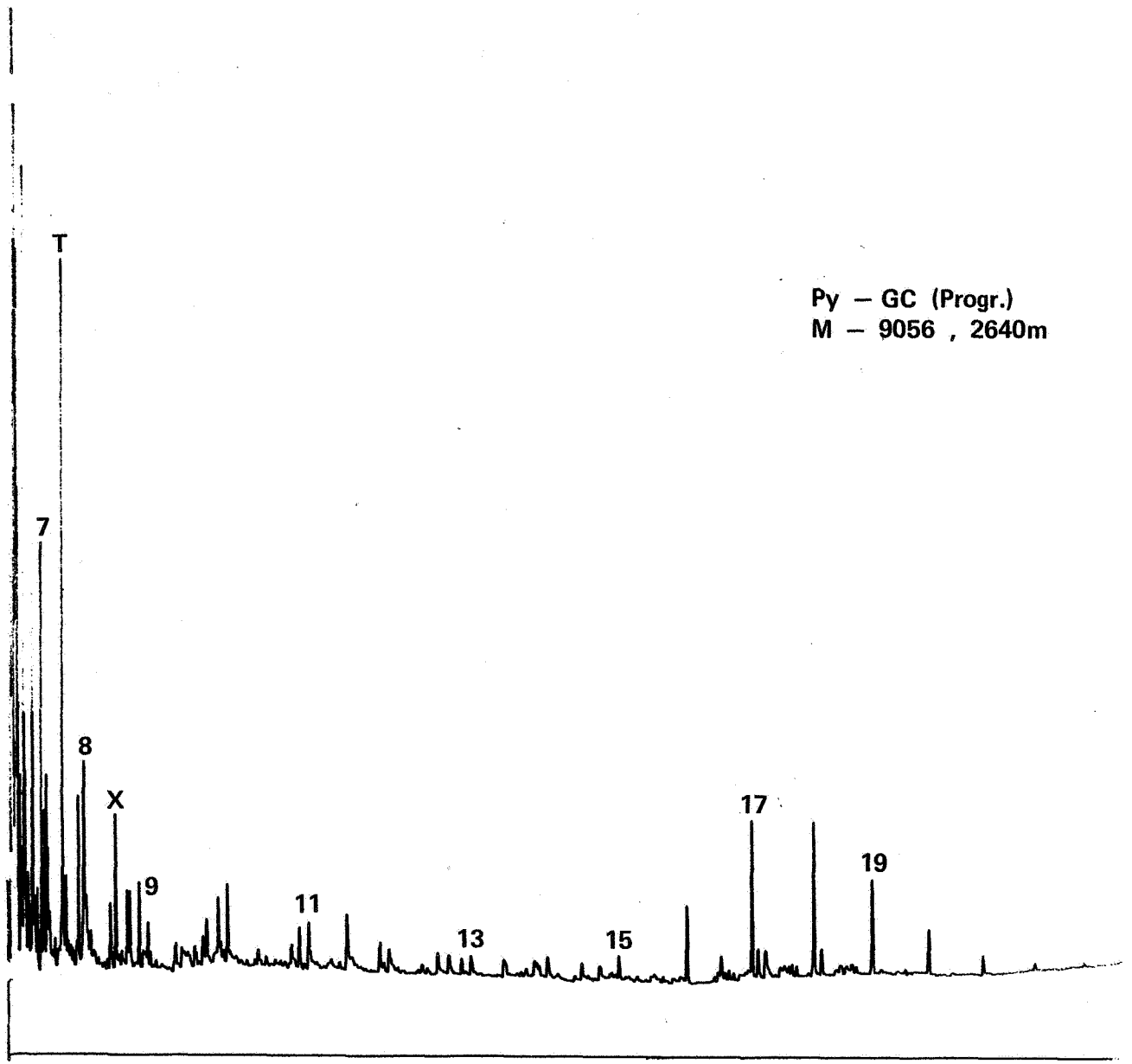
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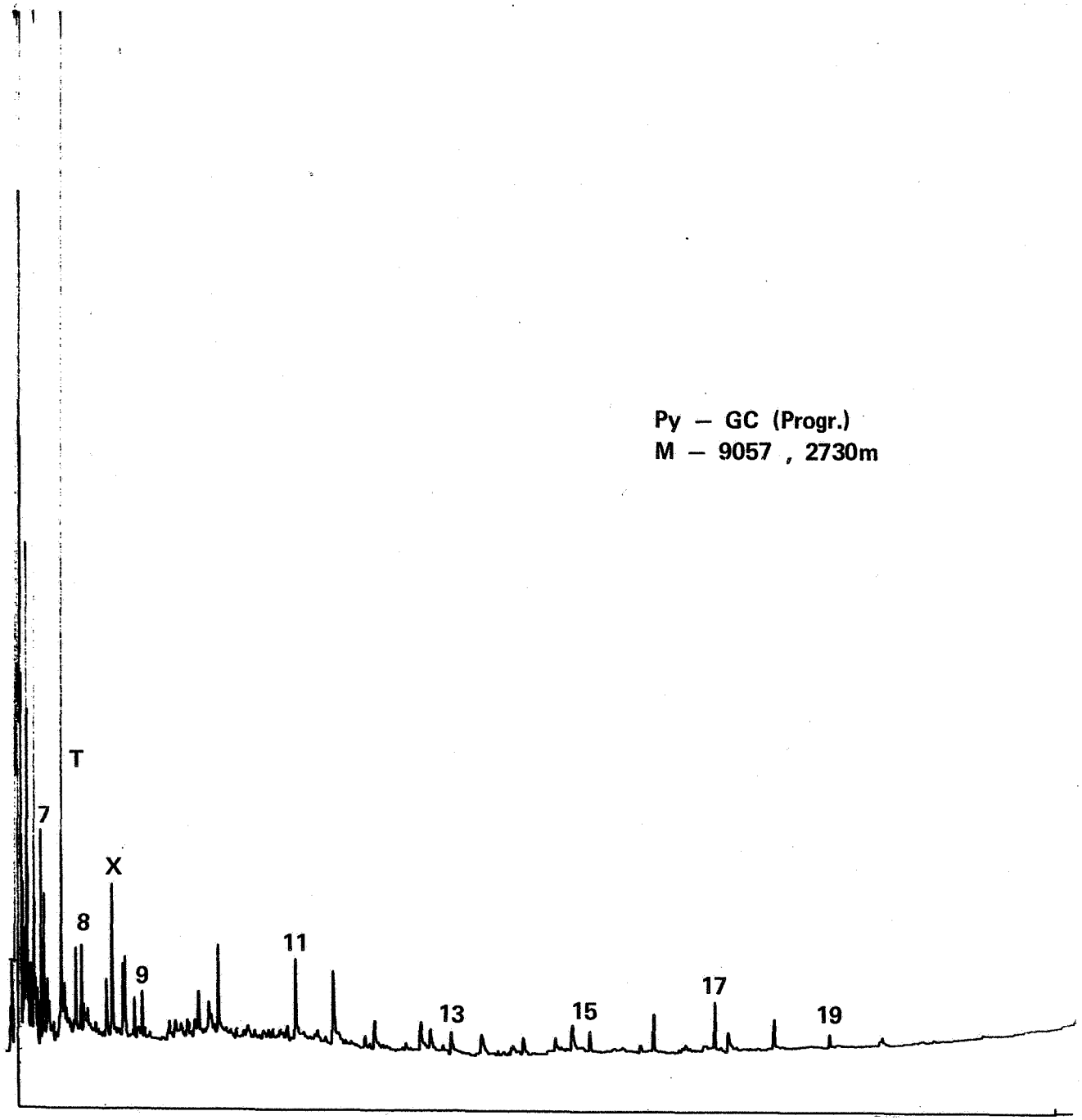
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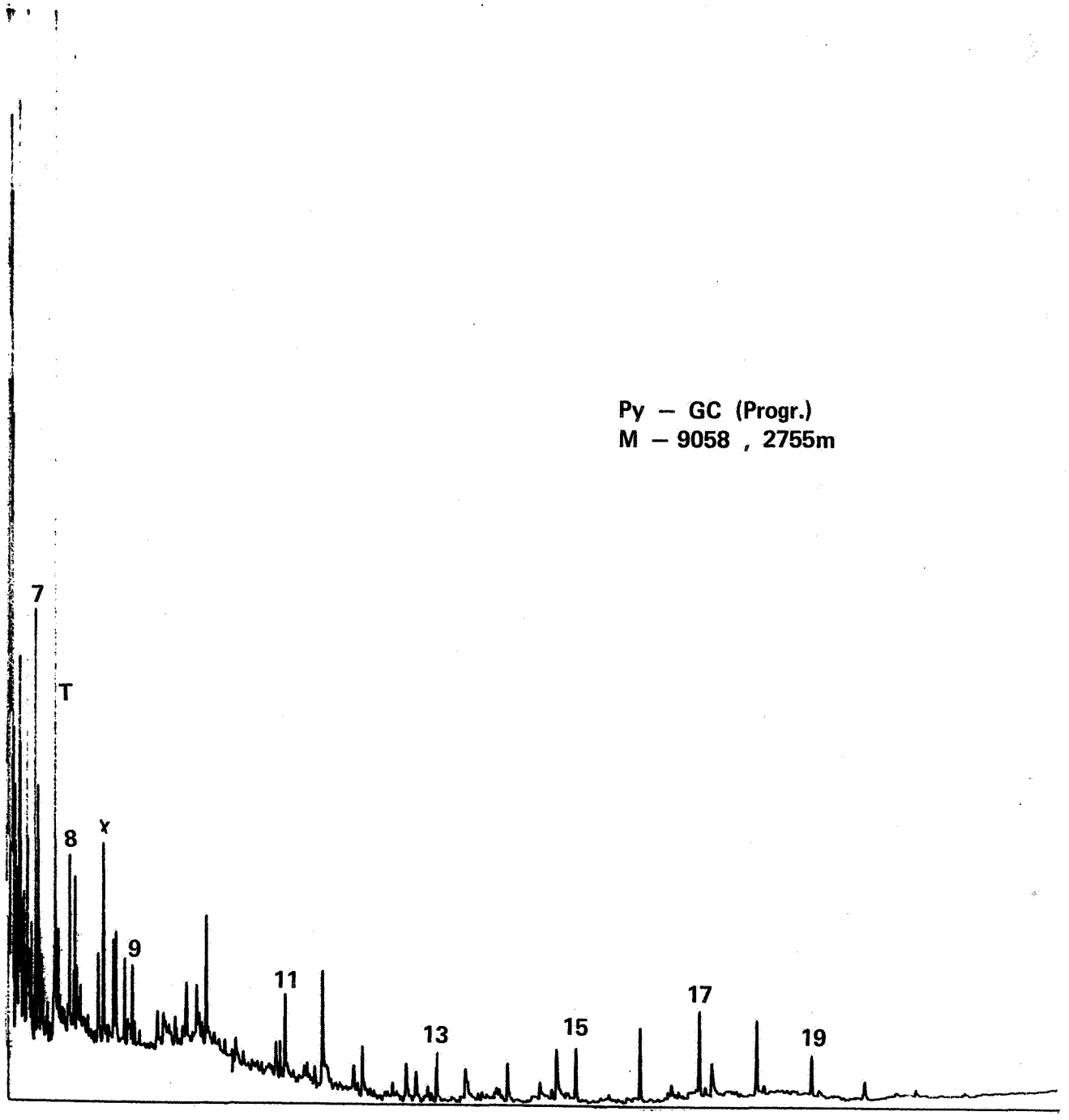
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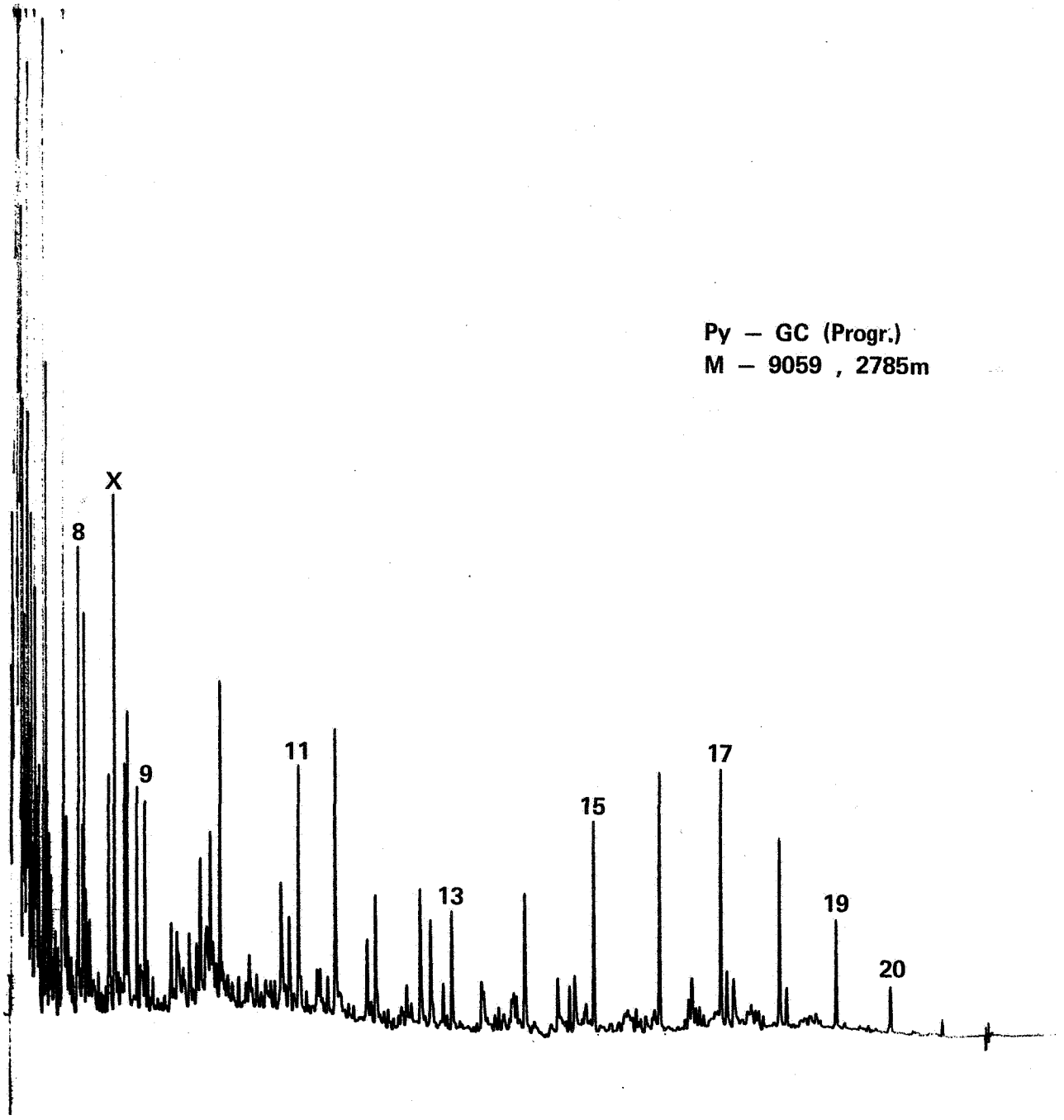
Py – GC (Progr.)
M – 9059 , 2785m
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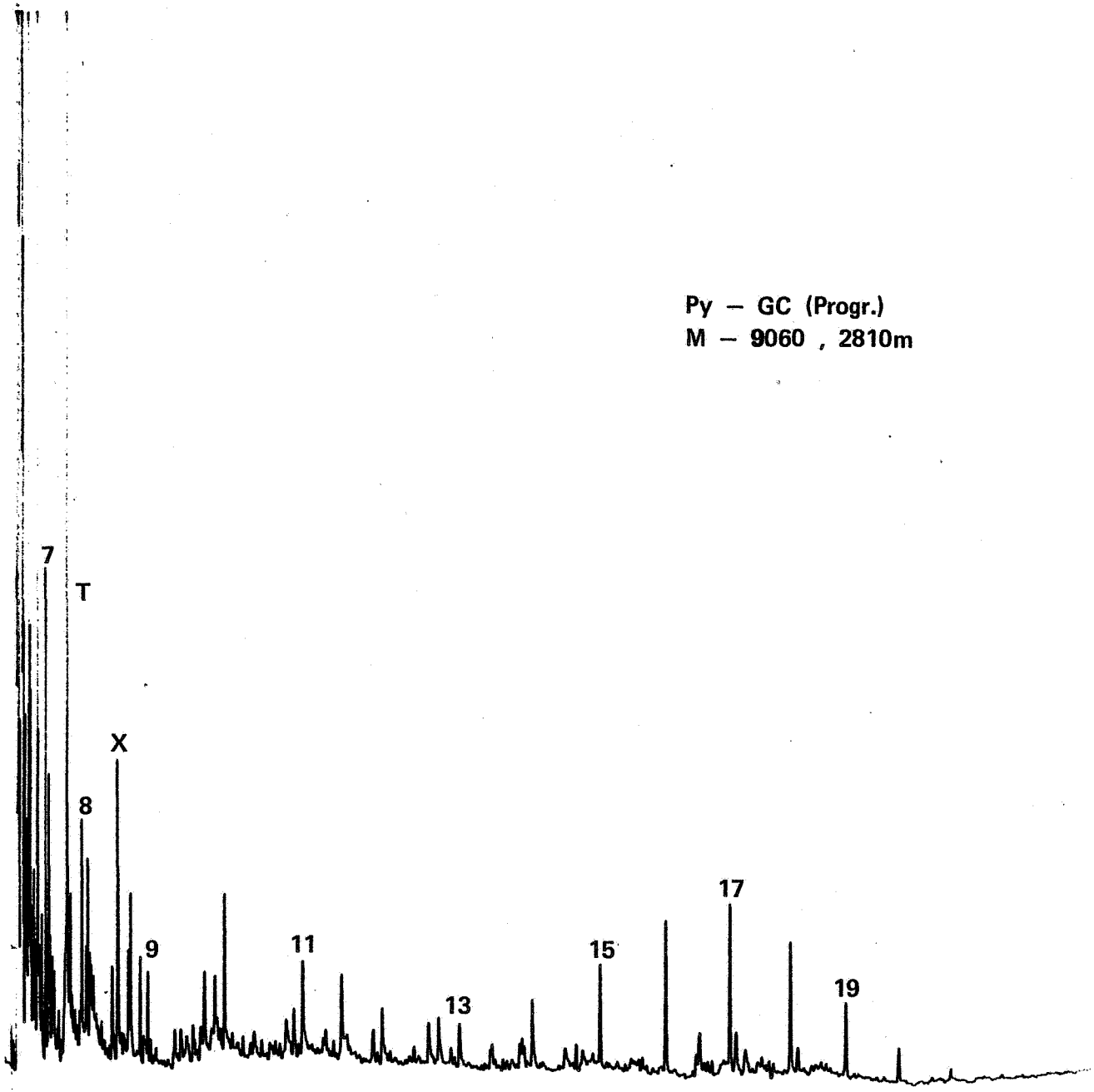
Py – GC (Progr.)
M – 9060 , 2810m
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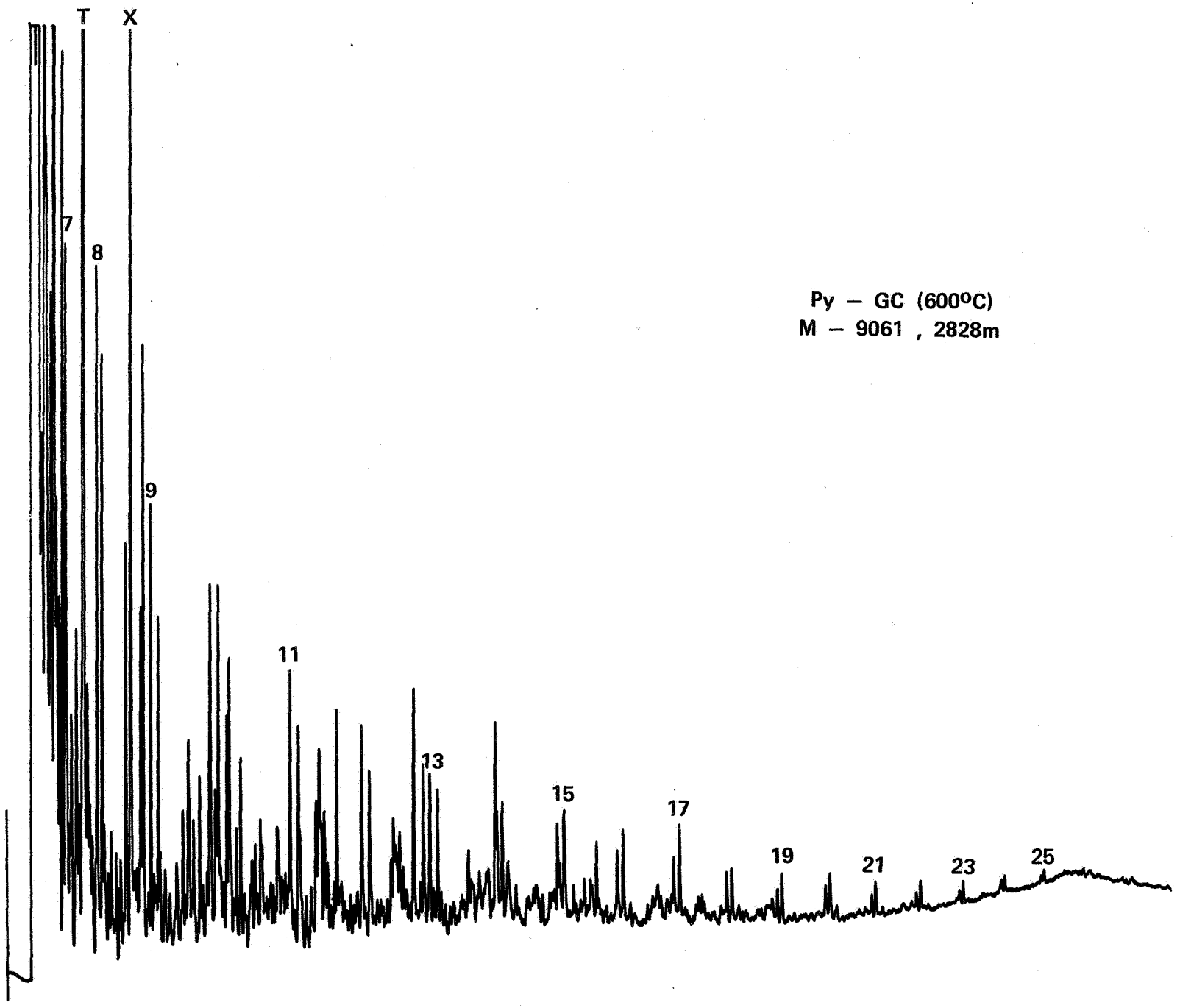
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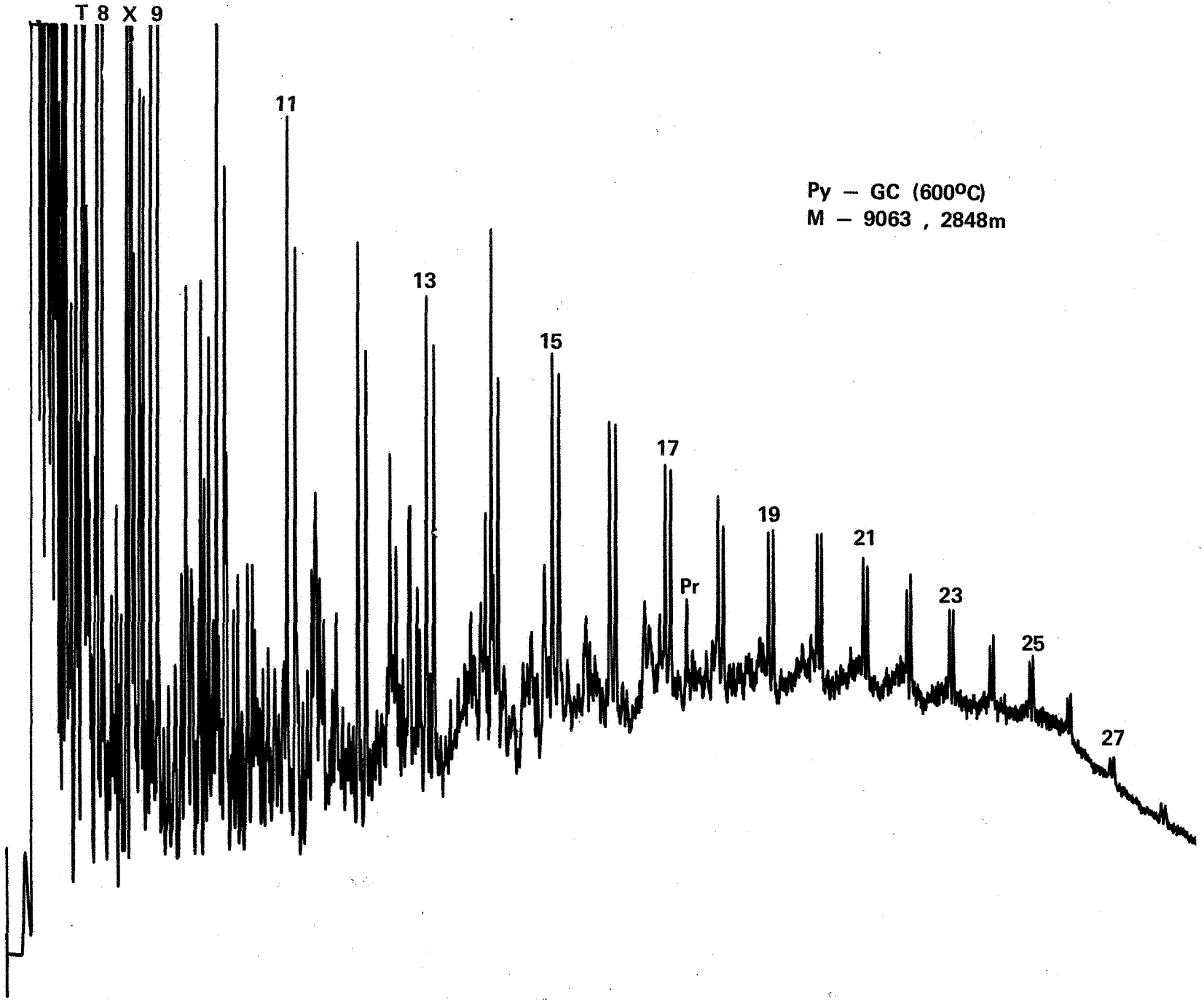
Py – GC (600°C)
M – 9061 , 2828m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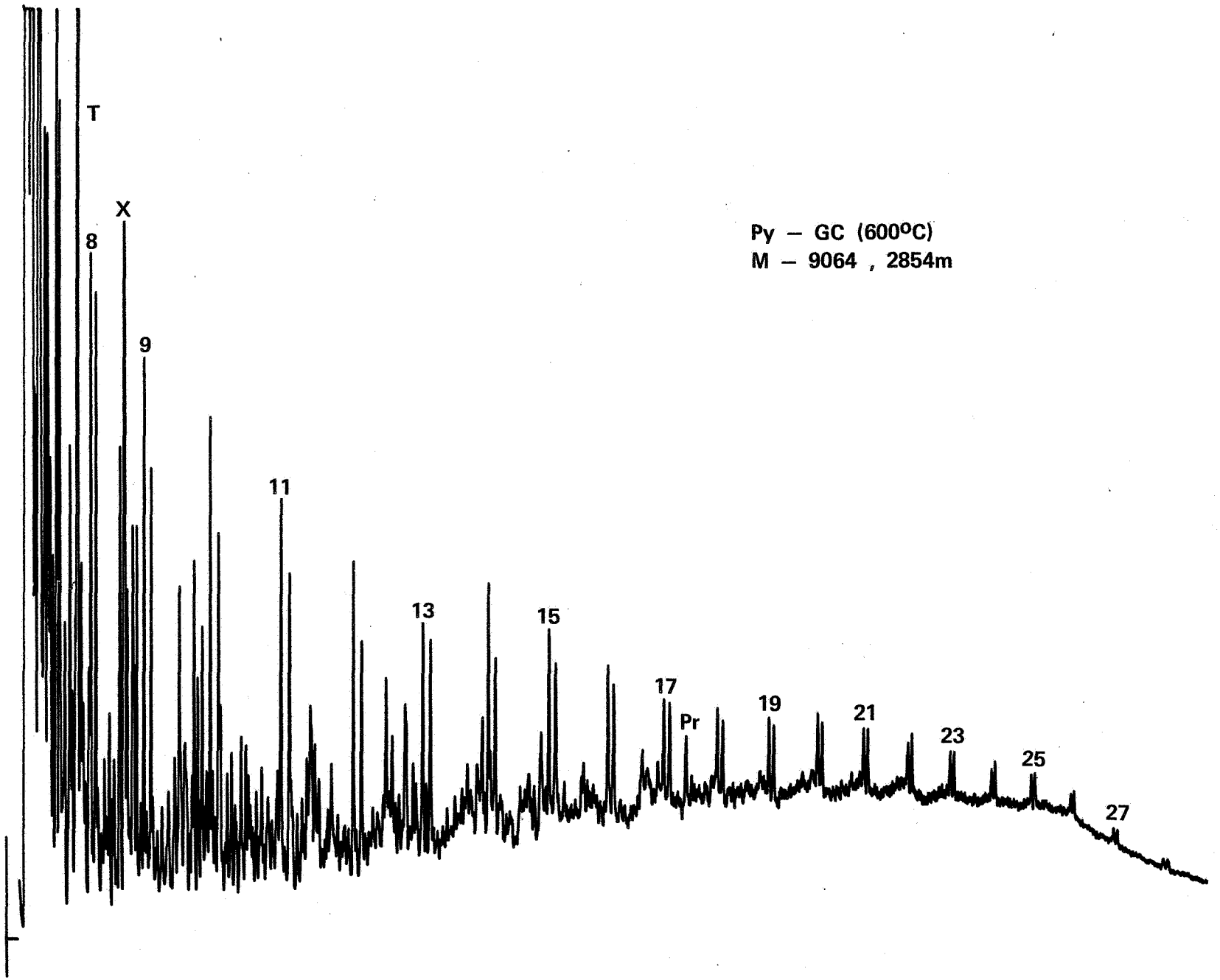
Py – GC (600°C)
M – 9063 , 2848m


Py – GC (600°C)
M – 9064 , 2854m
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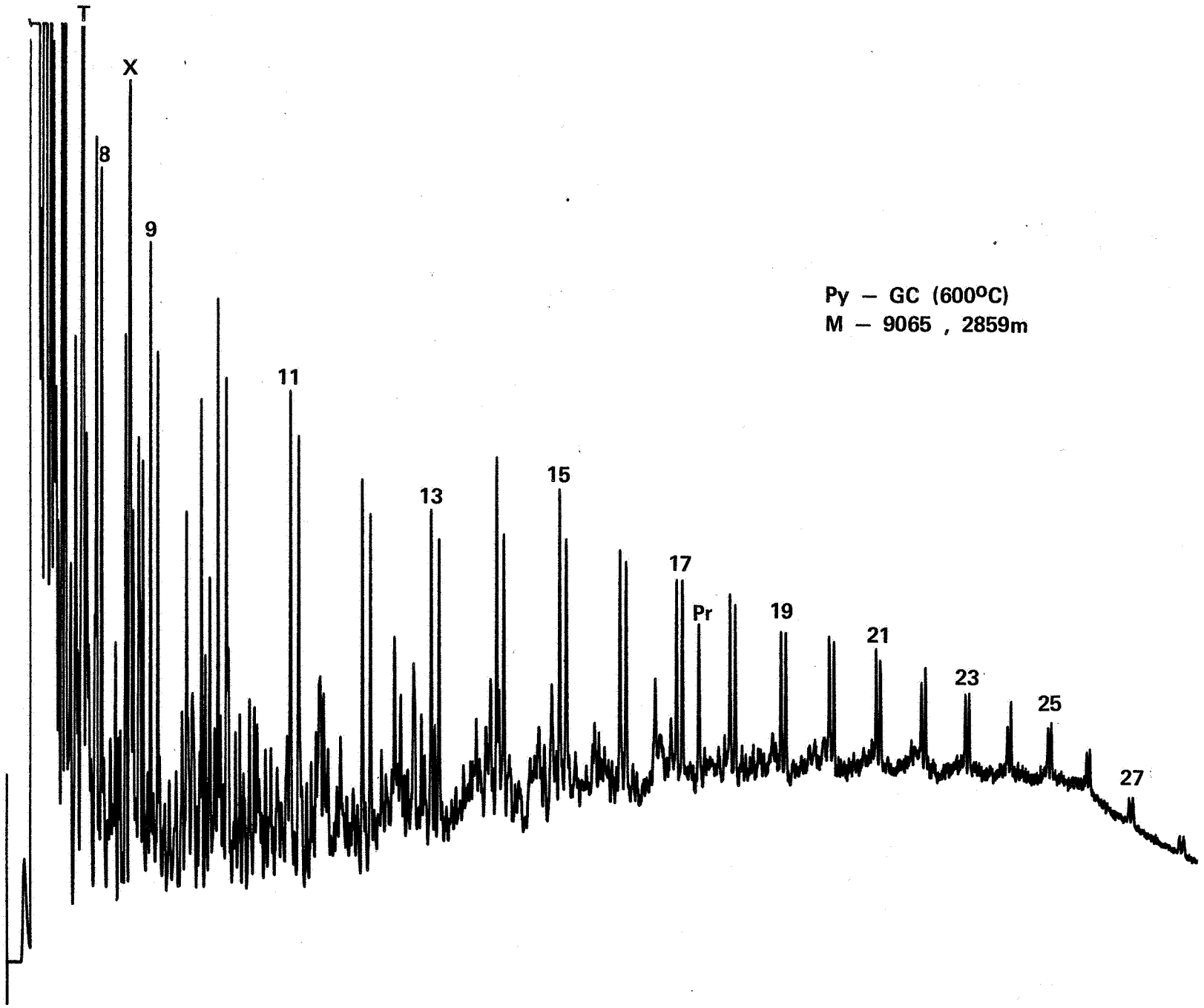
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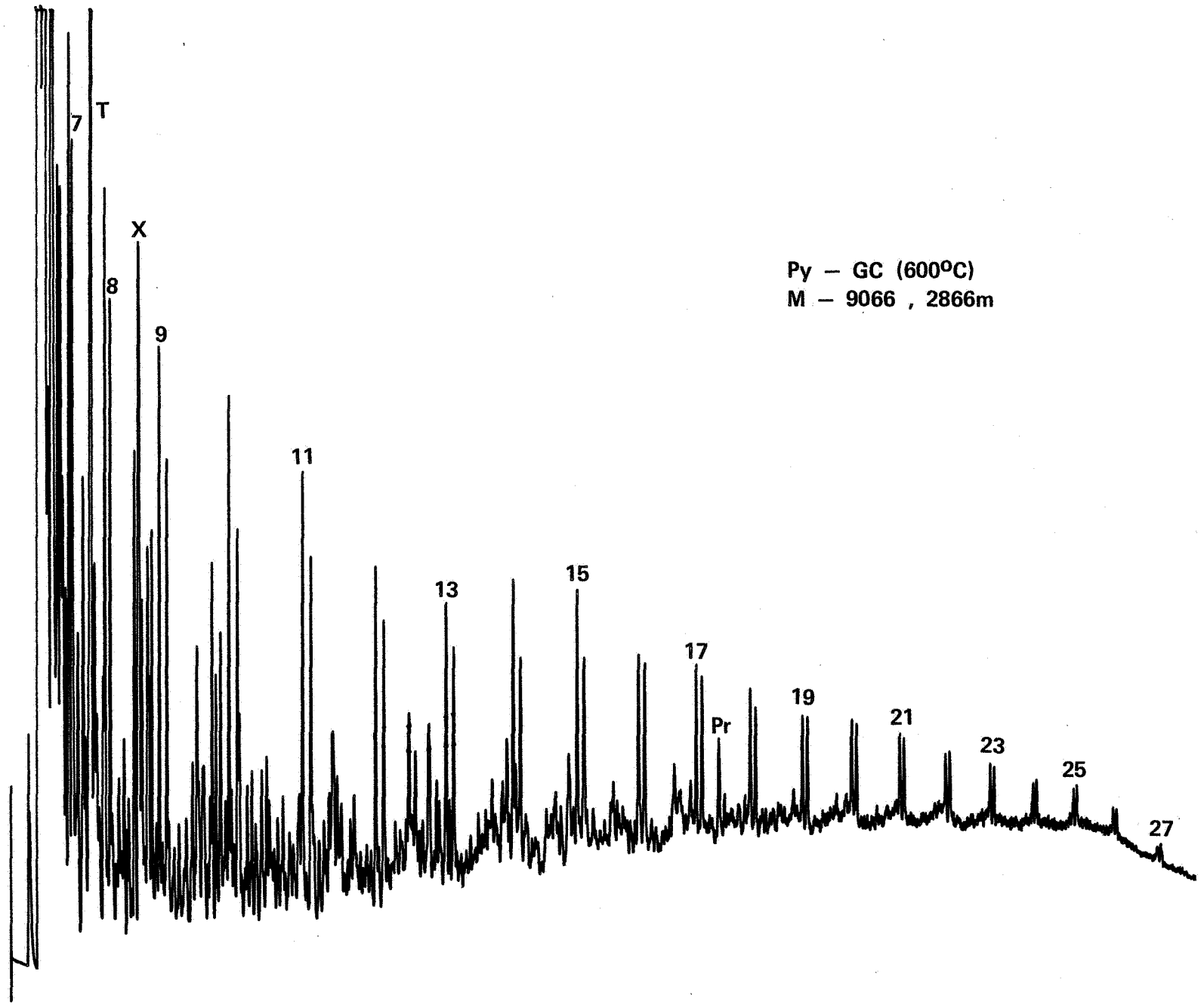
Py – GC (600°C)
M – 9065 , 2859m


Py – GC (600°C)
M – 9066 , 2866m
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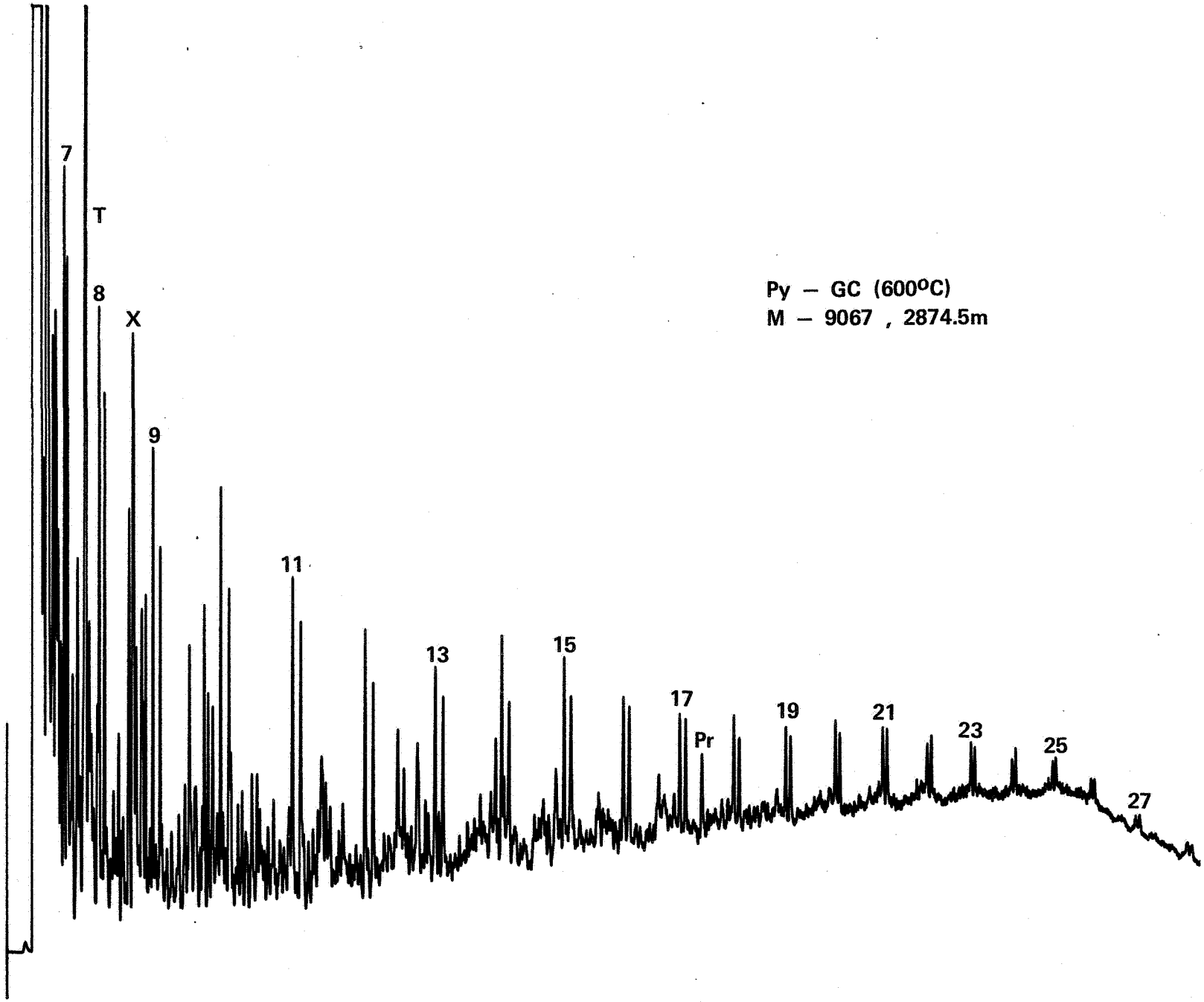
Py – GC (600°C)
M – 9067 , 2874.5m
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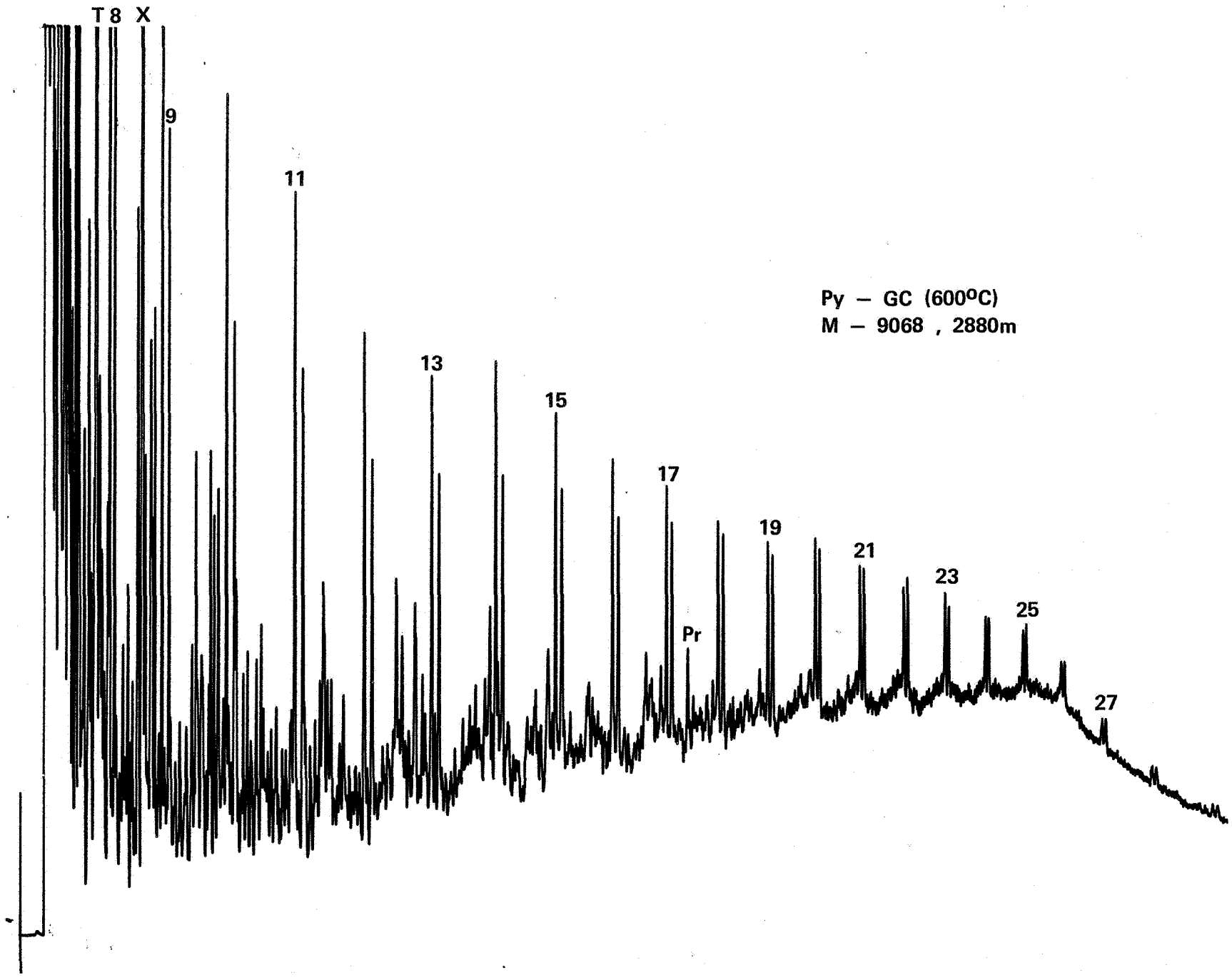
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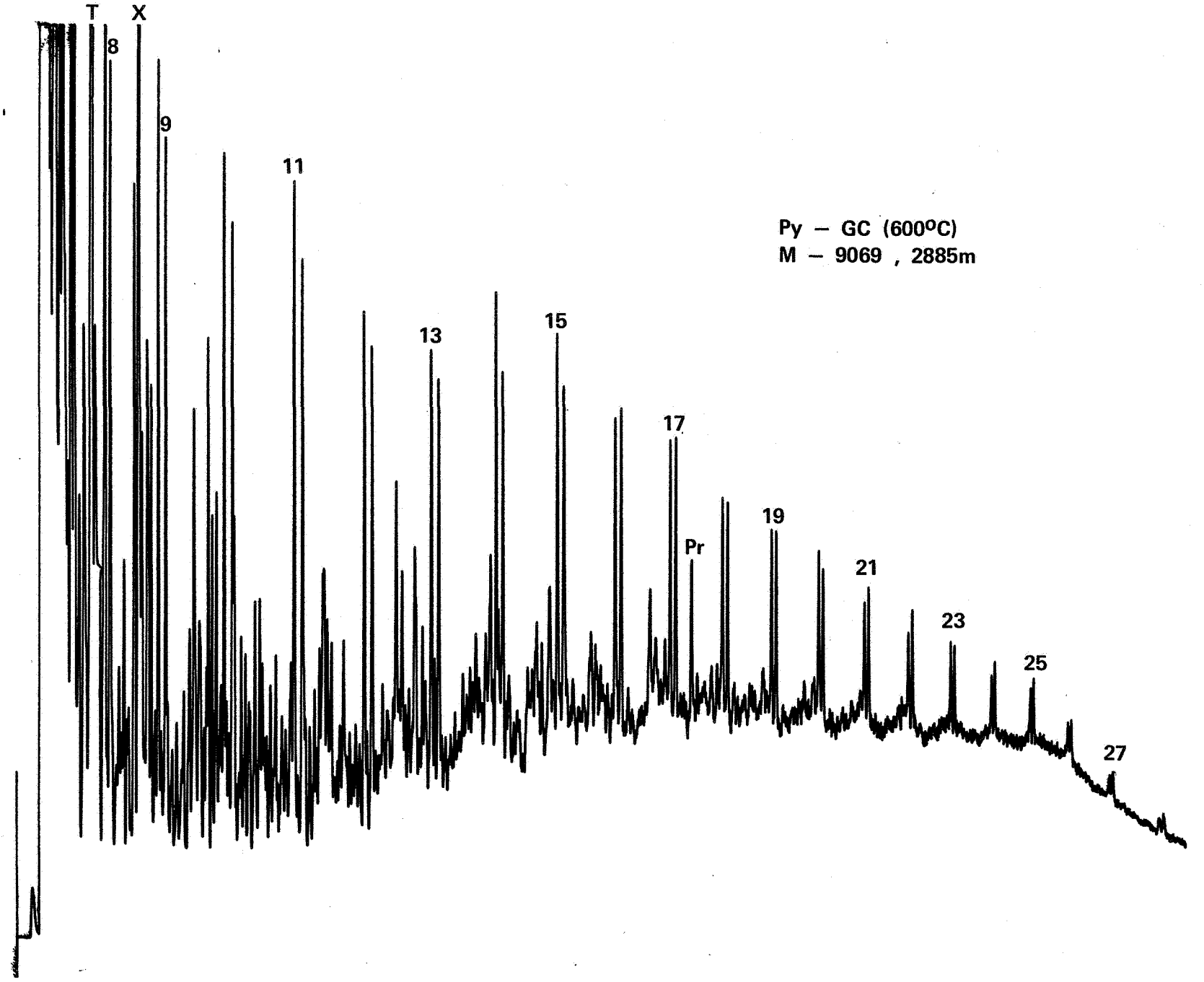
Py – GC (600°C)
M – 9068 , 2880m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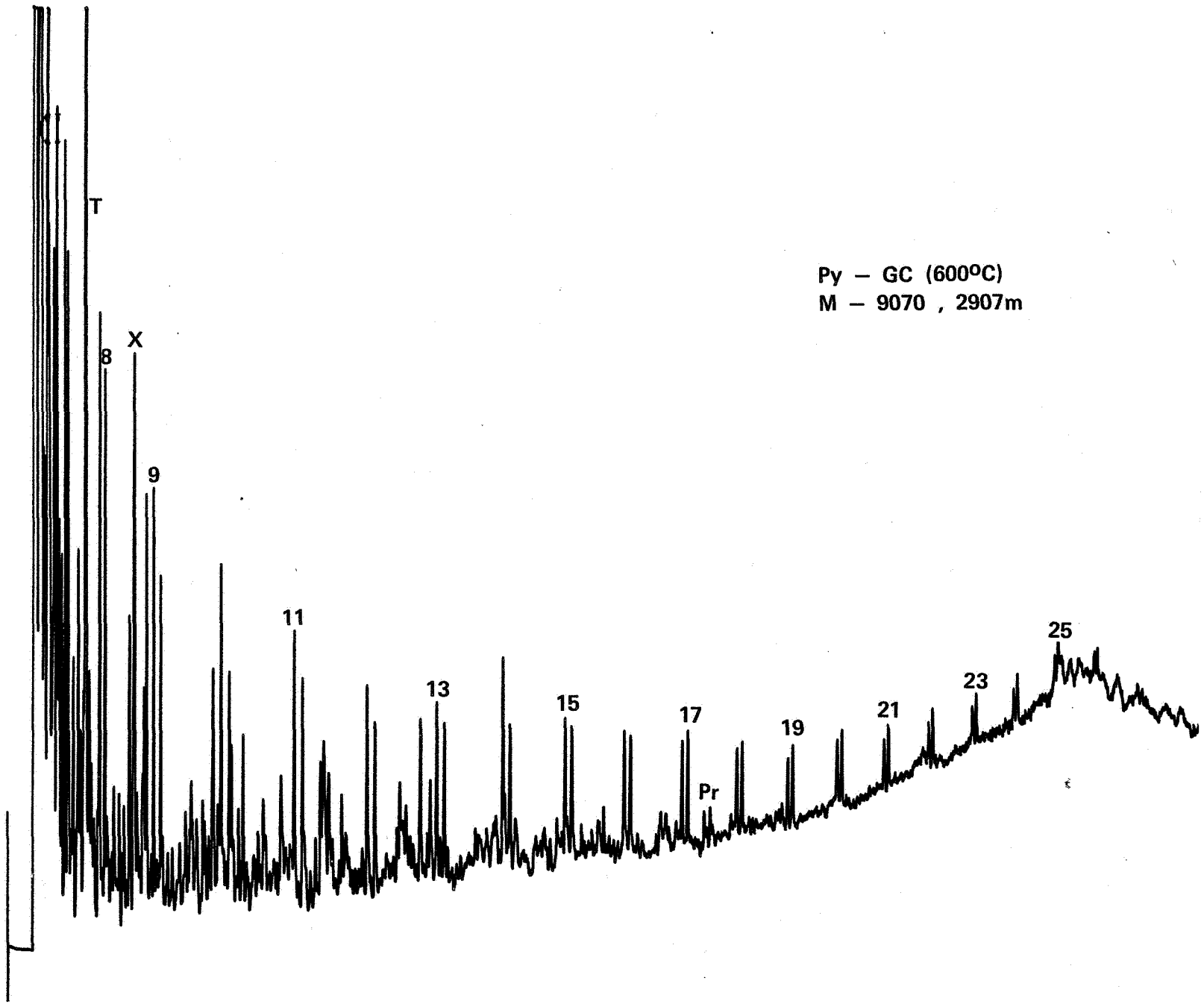
Py – GC (600°C)
M – 9069 , 2885m


Py – GC (600°C)
M – 9070 , 2907m
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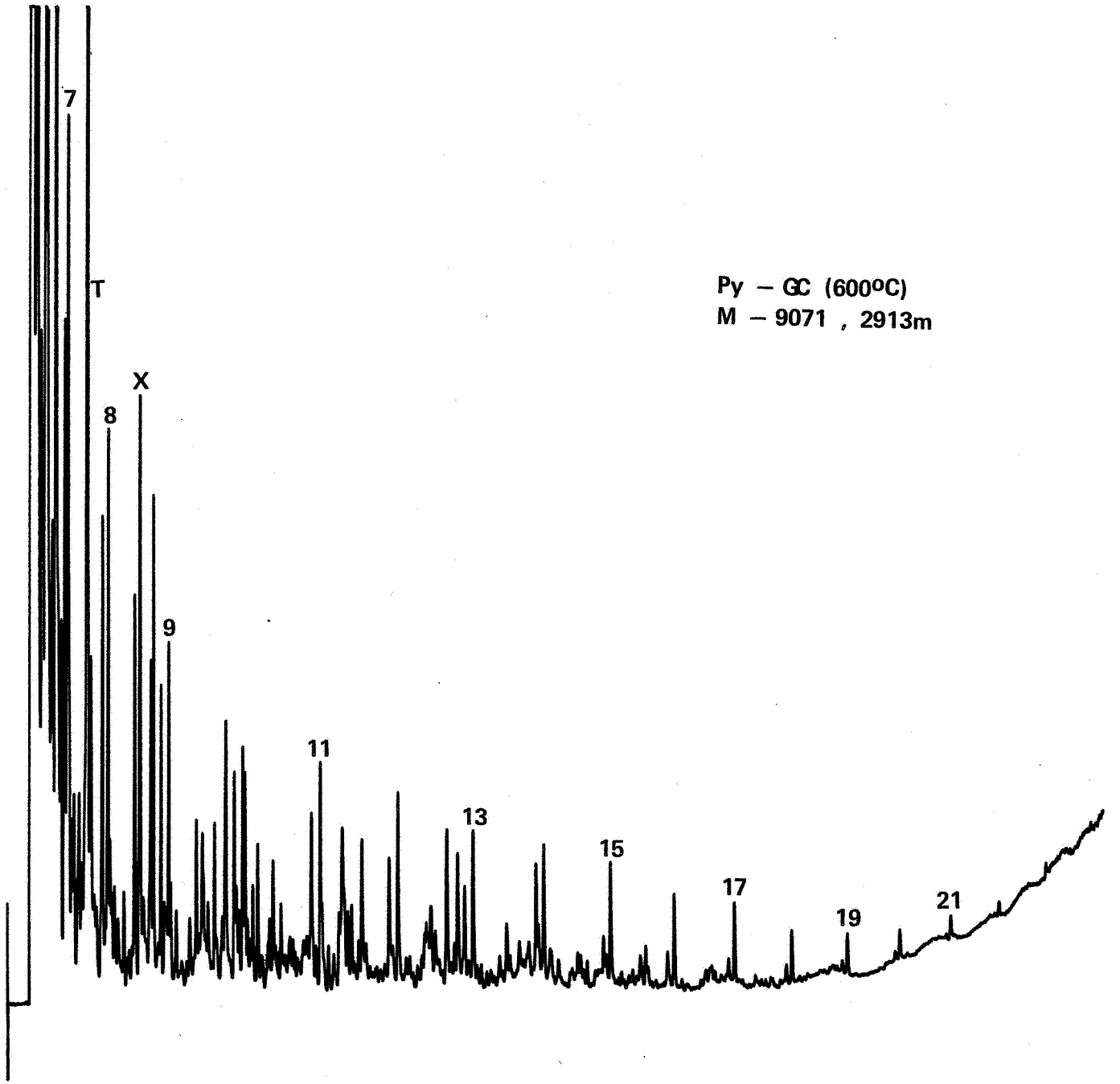
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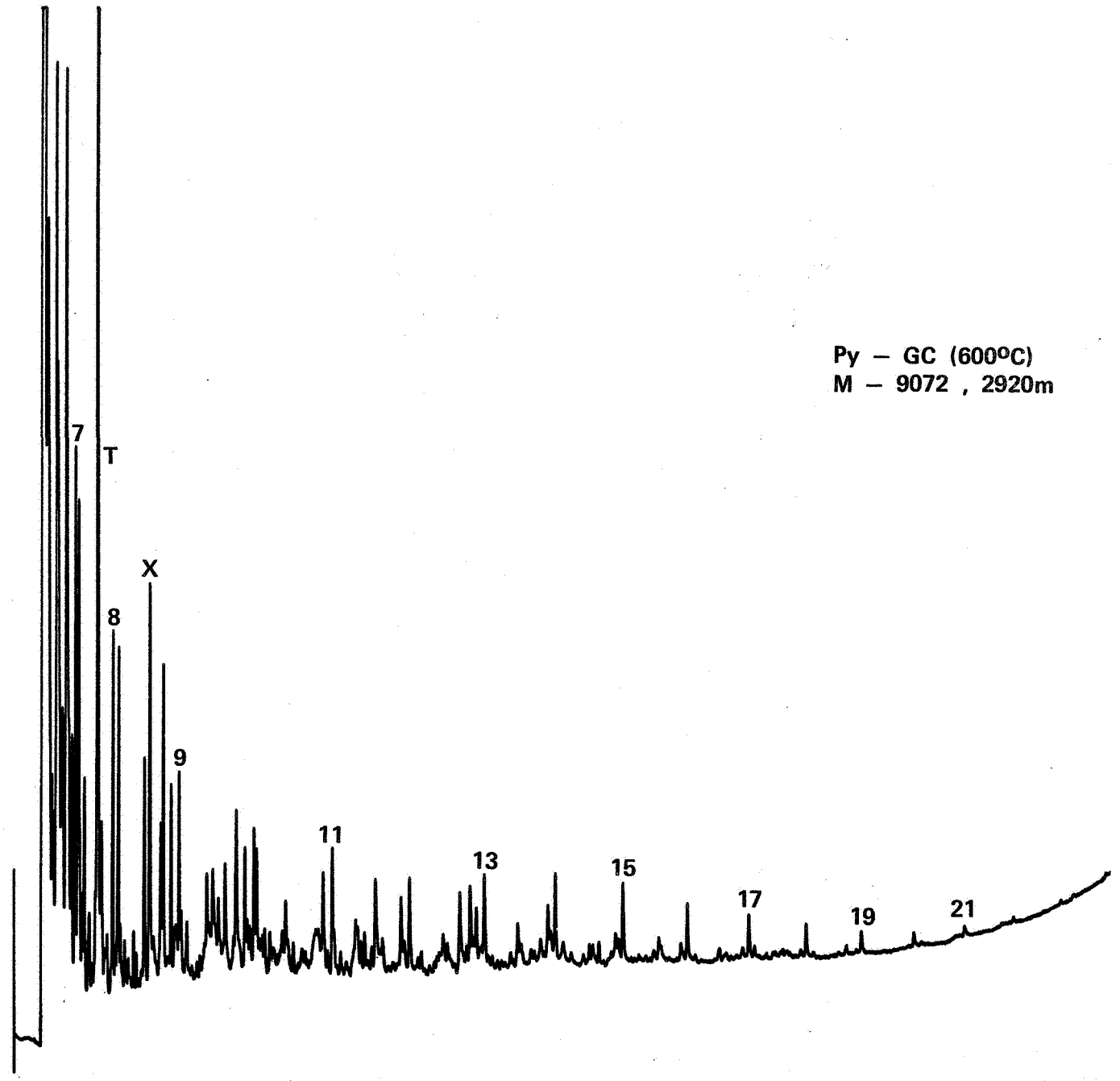
Py – GC (600°C)
M – 9071 , 2913m


Py – GC (600°C)
M – 9072 , 2920m
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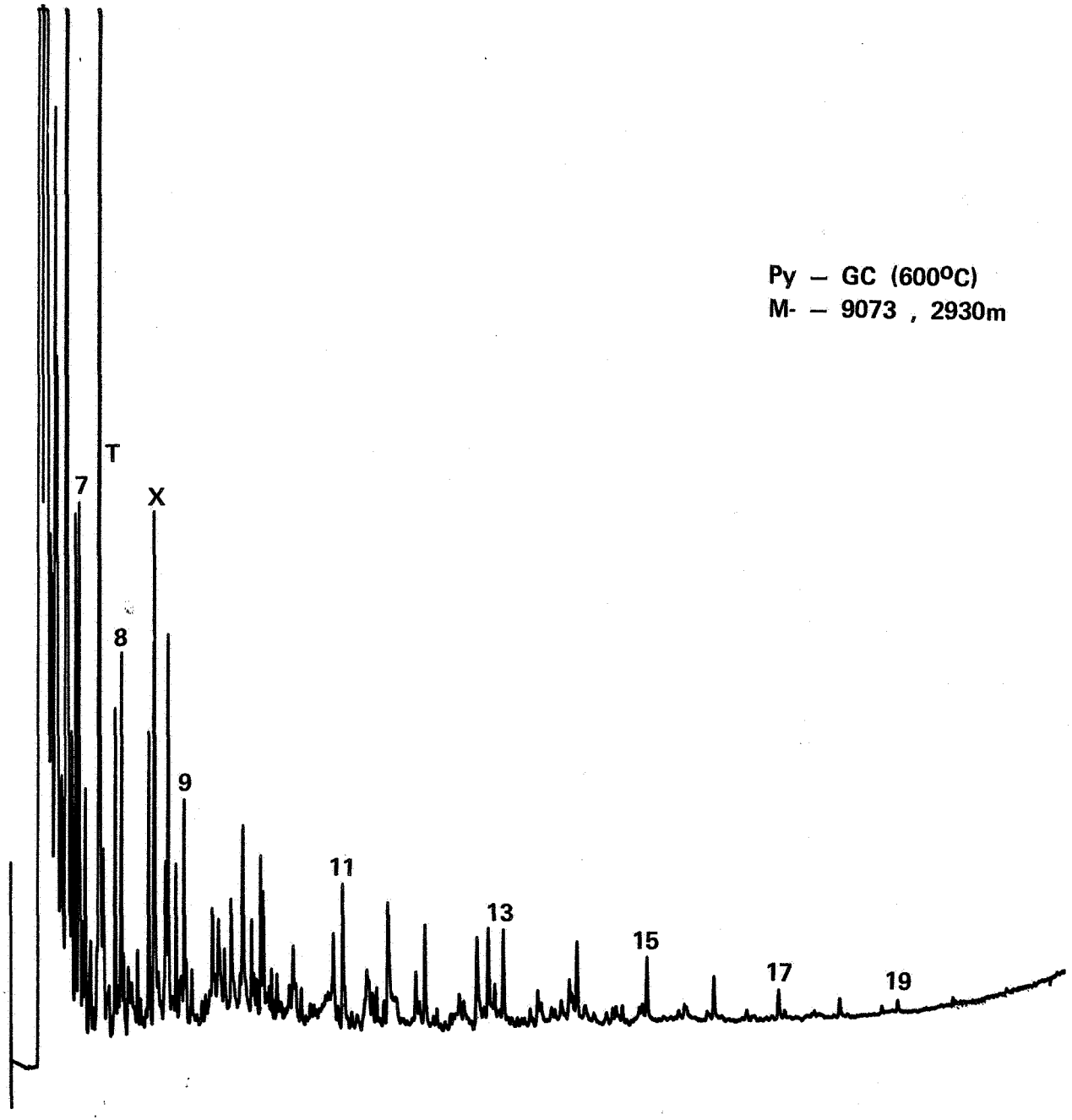
Py – GC (600°C)
M- – 9073 , 2930m
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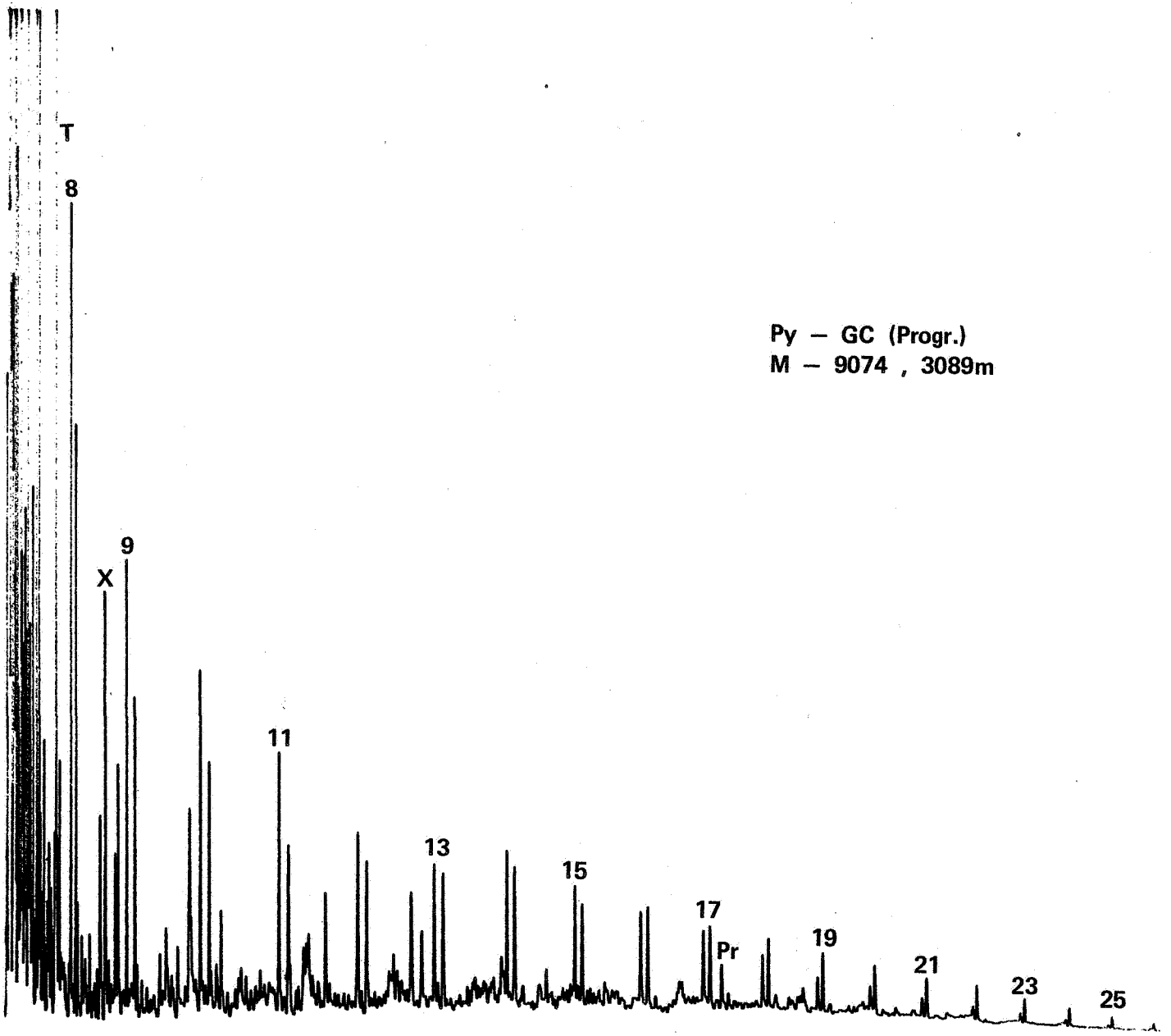
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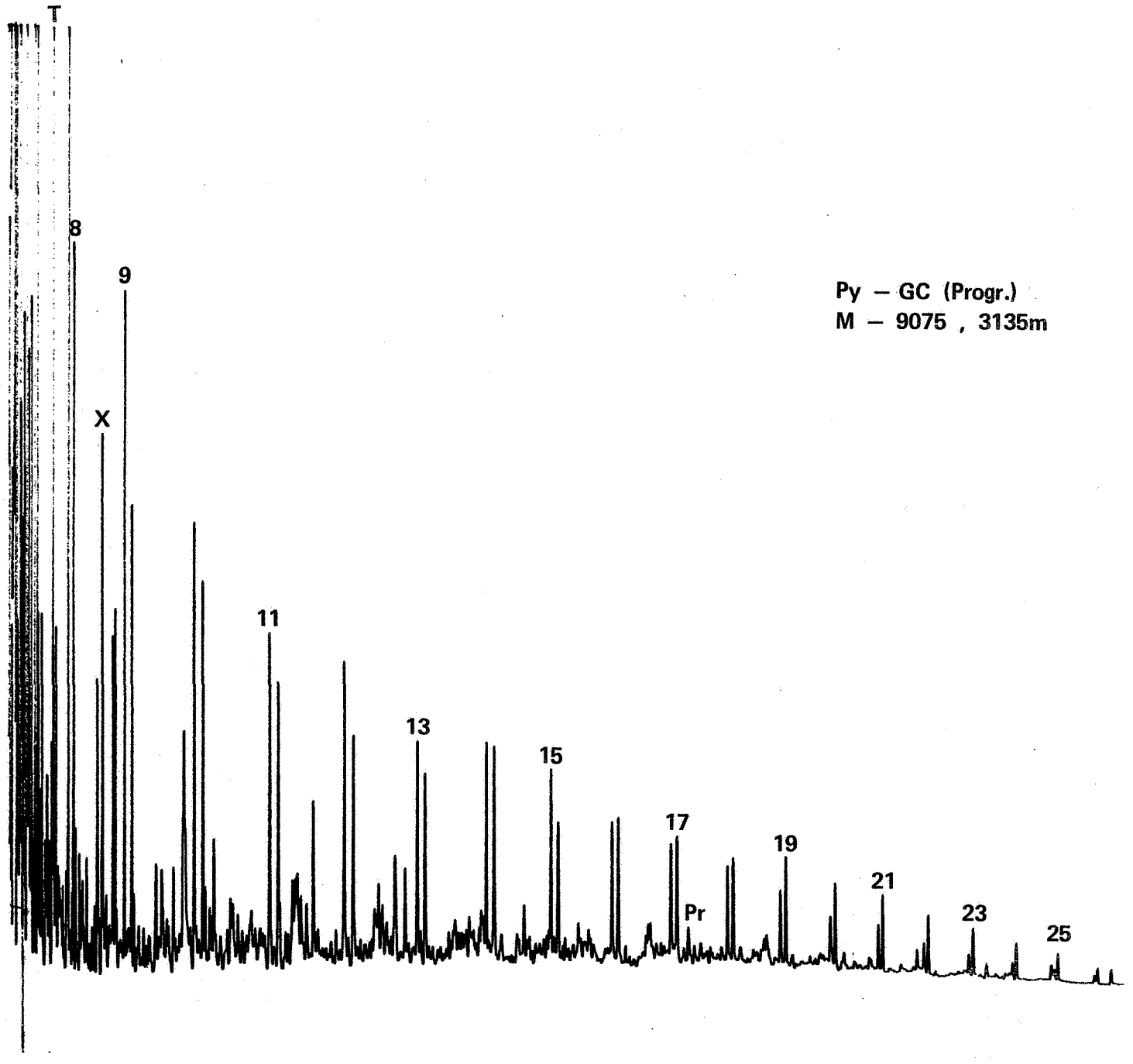
Py – GC (Progr.)
M – 9074 , 3089m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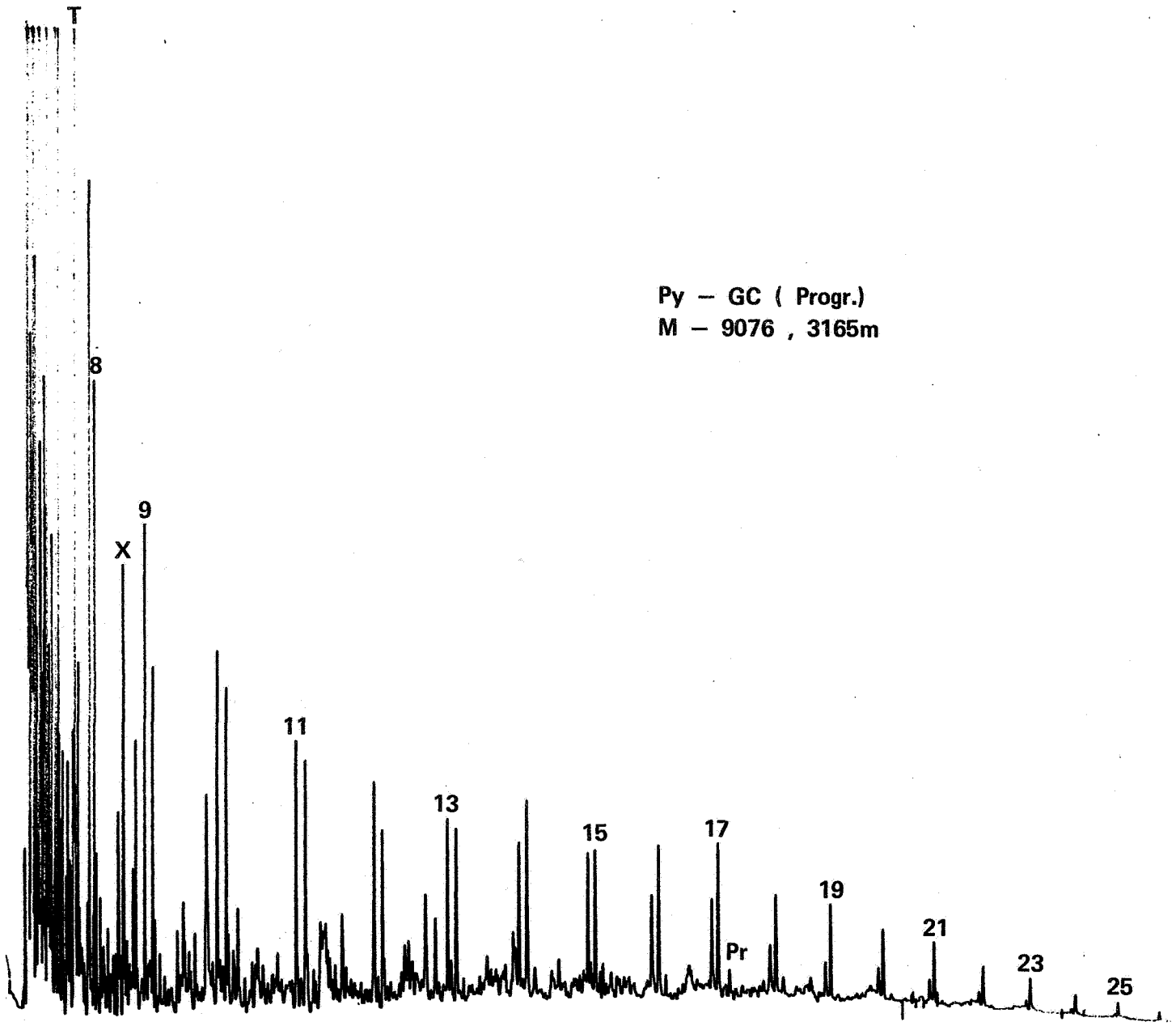
Py – GC (Progr.)
M – 9075 , 3135m


Py – GC (Progr.)
M – 9076 , 3165m
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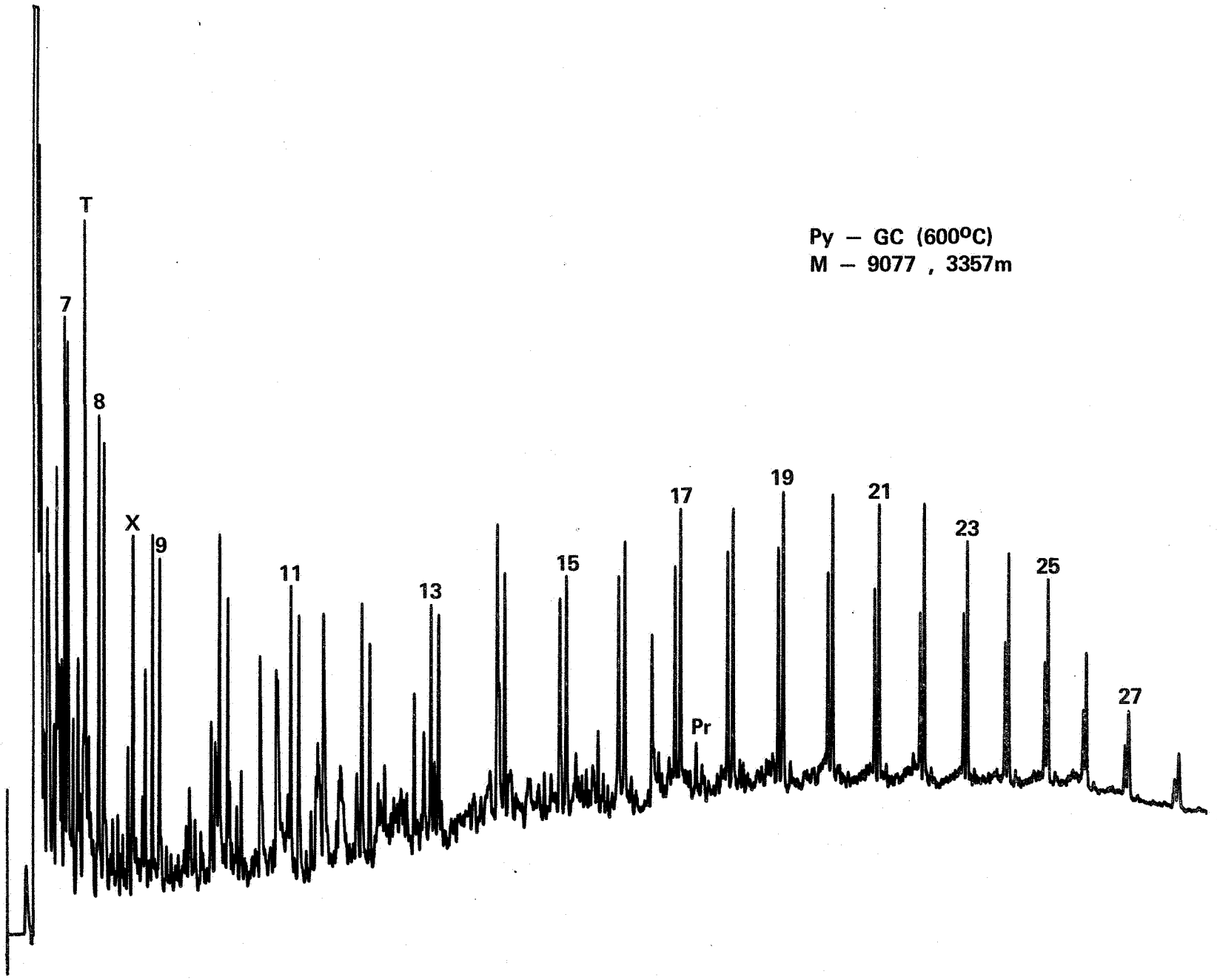
Py – GC (600°C)
M – 9077 , 3357m
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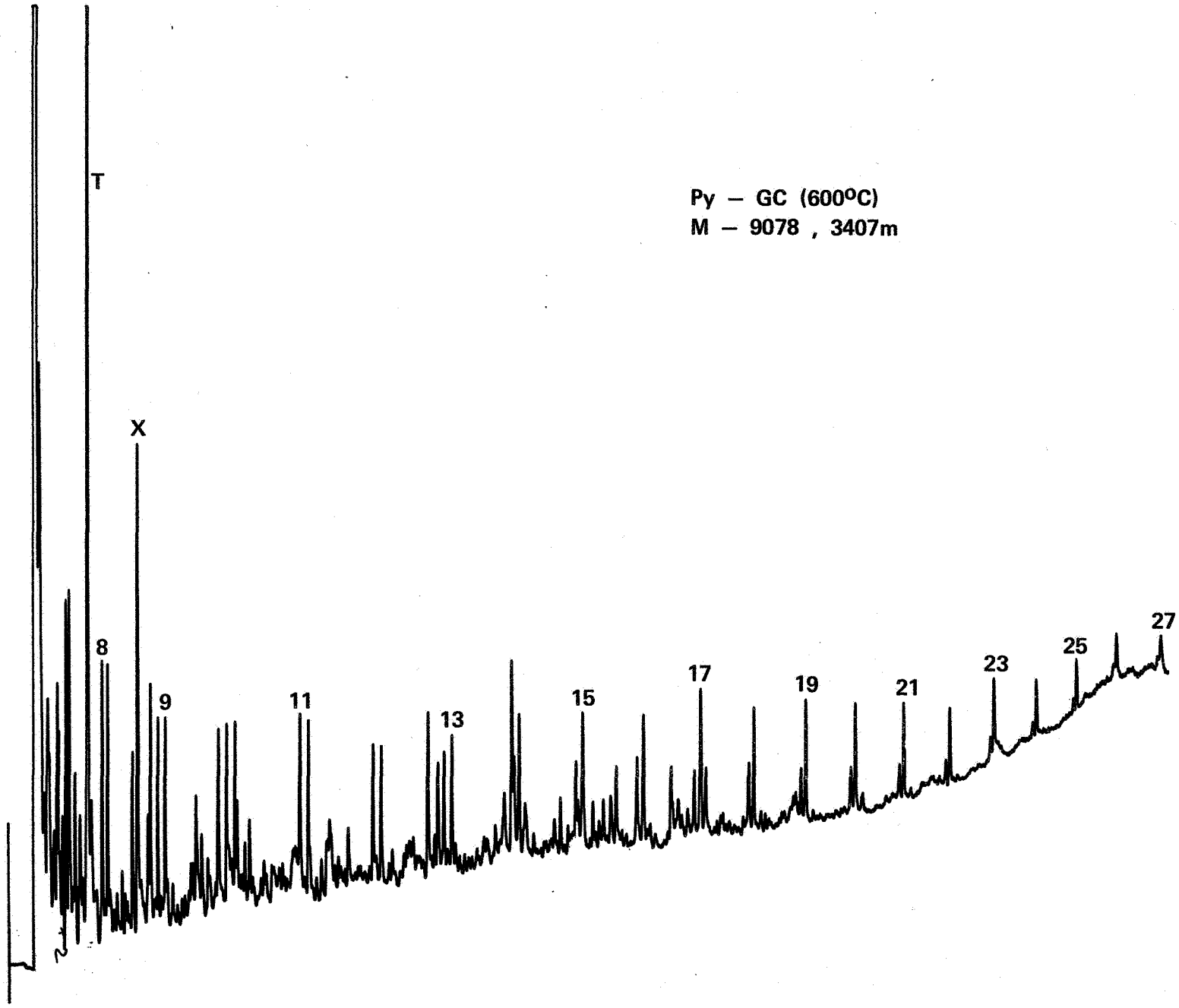
Py – GC (600°C)
M – 9078 , 3407m
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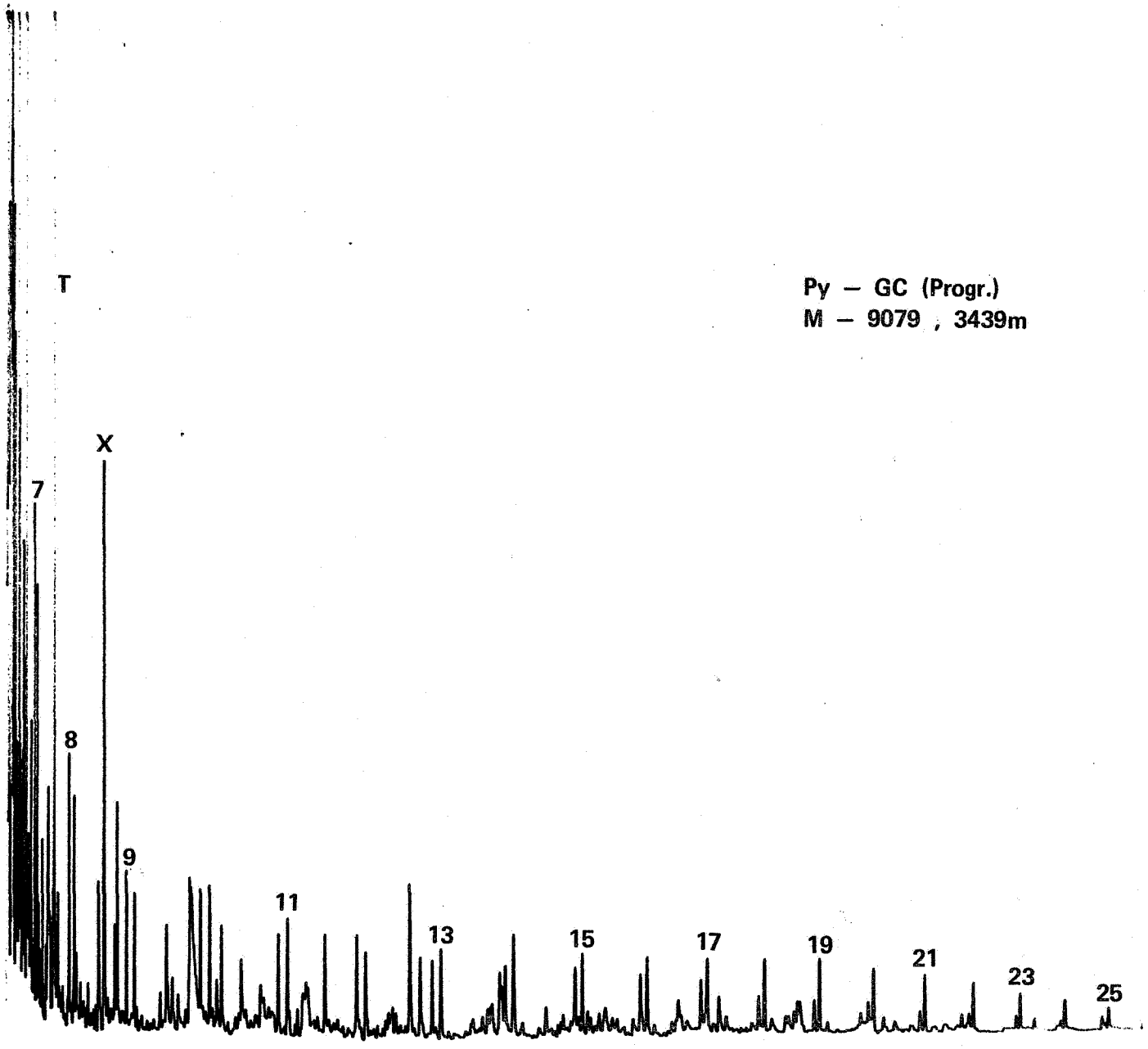
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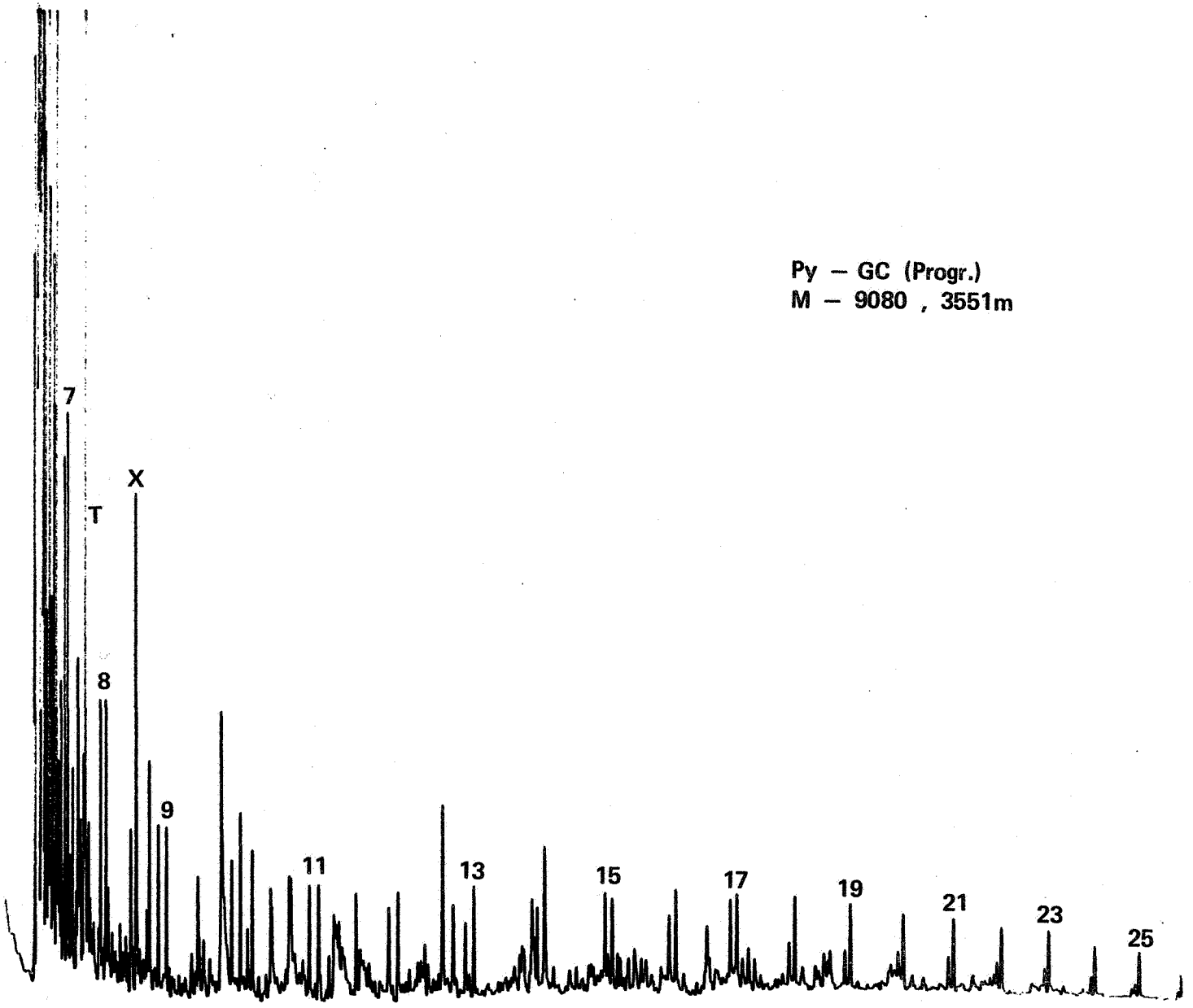
Py – GC (Progr.)
M – 9079 , 3439m


Py – GC (Progr.)
M – 9080 , 3551m
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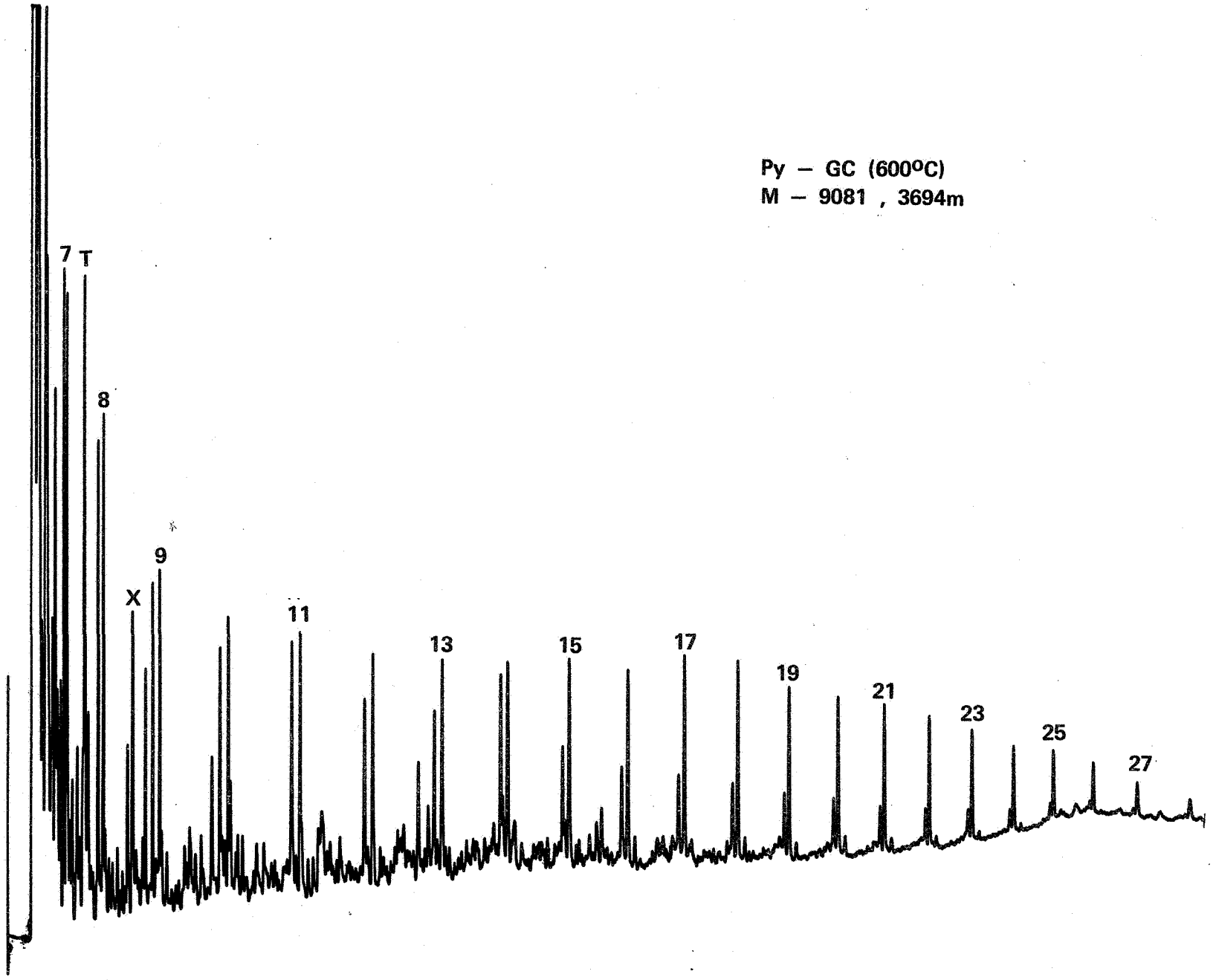
Py – GC (600°C)
M – 9081 , 3694m
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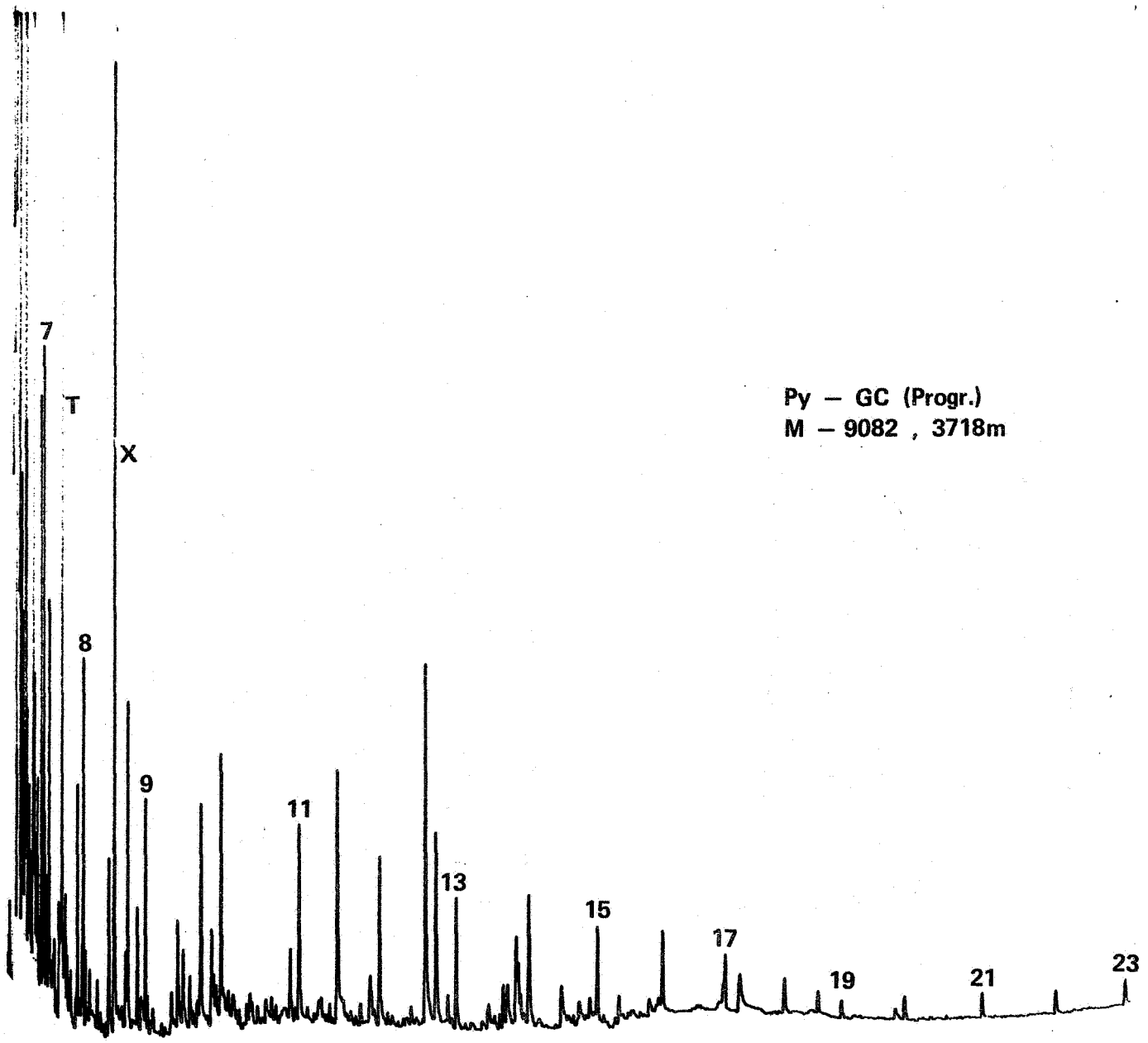
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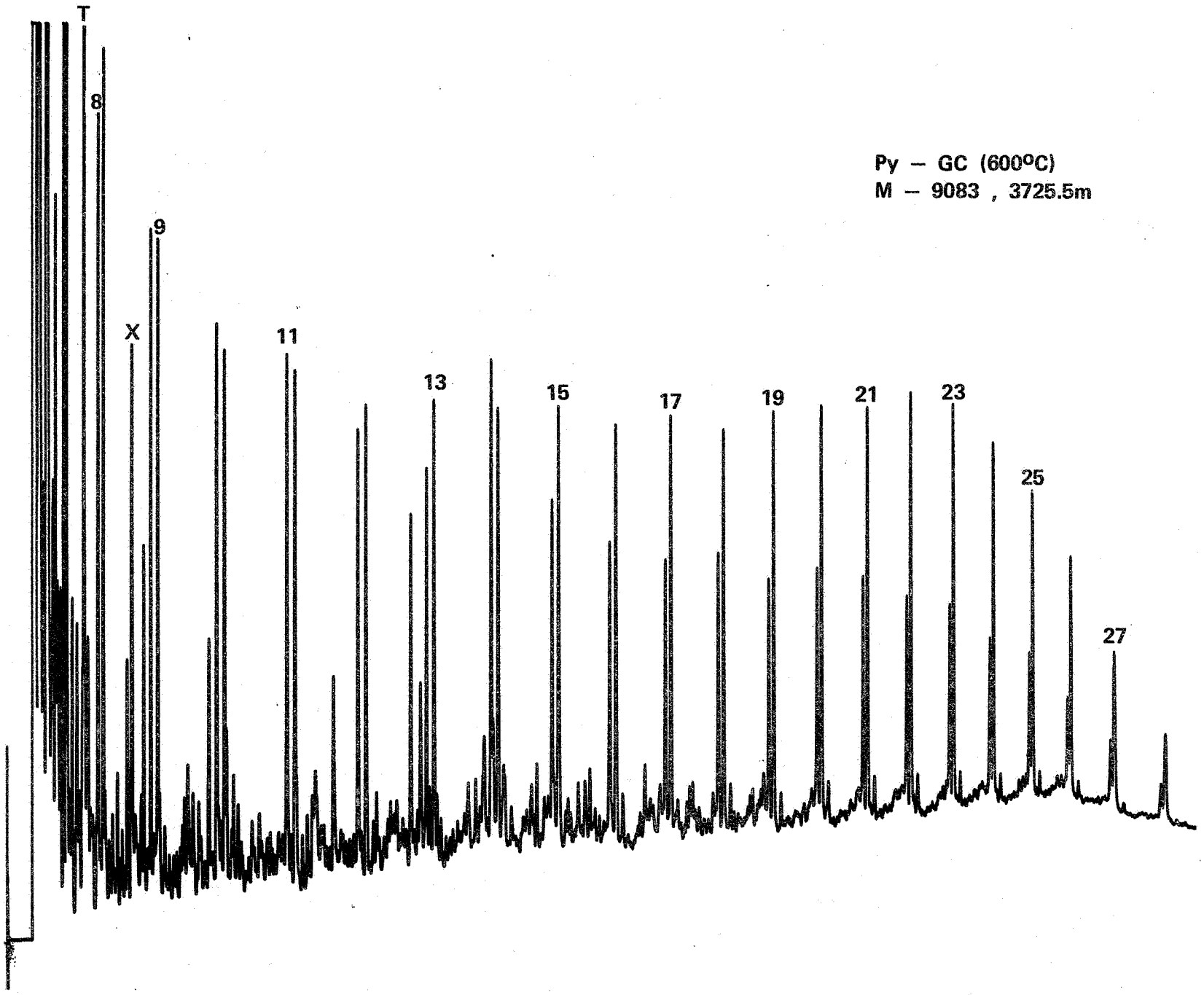
Py – GC (Progr.)
M – 9082 , 3718m


Py – GC (600°C)
M – 9083 , 3725.5m
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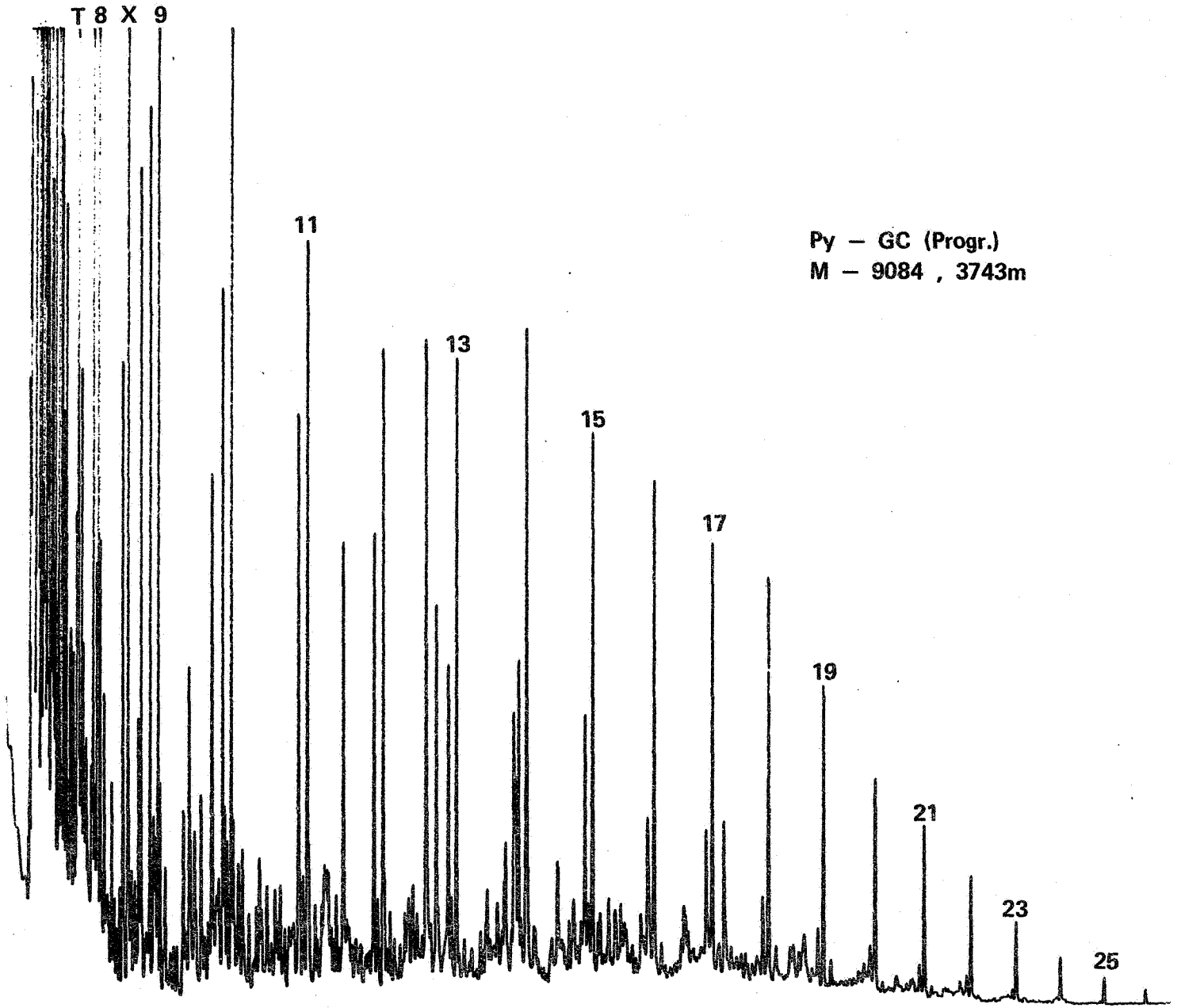
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Py – GC (Progr.)
M – 9084 , 3743m