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CONTINENTAL SHELF INSTITUTE

A CORRELATION OF THE HOT SHALE UNIT IN THE WELLS 31/2-1, 31/2-2, 31/4-2, 31/4-3	
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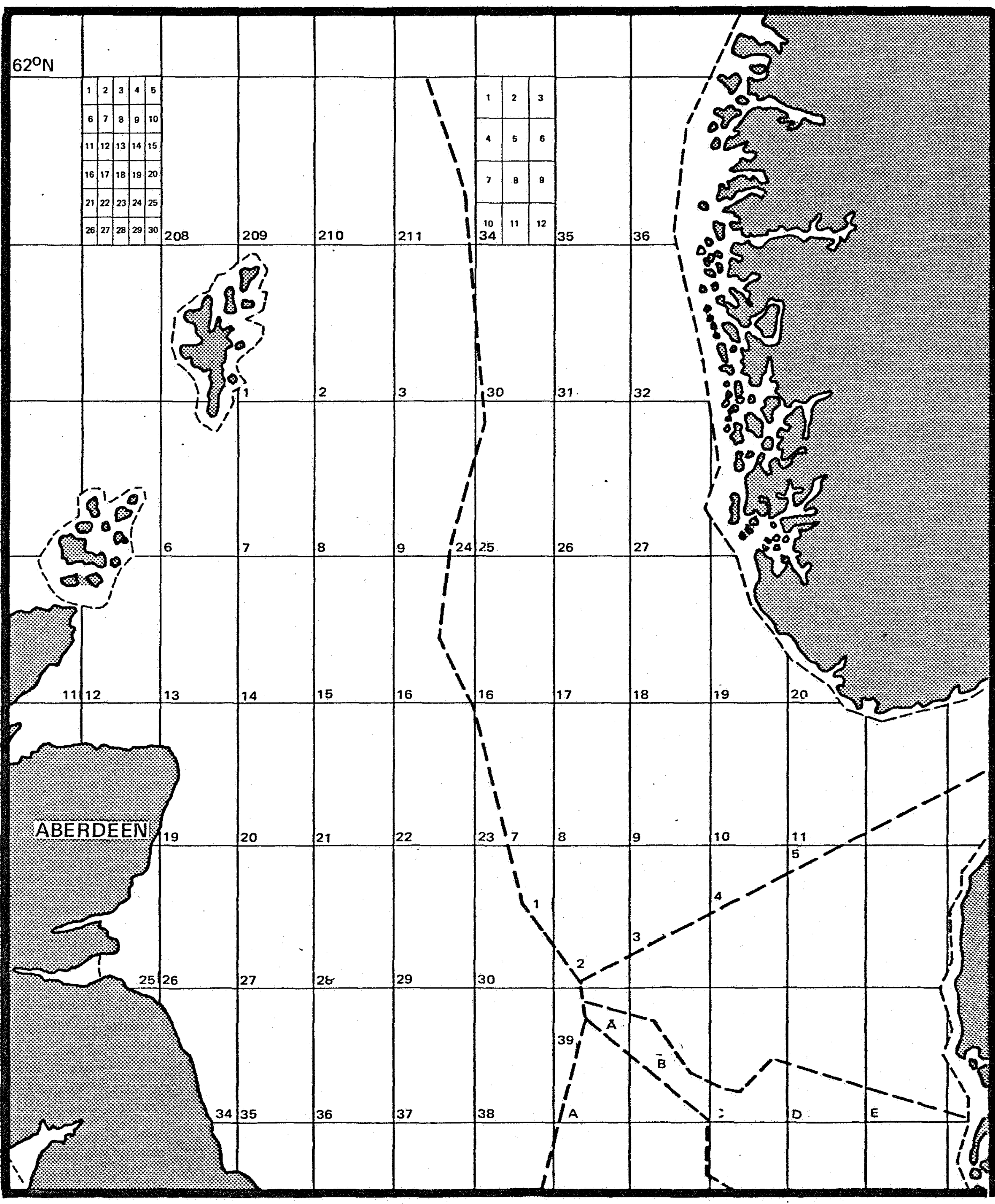
SUMMARY.:

According to the various organic geochemical analyses the hot shale unit is markedly less mature than the condensate. An extensive alternation of the oil has taken place if the hotshale was the source for the condensate. The results of the individual analyses from the wells 31/4-2 and 31/4-3 are very similar, while there is no correlation with the hotshale in 31/2-2.

The hotshale ranges in age from at least Late Kimmeridgian to Late Berriasian age and thin, incomplete sections could give differing dates within this age range, judged from the presence of some selected dinoflagellates. Thus the presence of the hotshale unit enables a general correlation of the deposits around the Jurassic/Cretaceous boundary though individual hotshales may differ in age. Late Berriasian deposits are within the hotshale of 31/4-3, while they are above this unit in 31/4-2. The closest correlations are between 31/4-3 and 31/2-2. The evidence seems in favour of an environmental model in which the facies resulting in the hotshale deposits began and ended at slightly differing times over the area.

BLOCK CONCESSION SYSTEMS IN THE NORWEGIAN AND BRITISH SECTORS OF THE NORTH SEA



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P A R T O N E

ORGANIC GEOCHEMICAL STUDIES

OBJECTIVES:

A: To correlate zones in wells 31/4-2, 31/4-3, 31/2-1 and 31/2-2, defined by well logs as "Hotshale", and examine if condensate found in well 31/4-2 could have been sourced from this "Hotshale".

B: Estimate the source rock potential of these zones.

EXPERIMENTAL AND DESCRIPTION OF INTERPRETATION LEVELS

Total Organic Carbon (TOC)

Picked cuttings of the various lithologies in each sample were crushed in a centrifugal mill. Aliquotes of the samples where then weighed into Leco cruisibles and treated with hot 2N HCl to remove carbonate and washed twice with destilled water to remove traces of HCl. The cruisibles were then placed in a vacuum oven at 50^{o}C and evacuated to 20 mm Hg for 12 hrs. The samples were then analysed on a Leco E C 12 carbon determinator, to determine the total organic carbon (TOC).

Extractable Organic Matter (EOM)

From the TOC results samples were selected for extraction. Of the selected samples, approximately 100 gm of each was extracted in a flow through system (Radke et al., 1978 (Anal. chem. 49, 663-665)) for 10 min. using dichloromethane (DCM) as solvent. The DCM used as solvent was destilled in an all glass apparatus to remove contaminants.

Activated copper filings were used to remove any free sulphur from the samples.

After extraction, the solvent was removed on a Buchi Rotavapor and transferred to a 50 ml flask. The rest of the solvent was then removed and the amount of extractable organic matter (EOM) determined.

Chromatographic Separation

The extractable organic matter (EOM) was separated into saturated fraction, aromatic fraction and non hydrocarbon fraction using a MPLC system with hexane as eluant (Radke et al., Anal. chem., 1980). The various fractions were evaluated on a Buchi Rotavapor and transferred to glass-vials and dried in a stream of nitrogen. The various results are given in Table III-VI.

Gas chromatographic analyses

The saturated fraction was diluted with n-hexane and analysed on a HP 5730 A gaschromatograph, fitted with a 25 m OV101 glasscapillary column and an automatic injection system. Hydrogen (0.7 ml/min.) was used as carrier gas and the injection was performed in the splitt mode (1:20).

Vitrinite Reflectance

Samples, taken at various intervals, were sent for vitrinite reflectance measurements at Geoconsultants, Newcastle-upon-Tyne. The samples were mounted in Bakelite resin blocks; care being taken during the setting of the plastic to avoid temperatures in excess of 100^{o}C. The samples were then ground, initially on a diamond lap followed by two grades of corundum paper. All grinding and subsequent polishing stages in the preparation were carried out using isopropyl alcohol as lubricant, since water leads to the swelling and disintegration of the clay fraction of the samples.

Polishing of the samples was performed on Selvyt cloths using three grades of alumina, 5/20, 3/50 and Gamma, followed by careful cleaning of the surface.

Reflection determinations were carried out on a Leitz M.P.V. microphotometer under oil immersion, R.I. 1.516 at a wavelength of 546 nm. The field measured was varied to suit the size of the organic particle, but was usually of the order of 2 micron diameter.

The surface of the polished block was searched by the operator for suitable areas of vitrinite material in the sediment. The reflectance of the organic particle was determined relative to optical glass standards of known reflectance. Where possible, a minimum of twenty individual particles of vitrinite was measured, although in many cases this number could not be achieved.

The samples were also analysed in UV light, and the colour of the fluorescing material determined. Below, a scale comparing the vitrinite reflectance measurements and the fluorescence is given.

VITRINITE REFLECTANCE R.AVER. 546nm 1·516		0·20	0·30	0·40	0·50	0·60	0·70	0·80	0·90	1·00	1·10
% CARBON CONTENT D.A.F.		57	62	70	73	76	79	80·5	82·5	84	85·5
LIPTINITE FLUOR. EXC. 400nm BAR. 530nm	nm	725	750	790	820	840	860	890	940		
	COLOUR	G	G/Y	Y	Y/O	L.O.	M.O.	D.O.	O/R	R	
	ZONE	1	2	3	4	5	6	7	8	9	

NOTE LIPTINITE NM = NUMERICAL MEASUREMENT OF OVERALL SPORE COLOUR AND NOT PEAK FLUORESCENCE WAVELENGTH

RELATIONSHIP BETWEEN LIPTINITE FLUORESCENCE COLOUR, VITRINITE REFLECTANCE AND CARBON CONTENT IS VARIABLE WITH DEPOSITIONAL ENVIRONMENT AND CATAGENIC HISTORY. THE ABOVE IS ONLY A GUIDE. LIPTINITE WILL OFTEN APPEAR TO PROGRESS TO DEEP ORANGE COLOUR AND THEN FADE RATHER THAN DEVELOP O/R AND RED SHADE. TERMINATION OF FLUORESCENCE IS ALSO VARIABLE.

Processing of samples and Evaluation of Visual Kerogen

Crushed rock samples were treated with hydrochloric and hydrofluoric acids to remove the minerals. A series of microscopic slides contain strew mounts of the residue:

T-slide represents the total acid insoluble residue.
N-slide represents a screened residue (15 µm meshes).
O-slide contains palynodebris remaining after flotation ($ZnBr_2$) to remove disturbing heavy minerals.
X-slides contain oxidized residues, (oxidizing may be required due to sapropel which embeds palynomorphs, or too high coalification preventing the identification of the various groups).

T and/or O slides are necessary to evaluate kerogen composition/palynofacies which is closely related to sample lithology.

Screened or oxidized residues are normally required to concentrate the larger fragments, and to study palynomorphs (pollen, spores and dinoflagellates) and cuticles for paleodating and colour evaluation.

So far visual evaluations of kerogen have been undertaken from residues mounted in glycerine jelly, and studied by Leitz Dialux in normal light (halogene) using x10 and x63 objectives. By x63 magnification it is possible to distinguish single particles of diameters about 2 and, if wanted, to make a more refined classification of the screened residues (particles >15 µm).

The colour evaluation is based on colour tones of spores and pollen (preferably) with support from other types of kerogen (woody material, cuticles and sapropel). These colours are dependant upon the maturity, but also are under influence of the paleo-environment (lithology of the rock, oxidation and decay processes). The colours and the estimated colour index of an individual sample may therefore deviate from those of the neighbouring samples. The techniques in visual kerogen studies are adopted from Staplin (1969) and Burgess (1974).

In interpretation of the maturity from the estimated colour indices we follow a general scheme that is calibrated against vitrinite reflectance values (R_o).

R_o	0.45	0.6	0.9	1.0	1.3	
Colour index	2-	2	2+	3-	3	3+
Maturity intervals	Moderate mature	Mature (oil window)			Condensate window	

Rock-Eval Pyrolyses

100 mg crushed sample was put into a platinum cruisible whose bottom and cover are made of sintered steel and analysed on a Rock-Eval pyrolyser.

GC-MS Analysis

Sixteen saturated hydrocarbon fractions were analysed by Selected Ion Monitoring (SIM) and Sequential Scanning using a VG-Micromass 70-70 double focusing magnetic mass spectrometer coupled directly to a Pye 204 gas chromatograph via an all glass line. A 20 metre by 0.3 mm I.D. glass capillary column coated with OV-1 was temperature programmed from 120^{0}C to 260^{0}C at 4^{0}C/min. with helium carrier gas at a flow rate of 1 ml/minute. Data aquisition was by a VG-Data Systems "Multispec" data system. The sequential scanning was performed at 1 sec/decade and SIM recording at 200 msec dwell time per ion.

RESULTS AND DISCUSSION

Total Organic Carbon

The samples from 31/2-1 were of a very poor quality and the "hotshale" cuttings extremely difficult to locate in the samples. The TOC values of the three samples from this well therefore show very variable results, 1.3 - 3.5% organic carbon. The samples from 31/4-2 and 31/4-3 do, however, show values which are far higher, 6.2 and 5.7% respectively. The two analysed core samples from 31/2-2, 1515 and 1537 m both have a good abundance of organic carbon, 2.6%.

Extraction and Chromatographic Separation

None of the samples from 31/2-1 were analysed while one sample from each of the wells 31/4-2 and 31/4-3 were analysed, both showing a rich abundance of extractable hydrocarbons. When the extractability is normalized to organic carbon, both samples have a fair to good extractability. This low extractability is probably due to the low maturity. With increased maturity, the extractability is believed to be much higher. The two analysed samples from 1515 and 1537 m show a large difference in extractability both in weight ppm of whole rock and normalized to organic carbon. The lowermost sample has an extractability normalized to organic carbon slightly below the values found for 31/4-2 and 3 while the sample from 1515 m has a far higher value.

The gas chromatograms of both the saturated and aromatic hydrocarbon fractions were examined. The gas chromatograms of the saturated hydrocarbon fractions of the two core samples from 31/2-2 show large similarities with large concentrations of pristane and phytane together with a large input of high molecular weight n-alkanes with high CPI values. Steranes and triterpanes have a strong abundance.This is typical for immature samples with a large percentage of terrestrial material.

The gas chromatograms of the aromatic fractions of these samples do not show distinct features as is normally seen in aromatic fractions of geological samples. In the light end fraction hardly any compounds are detected while in the heavy end fraction a large unresolved envelope together with a few peaks are detected. Presently it is not known why such a strange chromatogram is detected for these samples. It could be due to the low maturity of the samples in combination with the type of kerogen present.

The gas chromatograms of the saturated hydrocarbon fractions of the "hot-shale" samples from 31/4-2 and 31/4-3 differ drastically from those from 31/2-2, especially in the heavy molecular end. The CPI value is low for such a low maturity and the gas chromatograms are front biased. The pristane/nC_{17} ratio is approximately 1.0 in the sample from 31/4-3 while it is slightly above 1 in the sample from 31/4-2. This could either be due to a slight change in maturity or a change in the environment of deposition or in the kerogen composition. Both the gas chromatograms indicate a slight input of terrestrial material while the main part of the organic matter will be of amorphous origin.

The gas chromatograms of the aromatic fractions of the samples from 31/4-2 and 31/4-3 differ only slightly from each other while they are distinctly different from the samples from 31/2-2 in that both these samples show distinct pattern in the light end normal for geological samples and hardly any at all in the heavy end.

Vitrinite Reflectance Measurements

Sample 31/4-2, 2158 - 2178 m: Pyritic shale, R_o = 0.36(18)

The sample has extensive bitumen wisps and stringers, otherwise a low content of inertinite particles and occasional wispy particles of vitrinite. UV light shows a yellow/orange and light orange fluorescence from spores and overall background hydrocarbons together with a moderate to rich exinite content.

Sample 31/4-3, 2010 - 40 m: Pyritic shale, R_o = 0.33(22)

The sample is rich in bitumen with strong staining, wisps and stringers. Otherwise a low content of small particles of vitrinite and inertinite. A few coal fragments. UV light shows a yellow/orange and light orange fluorescence from spores and a moderate to rich exinite content.

Sample 31/2-2, 1516 m: Pyritic shale, R_o = 0.49(4)

The sample is rich in bitumen wisps and staining, otherwise a low moderate content of particles of reworked material and vitrinite. Only a trace of doubtful vitrinite particles. UV light shows a yellow/orange and light orange fluorescence from spores and a moderate to rich exinite content.

Sample 31/2-2, 1537 m: Shale, R_o = 0.33(7) and 0.56(1)

The sample contains bitumen wisps and staining and a moderate content of reworked and inertinite particles. Only a trace of doubtful vitrinite particles. UV light shows a yellow to light orange fluorescence from spores and a moderate exinite content.

Visual kerogen analysis

The proportions of amorphous material in relation to non-marine material is estimated to vary from about 45% to 90% in the twelve investigated samples. Otherwise there is a close resemblance between the total acid insoluble residues of the "Hotshales".

The samples yielded fairly rich organic residues which consist mostly of finely dispersed amorphous material, but there are also some medium-sized and large fragments. In all samples seen, the sapropel and/or the sapropelized terrestrial material, tends to be recorded as coherent masses, here termed aggregates. Due to this, palynomorphs, as well as other categories of kerogen are difficult to distinguish and interprete and the amount of sapropelized terrestrial material under estimated. The colour tones of the palynomorphs, when embedded in debris, may appear darker than for clean palynomorphs of layers below and above the Hotshales.

The more detailed subdivision and study of the kerogen had to be undertaken on the basis of screened (15 μm) or chemically oxidized residues.

Pollengrains, especially those with bladders/airsacs, are generally of poor preservation due to decay processes. The artificial structures created make identification difficult or impossible even to generic level. Dinoflagellate cysts have the appearance of being very thinwalled and crumbled.

Cuticular material appears as large to very small fragments. Their structures are dissolved and this type of reservation is here termed sapropelization. Small fragments cannot be distinguished from true sapropel. The large fragments still show superficial resemblance with cuticles.

Pyrite or a related mineral, sticking to outer and inner surfaces of the palynomorphs, and filling cavities as individual crystals or as small globules, is removed by oxidation. Imprints and thickened edges often remain retaining the shape of the crystals.

The following variations were observed for the individual samples or wells.

31/4-2 2158 - 78 m and 31/4-3 2010-40 m and 2015 m swc

The total residues were dominated by amorphous material. Both screening and oxidation result in increase of cuticular material and palynomorphs. The palynomorphs include mainly pollen with air sacks and simple gymnosperm pollen dominate. The colour index is 1+/2- or 2-/2.

The depositional environment is estimated to have been a low energy area, close to vegetation, but marine. We suspect that sapropelized cuticular (herbaceous) material in the total residues was under estimated because it could not be distinguished from true sapropel.

31/2-1 1390 m to 1492 m

1390 m to 1402 m: The interval contains fairly well or well preserved palynomorphs, but the residues are completely dominated by aggregates of amorphous material even after oxidation.

1414 m to 1438 m: The palynomorphs of this interval are poorly to fairly well preserved. Pyrite is common and partly fills cavities. Amorphous material in aggregates (true sapropel or mixed with sapropelized material) dominating the screened slides. The interval is characterized by a relative increase in terrestrial material, including sapropelized cuticles. The lowest samples 1432 m and 1438 m contain less dence aggregates. From 1426 m to

1438 m pollen grains are also more frequent than cysts and support deposition more close to shore line, but in a low energy area. The colour index is 1/1+.

1444 m to 1492 m: Terrestrial material is clearly dominant in this interval. On the basis of minerals being more frequent in the samples and on the presence of mud additives in the lowest sample, we believe that the samples represent deposits more poor in organic material than the interval above. Probably deposition took place in a more high energy area.

31/2-2 1515,12 m core and 1535 m core

The organic residues are relatively smaller than in the 31/4-2, 31/4-3 and 31/2-1 wells. The organic residues consisted of about 75% amorphous, 25% clearly terrestrial material. The terrestrial material was more finely dispersed, half of it was indeterminated land derived, the other half woody material. The screening and oxidation result in an increase of palynomorphs and woody matter. The dominant group of palynomorphs is simple, small gymnosperm pollen. The colour index is 1/1+.

The depositional environment is estimated to have been a low energy area, marine, probably at larger distance from the vegetation than for 31/2-1, 31/4-2 and 31/4-3, and with relatively lower sedimentation rate of organic material.

Rock-Eval Pyrolysis

Samples from all four wells were pyrolysed on a Rock-Eval instrument. All the samples have high oxygen indeces which could partly be due to the low maturity, partly due to kerogen type III in the sample and partly due to decarboxylation of the samples. The hydrogen index varies considerably for the analysed samples. The highest index is registered for the samples from 31/4-2 and 31/4-3 while the index is rather low for the samples from both 31/2-1 and 31/2-2. This would then indicate that the amount of kerogen type II is high in the samples from wells 31/4-2 and 31/4-3 and far lower in the samples from 31/2-1 and 31/2-. This is in direct contradiction to the visual kerogen examination.

SOURCE ROCK EVALUATION

Based on the various analyses, all the samples were found to be immature. The typing of kerogen shows contradicting results from the visual kerogen and the Rock-Eval pyrolysis. The gas chromatograms of the saturated hydrocarbon fractions support the Rock-Eval analysis showing a large input of heavy alkanes indicating a more terrestrial source for the samples from 31/2-2.

On the basis of this we would rate the analysed interval in 31/4-2 and 31/4-3 to have a rich potential as source rocks for oil (and gas) while the interval in both 31/2-1 and 31/2-2 are more gas prone.

CORRELATION STUDIES

The saturated and aromatic hydrocarbon fractions of the "hotshale" samples were correlated to the saturated and aromatic fractions of the condensate from 31/4-2.

In our correlation of these samples we have concentrated on the steranes (m/z=217), aromatic steranes (m/z=253), triterpanes (m/z=191) in the saturated fractions and dialkyl benzenes (m/z=105), dimenthyl naphtalenes (m/z=144), phenantrenes (m/e=178), methylphenantrenes (m/z=206) in the aromatic fractions.

The variation in steranes and triterpanes due to maturity and migration is more known than the variation in aromatic compounds. In our discussion we will refer to papers by Seifert et. al published during the last 2-3 years. These authors have shown that some of compounds and ratios between compounds are very dependent on migration and maturity, while others are mainly source dependent. Of the latter is the ratio of 5α(H)-24-Methylcholestane/ 5α(H)-24-Ethylcholestane (Peak 7/9).

Saturated Fractions

Visual comparison of the m/z 217 shows that the sterane distributions for 31/4-2 and 31/4-3 are very similar. A strong similarity is also seen between the two samples from 31/2-2 while comparatively strong differences are found between the samples from 31/2-2 and those from 31/4-2 and 31/4-3. When the 217 traces of the two condensate samples are compared these are found to be similar to each other. However, the distributions for 31/4-2, 31/4-3, 31/2-2 and the condensates are markedly different. Eleven of the most abundant steranes in each fraction (peak height) are normalized each to peak 9(24-ethylcholestane). The values obtained are listed in table 10. The major components of 31/4-2, 31/4-3 and 31/2-2 are the regular steranes (pk. 5 cholestane, pk 7, 24-methylcholestane and pk 9, 24-ethylcholestane) whereas those in the condensates are the rearranged diasteranes (clearly seen in the m/z 259 traces). From the data obtained, samples 31/4-2, 31/4-3 and 31/2-2 are for less mature than the condensates. Indeed the samples from 31/2-2 and 31/4-3 appear less mature than 31/4-2 (i.e. ratios of pk 1 and 2 (the C_{27} αβ, βα diacholestane).

The aromatic steranes (m/z 253) are abundant components of 31/4-2, 31/4-3 and 31/2-2. Furthermore the distribution of these components is very similar for three of the samples while the sample from 1516 m in 31/2-2 shows large differences. Aromatic steranes, if present in the condensates, are present in only very low abundances.

Triterpanes (m/z 191) are more maturity dependant than some of the sterane ratios. Due to the very nature of the samples, triterpanes are much less abundant in the condensate samples than in samples 31/4-2, 31/4-3 and 31/2-2. However, the relative distribution of major triterpanes (i.e. C_{29}, C_{30} and C_{31} hopanes) are similar in each sample. The relative distribution of minor triterpanes in the condensate samples, although showing similarities to each other, differ to those of 31/4-2, 31/4-3 and 31/2-2. The distribution of the triterpanes in the samples from 31/4-2 is similar to the distribution in sample 31/4-3. The triterpane distribution of the two samples from 31/2-2 are very similar to each other and do not show the typical crude oil type distribution in the C_{31} - C_{35} hopane region. Indeed the distribution again suggests an immature origin. Relatively large differences are seen between the samples from 31/2-2 and those from 31/4-2 and 31/4-3.

Aromatic Fractions

The mass chromatograms for m/z 141 (methylnaphtalenes), 178 (phenanthrene) 184 (dibenzothiophene), 192 (methyl phenanthrenes) and dimethyl phenanthrenes are provided. The most striking features of the traces are as follows:

a) The major component of the 184 fragmentograms for 31/4-2, 31/4-3 and the two samples from 31/2-2 is dibenzonthiophene. This component is present in the condensates but not to the same extent. The 184 fragmentogram of the two samples from 31/2-2, especially the one from 1537 m also show large unresolved envelopes which is not seen in the samples from 31/4-2 and 31/4-3.

b) Phenanthrene is the dominant component of all the m/z 178 traces.

c) The methyl phenanthrene isomer distributions (m/z 192) for 31/4-3, and the condensates are similar, only with a change in the relative ratios of peak A and B. For the condensates peak A is the largest while this is reversed in sample 31/4-3. This change is very accentuated in the samples from 31/4-2 and 31/2-2. The latter samples are very similar to each other.

d) As for the mono-methyl phenanthrene isomers the isomer distribution of dimethyl phenanthrenes (m/z 206) for 31/4-3 and the condensates are similar while the samples from 31/4-2 and 31/2-2 show markedly differences. The samples from 31/2-2 are also markedly different from the sample from 31/4-2.

CONCLUSION

Based on the GC-MS analyses both of the saturated and aromatic fractions, the condensates do now show any resemblance to any of the extracts of hotshale. The "hotshale" is markedly less mature than the condensate and if the "hotshale" was the source for the condensate then extensive alteration of the oil has taken place.

The "hotshale" in wells 31/4-2 and 31/4-3 are very similar while there are large discrepancies between the samples from 31/4-2 and the above mentioned samples. This would then indicate that there is no correlation between the "hotshale" in 31/2-2 and that in 31/4-2 and 31/4-3.

APPENDIX ONE

TABLES I-X

A B B R E V I A T I O N S

ab = above
abn = abundant
ang = angular

bd = bedded
Biot = Biotite
Biv = Bivalve
bl = blue
blk = black
brit = brittle
brn = brown

C = Coal
Calc = Calcite
calc = calcareous
carb = carbonaceous
Cgl = Conglomerate
Chk = Chalk
Chl = Chlorite
Cht = Chert
Cl = Clay
cl = clayey
Clst = Claystone
cmt = cement
conc = concretion
cont = contorted
conv = convolute
crs = coarse
crm = cream
cryst = crystalline

dk = dark
dns = dense
Dol = Dolomite
dol = dolomitic
downw = downwards

Ech = Echinoderm

f = fine
fib = fibrous
fis = fissile
Fld = Feldspar
frag = fragment
fri = friable
Foram = Foraminifera
Fos = Fossils

Gast = Gastropod
glac = glacial

Glc = Glauconite
glc = glauconitic
gn = green
Gran = Granules
Gr = Granite
grd = graded
grns = grains
Gvl = Gravels
gvl = gravelly
gy = grey
Gyp = Gypsum

h = horizontal
hd = hard
hom = homogeneous

ig = igneous
Ill = Illite
incr = increasing
intbd = interbedded
irreg = irregular

Kaol = Kaolinite

lam = laminated
Lig = Lignite
lig = lignitic
lith = lithic
lns = lens(es)
low = lower
Ls = Limestone
lt = light
m = medium
mass = massive
matr = matrix
met = metamorphic
mdst = mudstone
mic = micaceous
mid = middle
Mrl = Marl
mrl = marly
mtl = mottled
Musc = Muscovite

nod = nodular
obs = observed
occ = occasional(ly)

Ool = oölite
ool = oölitic

otherw = otherwise

pa = pale
Pbl = Pebbles
pk = pink
plast = plastic
predom = predominant
purp = purple
Pyr = Pyrite
pyr = pyritic

Qtz = Quartz
qtz = quartzitic

red = red(dish)
rk = rock
rnd = rounded

S = Sand
sd = sandy
sc = scattered
Sch = Schist
sft = soft
Sh = Shale
Sid = Siderit(e) (ic)
sks = slickenslide
Slt = Silt
slt = silty
Sltst = Siltstone
sm am = small amounts
sph = sphericity
spic = spicules
srt = sorted
Sst = Sandstone
strgs = stringers
Styl = Stylolite
suc = sucroseic
surf = surface

text = texture
Tf = Tuff
tf = tuffaceous
trsl = translucent
trsp = transparent

v = vertical
viol = violet
vn = vein (s)
vy = very

w = with

wh = white

yel = yellow

Example of quantitative expressions (for silt):
(slt) - slightly silty, slt - moderately silty, slt - very silty

TABLE Ia

LITHOLOGICAL DESCRIPTIONS OF WELL 31/2-1 (cuttings)

Depth (m)	
1393	50% Clst, dk gy, (calc) 40% Clst, gy, (calc) 10% Lst, wh w Fos Fragm
1396	33% - 33% - 33% as ab
1399	50% - 35% - 15% as ab
1405	30% - 30% - 40% as ab, some Pyr
1408	35% - 35% - 30% as ab
1411	40% - 40% - 20% as ab
1417	50% - 30% - 20% as ab
1423	30% - 60% - 10% as ab, some Pyr
1435	40% - 40% - 20% as ab
1441	80% crs, m S 20% Clst, gy-dk gy Some Pyr
1447	45% Clst, dk gy, calc 20% Clst, gy 25% crs S 10% wh/lt gy Lst
1450	As ab

TABLE Ib

LITHOLOGICAL DESCRIPTIONS OF WELL 31/2-2 (sidewalls)

Depth (m)	
1449,1	Clst, redbrn
1458,5	Clst, greenish, some redbrn, calc
1470,0	Clst, lt greenish gy, calc, some dk gy-gy (non-calc), some Pyr rods
1482,0	Clst, gy/dk gy, calc, carb, slt
1484,0	As ab, but (calc)
1485,5	Clst, gy, fis w C Fragm , slt
1486-1540,92	As ab with some variation in silt and calcite content
1543,5	Sst, vy f-m, ang-subang, calc
1552	As ab, but (calc)

TABLE Ic

LITHOLOGICAL DESCRIPTIONS OF WELL 31/4-3 (cuttings)

Depth (m)	
1975-90	80% Lst, wh 20% Clst, gy, slt
1990-2005	70% Lst, wh 30% Clst, gygn, calc Sm am Pyr and blk fis Clst
2005-2020	As above

Depth (m)

2020-2035	65% Clst, gygn, slt 30% Lst, wh 5% Clst, blk, fis Sm am S, Pyr
2035-2050	60% Clst, gy(gn), slt, calc 20% Lst, wh 20% Sst, f-m, subang, quartz Sm am blk fis Clst and Pyr
2050-2065	50% Clst, gy(gn), slt, calc 40% Sst, m, subang 10% Lst, wh Sm am C Fragm.

TABLE Id

LITHOLOGICAL DESCRIPTIONS OF WELL 31/4-2 (cuttings and sidewalls)

Depth (m)

2130	80% Clst, gy, some brn, gn 20% Lst, wh
2140	90% Clst as ab 10% Lst, wh
2148 swc	Clst, (gn) lt gy/wh, scattered S grns, calc
2150	95% Clst, gy, gngy-lt gn, redbrn/brn, some dk gy (thin calc lam obs), some calc 5% Lst, wh
2155 swc	Clst, gy
2160	100% Clst, gy (obs lam), (brn) dk gy-blk (carb, vy fis, pyr), lt gngy-gn, redbrn (sd)/brn, some calc (especially lt gngy)

Depth (m)

2169 swc	Clst, gy
2170	100% Clst as ab

TABLE II

WEIGHT OF EOM AND CHROMATOGRAPHIC FRACTIONS

Well	IKU No.	Depth (m)	Rock Extr. (s)	EOM (ms)	Sat. (ms)	Aro. (ms)	HC (ms)	Non HC (ms)	TOC (%)
31/4-2			50.1	138.4	20.0	49.5	69.5	68.9	6.2
31/4-3		2011-18	33.0	123.4	11.5	50.3	61.8	61.6	5.7
31/2-2	K-2875	1516	41.3	13.3	2.0	.8	2.8	10.5	2.6
31/2-2	K-2876	1537	50.0	17.4	2.4	.5	2.9	14.5	2.6

T A B L E III

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS
(Weight ppm of rock)

Well	IKU No.	Depth (m)	EOM	Sat.	Aro.	HC	Non HC
31/4-2			2762	399	988	1387	1375
31/4-3		2011-18	3739	348	1524	1873	1867
31/2-2	K-2875	1516	322	48	19	68	254
31/2-2	K-2876	1537	348	48	10	58	290

TABLE IV

CONCENTRATION OF EOM AND CHROMATOGRAPHIC FRACTIONS
(ms/s TOC)

Well	IKU No.	Depth (m)	EOM	Sat.	Aro.	HC	Non HC
31/4-2			44.3	6.4	15.9	22.3	22.1
31/4-3		2011-18	65.5	6.1	26.7	32.8	32.7
31/2-2	K-2875	1516	12.3	1.9	.7	2.6	9.7
31/2-2	K-2876	1537	13.3	1.8	.4	2.2	11.1

T A B L E V

COMPOSITION IN % OF THE MATERIAL EXTRACTED FROM THE ROCK

Well	IKU No.	Depth (m)	Sat. EOM	Aro. EOM	HC EOM	Sat. Aro	Non HC EOM	HC Non HC
31/4-2			14.5	35.8	50.2	40.4	49.8	100.9
31/4-3		2011-18	9.3	40.8	50.1	22.9	49.9	100.3
31/2-2	K-2875	1516	15.0	6.0	21.1	250.0	78.9	26.7
31/2-2	K-2876	1537	13.8	2.9	16.7	480.0	83.3	20.0

TABLE VI

TABULATION OF DATAS FROM THE GAS CHROMATOGRAMS

IKU No.	Well	Depth (m)	Pristane/ nC_{17}	Pristane/ Phytane	CPI
K-1800			0.88	2.00	1.0
K-1804			0.88	2.00	1.0
	31/4-2		1.52	1.32	0.8
	31/4-3	2011-18	1.48	1.29	0.8
K-2875	31/2-2	1516	2.37	1.00	2.8
K-2876	31/2-2	1537	1.47	1.87	3.0

IKU

TABLE NO.: VII

VITRINITE REFLECTANCE MEASUREMENTS

Well No.	IKU No.	Depth	Vitrinite reflectance	Fluorescence in UV light	Exinite content
31/4-2		2158-78	0,36 (18)	Yellow/orange	Moderate-rich
31/4-3		2010-40	0,33 (22)	Yellow/orange	Moderate-rich
31/2-2	K2875	1516	0,49 (4)	Yellow/orange and light orange	Moderate-rich
31/2-2	K2876	1537	0,33(7), 0,56(1)	Yellow to light orange	Moderate

IKU

TABLE NO.: VIII

VISUAL KEROGEN ANALYSIS

(Trondheim 1980)

Sample	Depth	Composition of residue	Particle size	Preservation - palynomorphs	Thermal maturation index	Remarks
31/4-2	2158-78	Am,Cysts/He,Cut,Pollen	F	fair to poor	1/1+ 1+/2- 2-/2	Dense aggregates, pyrite and variable sapropelization result in differential preservation and rather variable colouring.
31/4-3	2010-40	Am,Cysts/He,Cut,Pollen	F	fair to poor	1/1+ 2-/2 2	
	2015 swc	Am,Cysts/He,Cut,Pollen	F	fair to poor	1/1+ 2	
31/2-1	1402	Am,Cysts/He,W,WR!	F	fair to good	1/1+ 2-/2	
	1414	Am,Cysts,Cut,W,WR!,Pollen	F	fair to poor	1+/2-	1414m to 1438m : aggregates of sapropel/sapropelized material The relative amount of cuticular material increase below 1420m. Distinction is difficult due to preservation. Pyrite is present in most samples.
	1420	Am,Cysts/He,Cut,W,WR!,Pollen	F	fair to good	1+/2	
	1426	Am,He,Cut,W'Pollen,WR!	F-M-L	fair to poor	1+	
	1432	Am/Cut,He,W,Pollen	F-M-L	fair to poor	1+/2	
	1438	Am/Cut,He,W,Pollen	F-M-L	fair to poor	1/1+ 1+/2-	
	1444	He,W,WR!/Am	F-M-L	fair to poor	1+/2-	
30/2-2	1515.2 c	Am/He,W,Pollen	F-M	fair to poor	1/1+	
	1535.0 c	Am/He,W,Pollen	F-M	fair to poor	1/1+	

ABBREVATIONS

Am	amorphous	Cy	cysts, algae	W	woody material	F	fine
He	herbaceous	P	pollen grains	C	coal	M	medium
Cut	cuticles	S	spores	R!	reworked	L	large

Colourindex variable for the individual saples, due to the differential preservation.

TABLE IX

Well	IKU No.	Depth (m)	S_1	S_2	S_3	C_{org}	Hydrogen Index	Oxygen Index	Oil of gas content (S_1+S_2)	Prod. Index	T_{max}
31/4-2			0.98	22.13	6.97	6.23	355.22	111.88	23.11	0.04	424^o
31/4-3		2011-18	1.55	25.14	3.95	5.71	440.28	69.18	26.69	0.06	420^o
31/2-2	K-2875	1516	0.16	5.64	1.56	2.61	216.09	59.77	5.80	0.03	426^o
31/2-2	K-2876	1532	0.63	7.01	2.05	2.61	268.58	78.54	7.64	0.08	433^o

T A B L E X

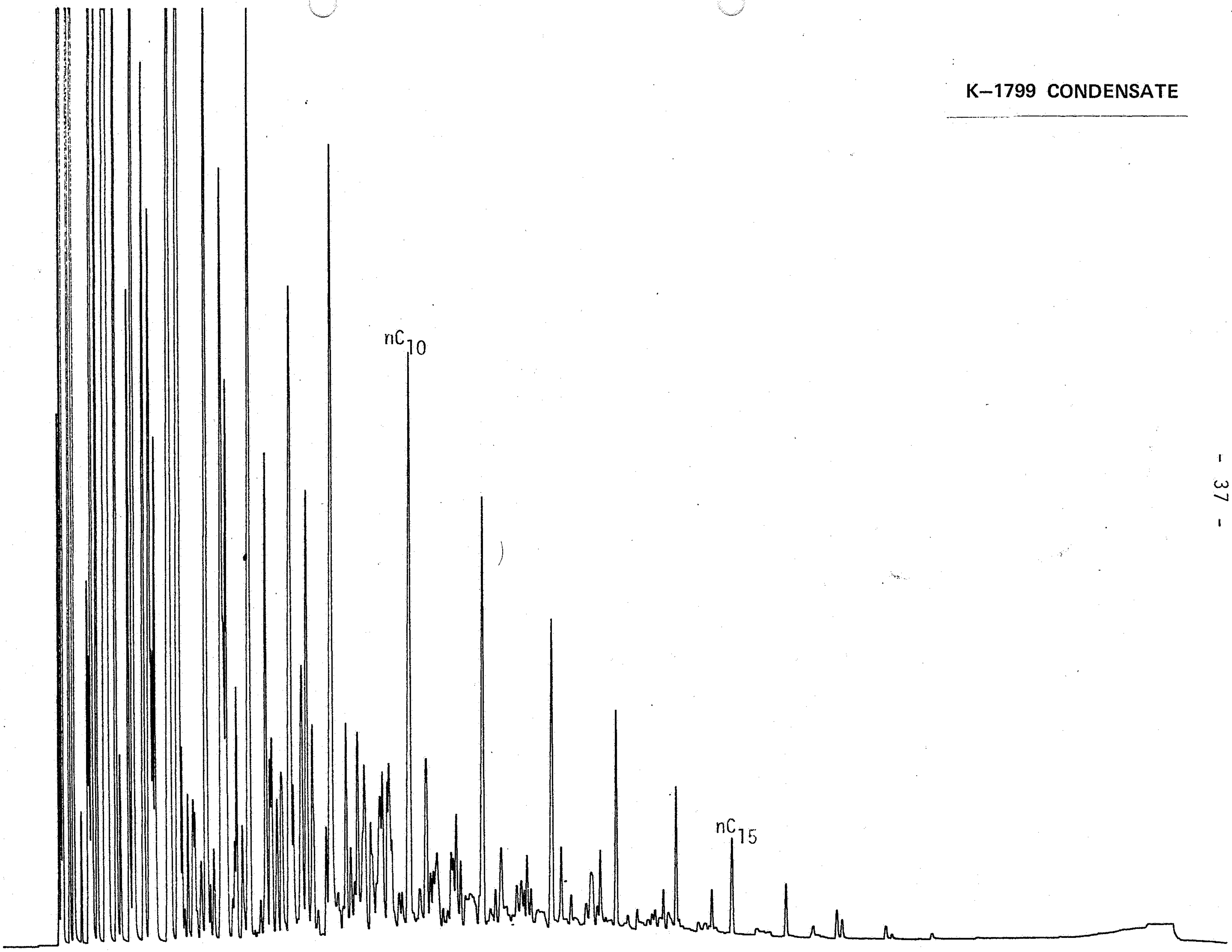
RATIOS OF PEAKS IN STERANE PROFILE RELATIVE TO 24-ETHYLCHOLESTANE

		Peak number m/c 217										
IKU No.	Sample	1	2	3	4	5	6	7	8	9	10	11
K-1800		3.22	1.90	0.41	2.4	0.66	0.70	0.93	1.48	1.0	0.48	0.33
	31/4-2	0.71	0.42	0.35	0.26	0.79	0.32	0.94	0.29	1.0	0.23	0.68
	31/4-3	0.33	0.28	0.49	0.22	1.20	0.27	1.11	0.31	1.0	0.75	0.56
K-2875	31/2-2											
	1516 m	0.37	0.24	0.47	0.12	1.20	0.43	0.81	0.47	1.0	0.08	0.33
K-2876	31/2-2											
	1537 m	0.23	0.18	0.48	0.12	1.25	0.38	0.77	0.45	1.0	0.09	0.43

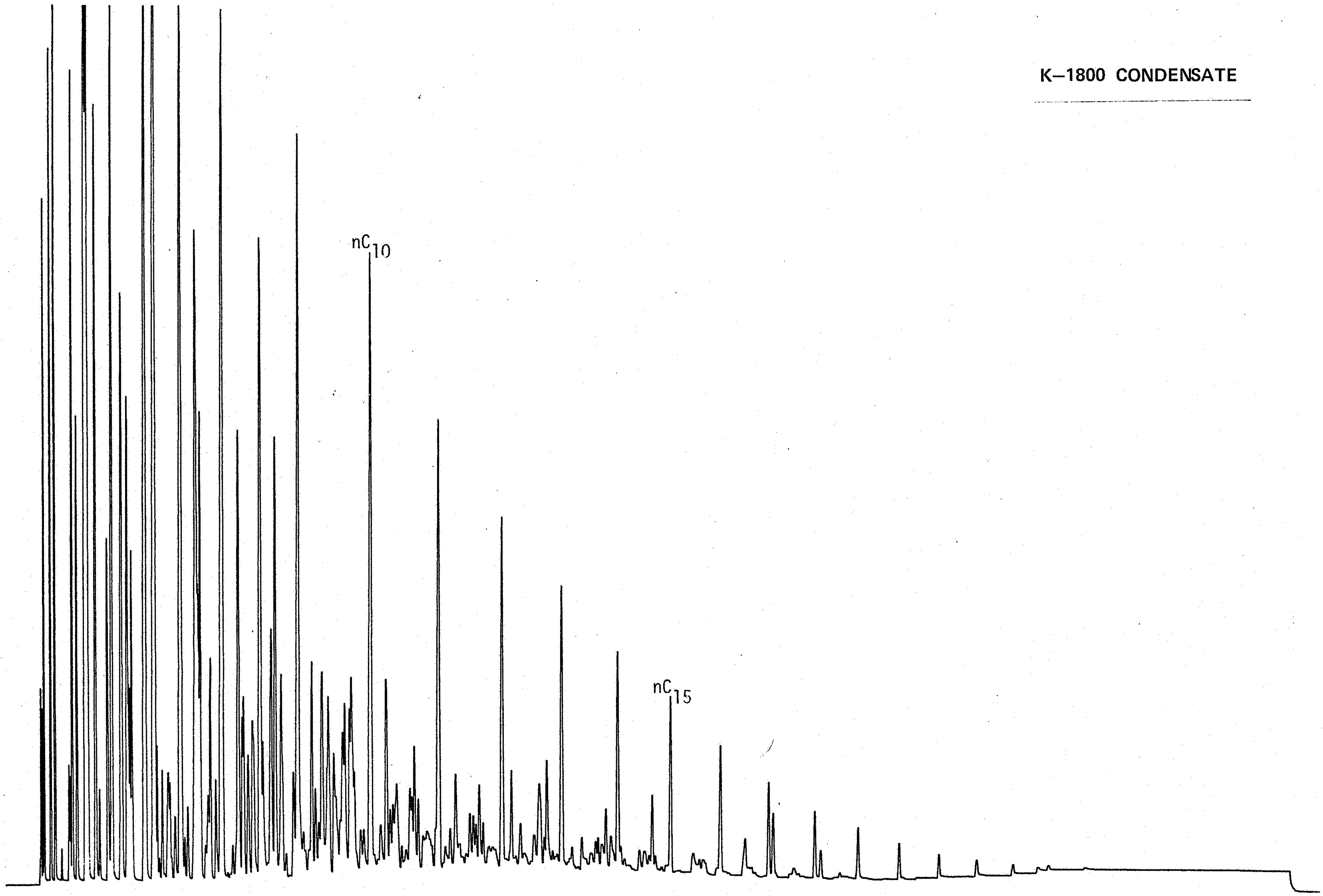
APPENDIX TWO

FIGURES

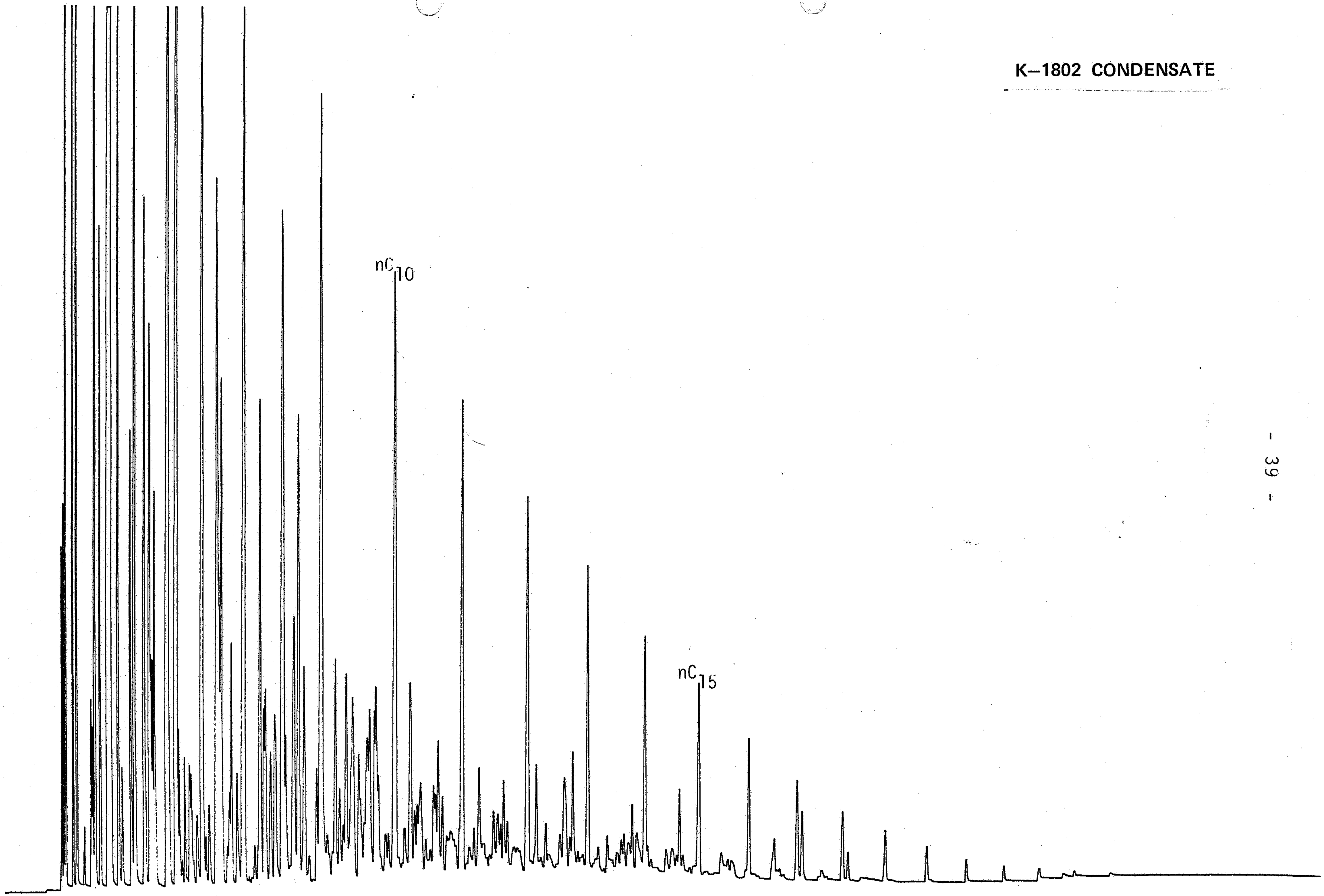
K–1799 CONDENSATE

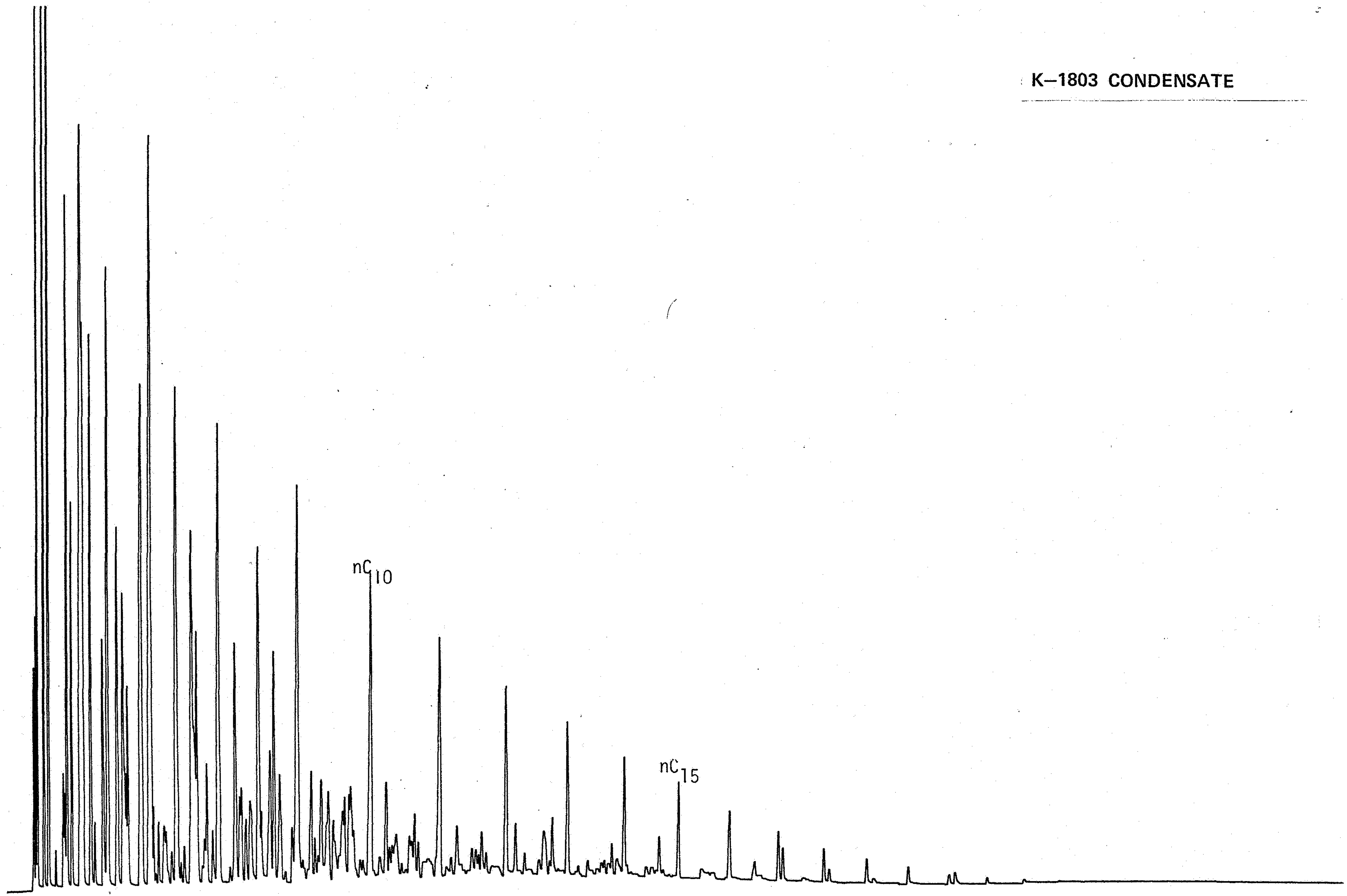


K–1800 CONDENSATE

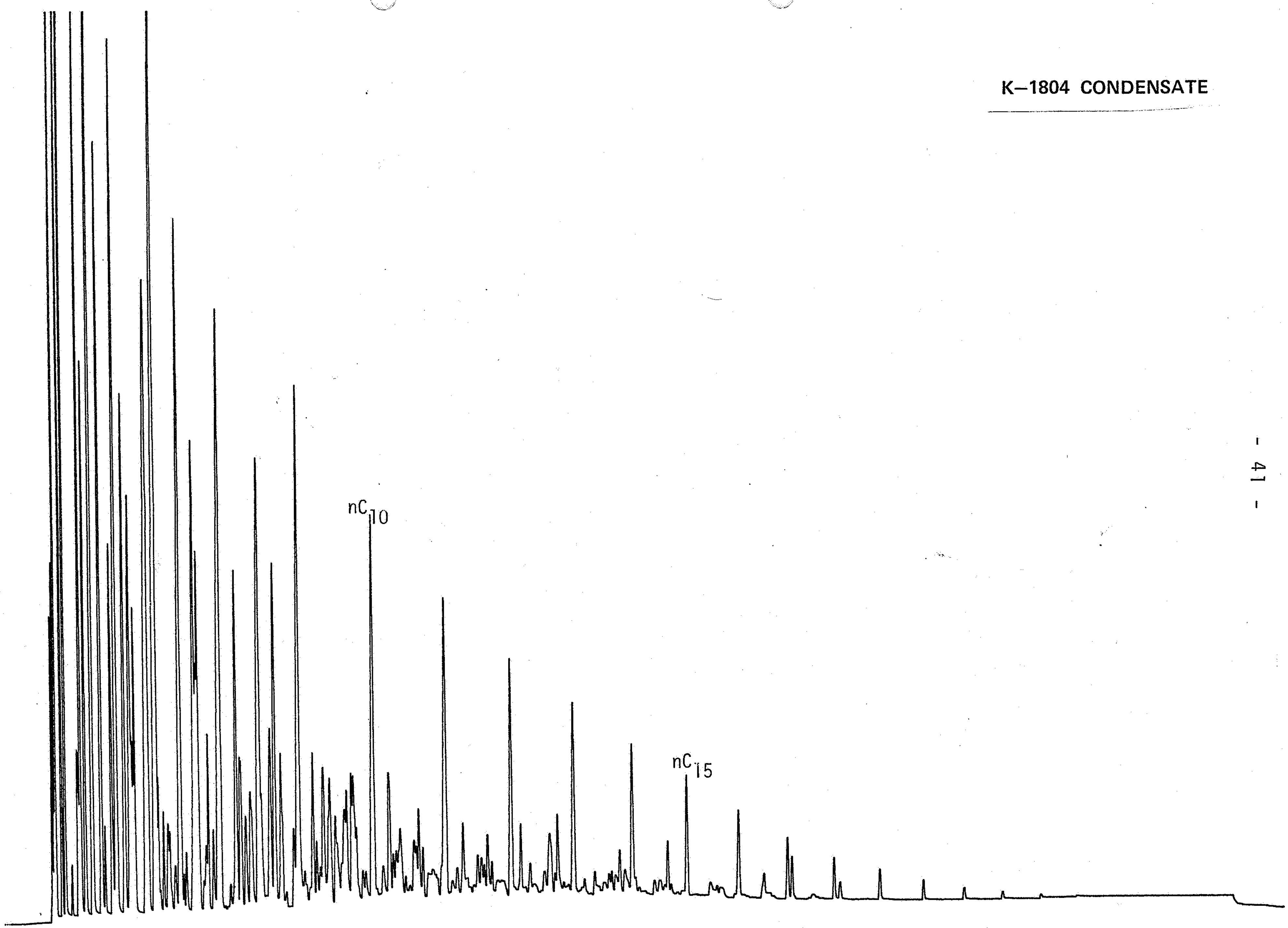


K–1802 CONDENSATE

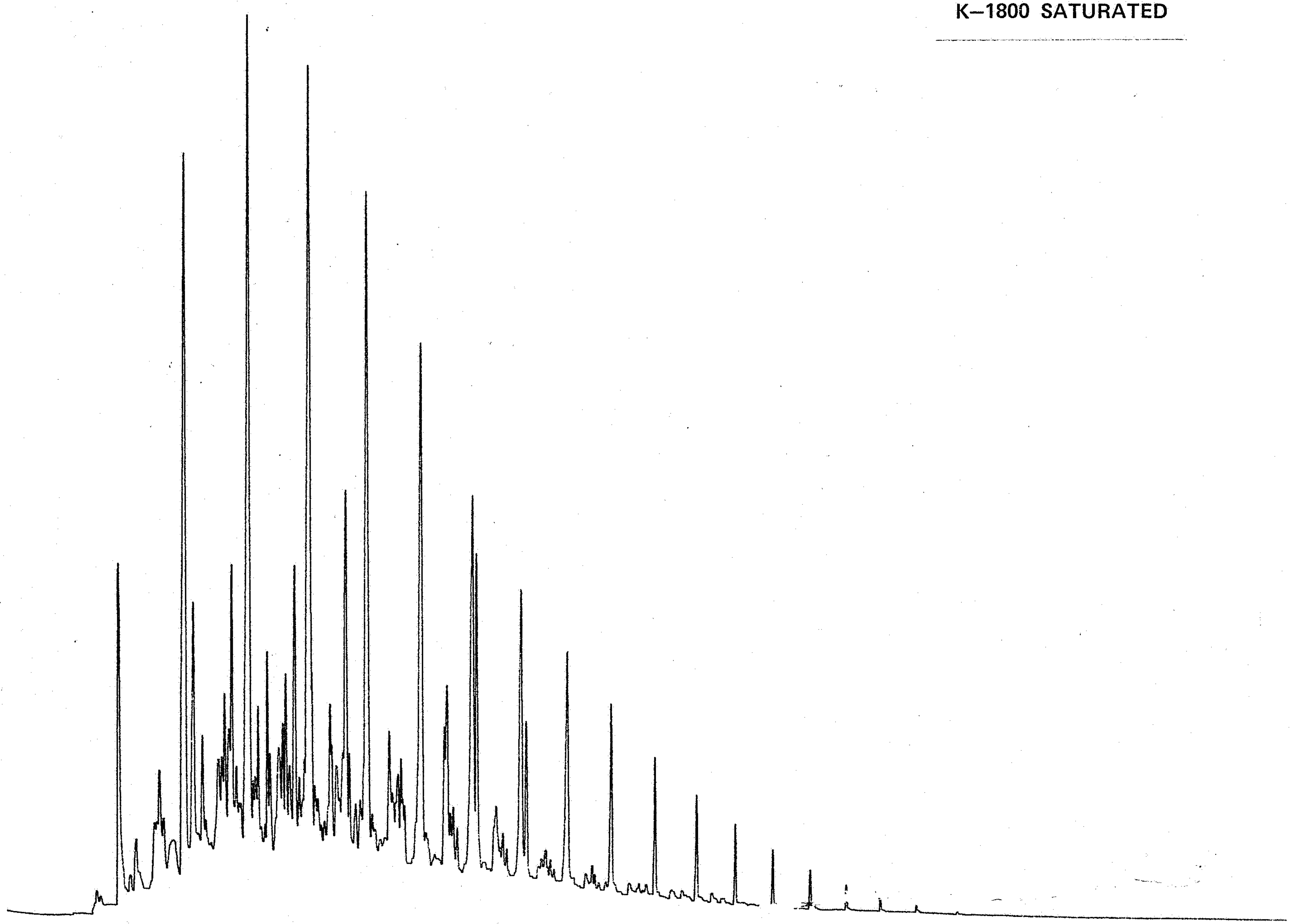



K–1803 CONDENSATE
nC_{10}
nC_{15}

K–1804 CONDENSATE



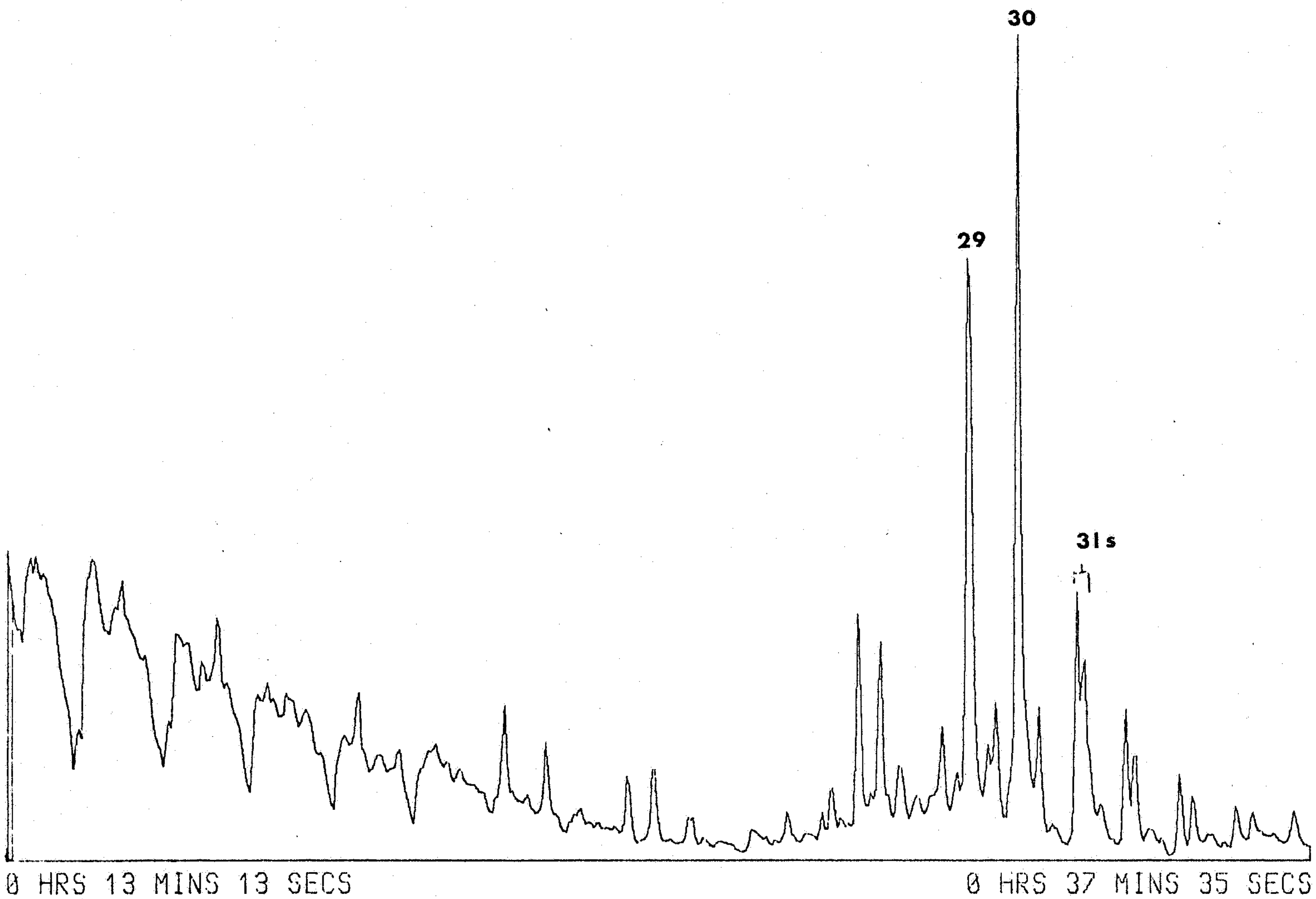
K–1800 SATURATED



I 0.0000] .2L RUN - 1 K1800
A181S ▥191S C197S D217S E253S
RETN TIME HEIGHT AREA UNCALIBRATED
0:13:13 30.37 239.57

CONDENSATE

M/Z = 191

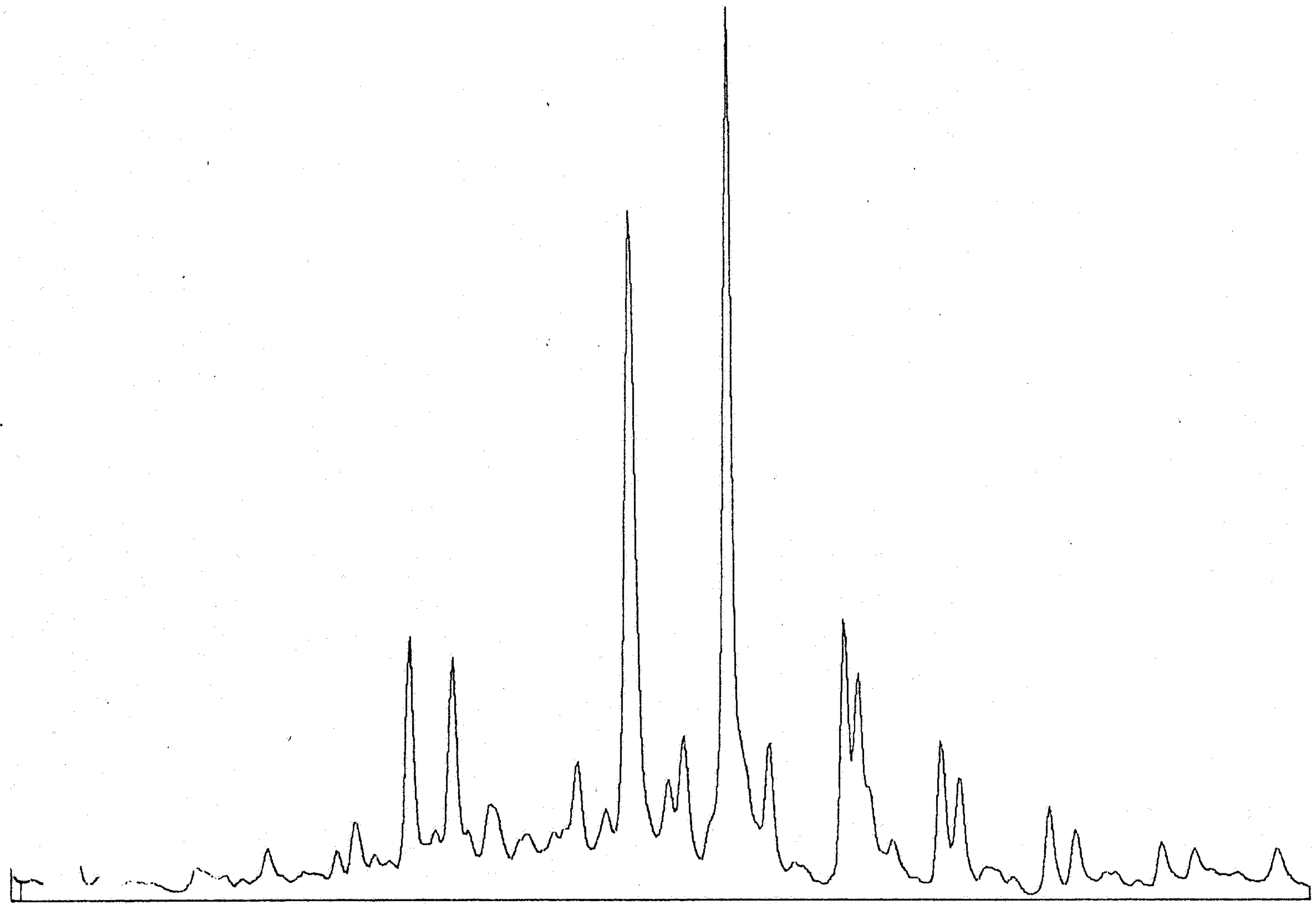


[0.0000] .2L RUN - 1 K1800
A181S ▩191S C197S D217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:25:24	28.69	194 15	

CONDENSATE

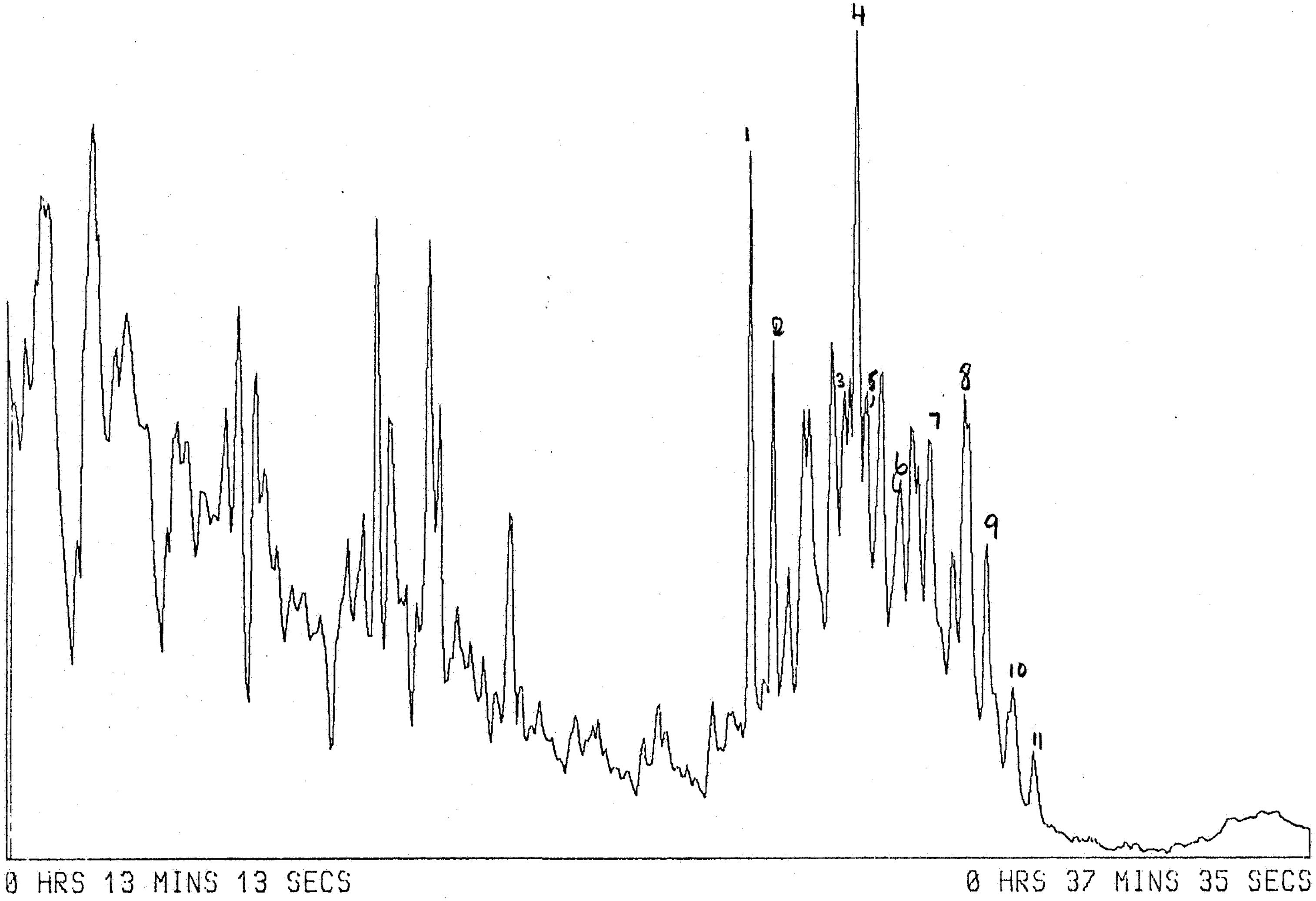
M/Z = 191



[0.0000] .2L RUN - 1 K1800
A181S B191S C197S ■217S E253S
RETN TIME HEIGHT AREA UNCALIBRATED.
0:13:13 30.37 239.57

CONDENSATE

M/Z = 217

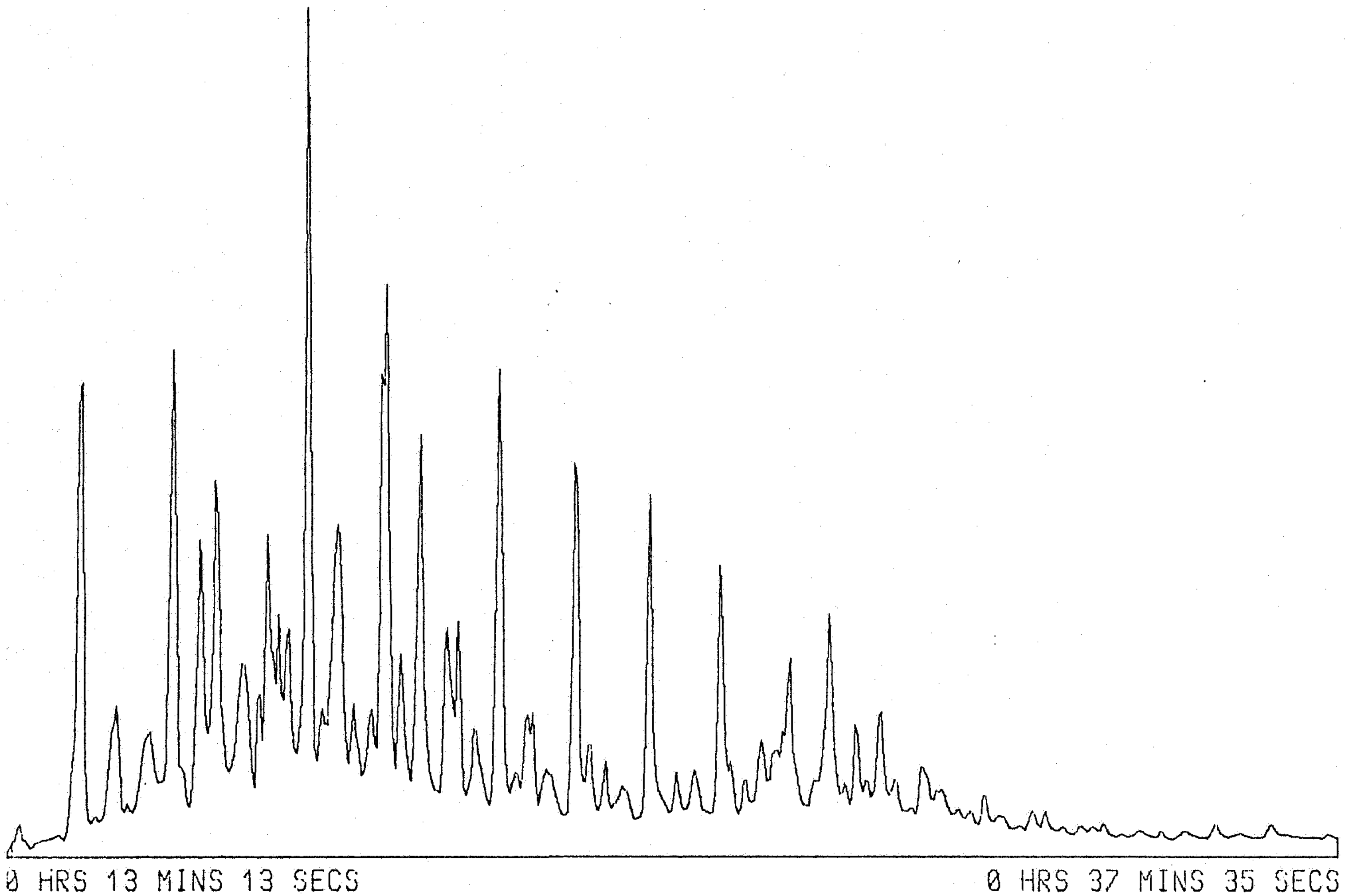


[0.0000] .2L RUN - 1 K1800
A181S B191S C197S D217S E253S

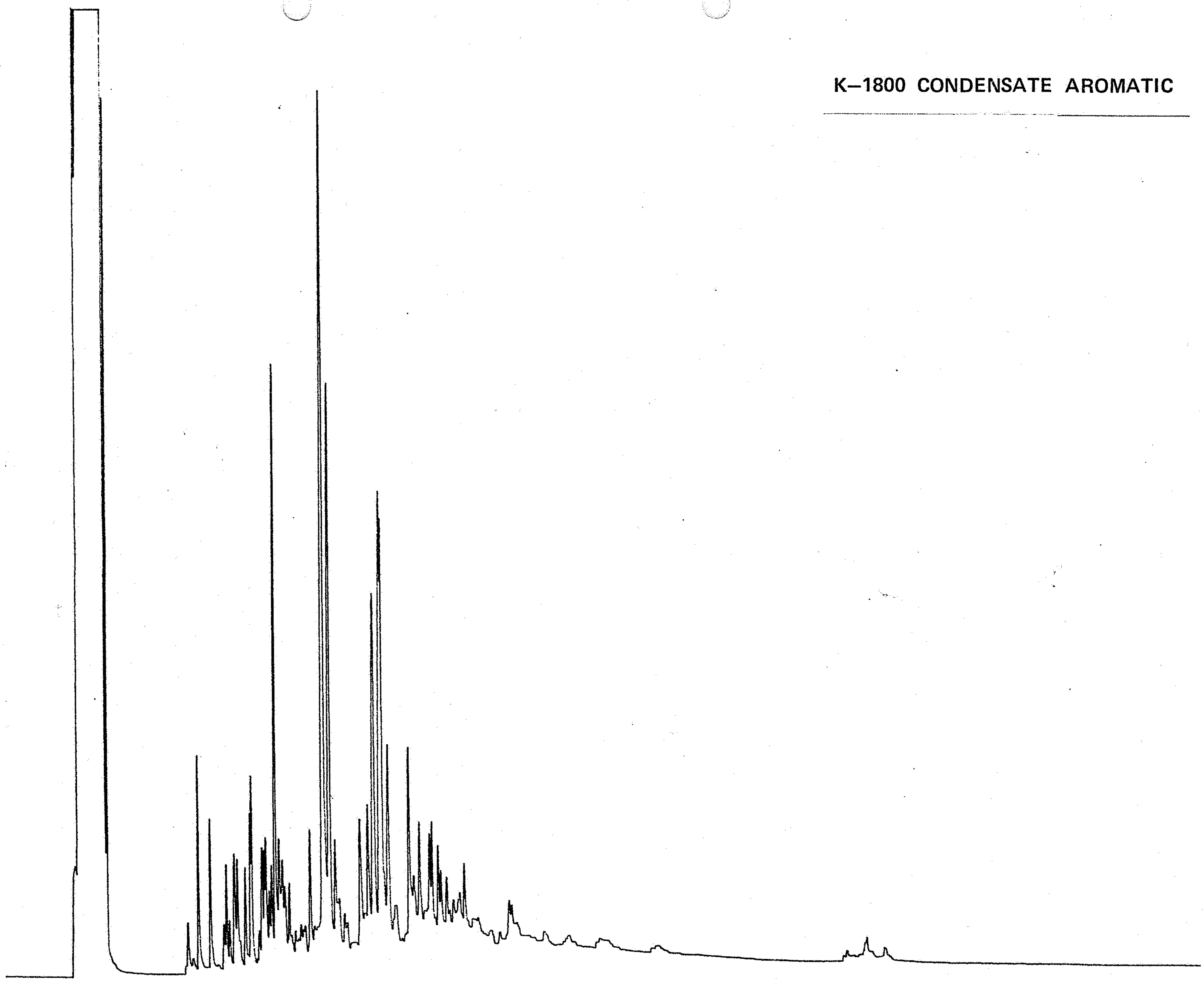
RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:13:13	30.37	239.57	

CONDENSATE

M/Z = 253



K–1800 CONDENSATE AROMATIC

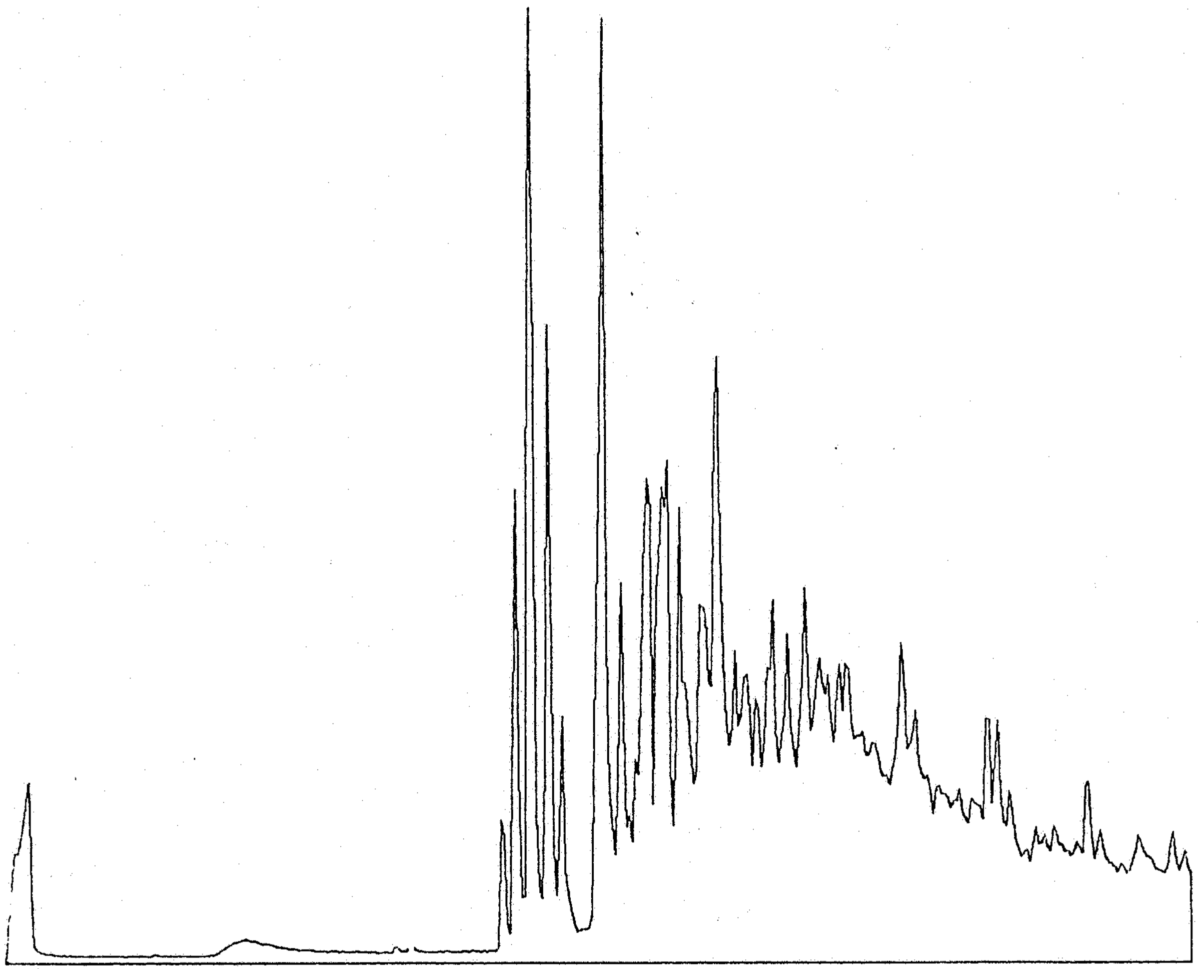


[0.0000] .2L RUN - 1 K1800 AROMATICS
A131S B141S C178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.19	8.23	

CONDENSATE

M/Z = 141



0 HRS 0 MINS 2 SECS

0 HRS 29 MINS 53 SECS

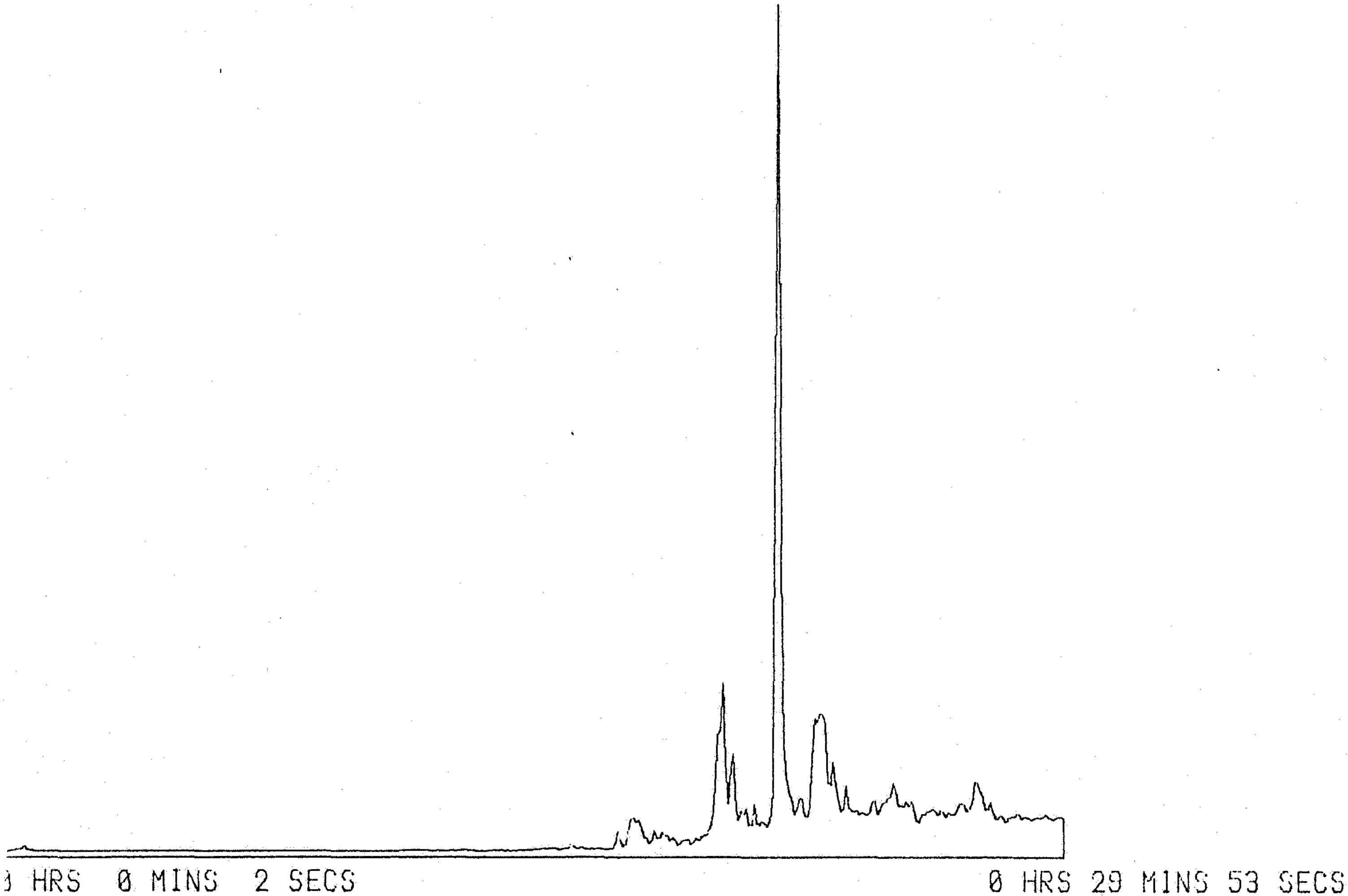
[0.0000] .2L RUN - 1 K1800 AROMATICS

A131S B141S ■178S D184S E192S F206S

CONDENSATE

M/Z = 178

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.19	8.23	

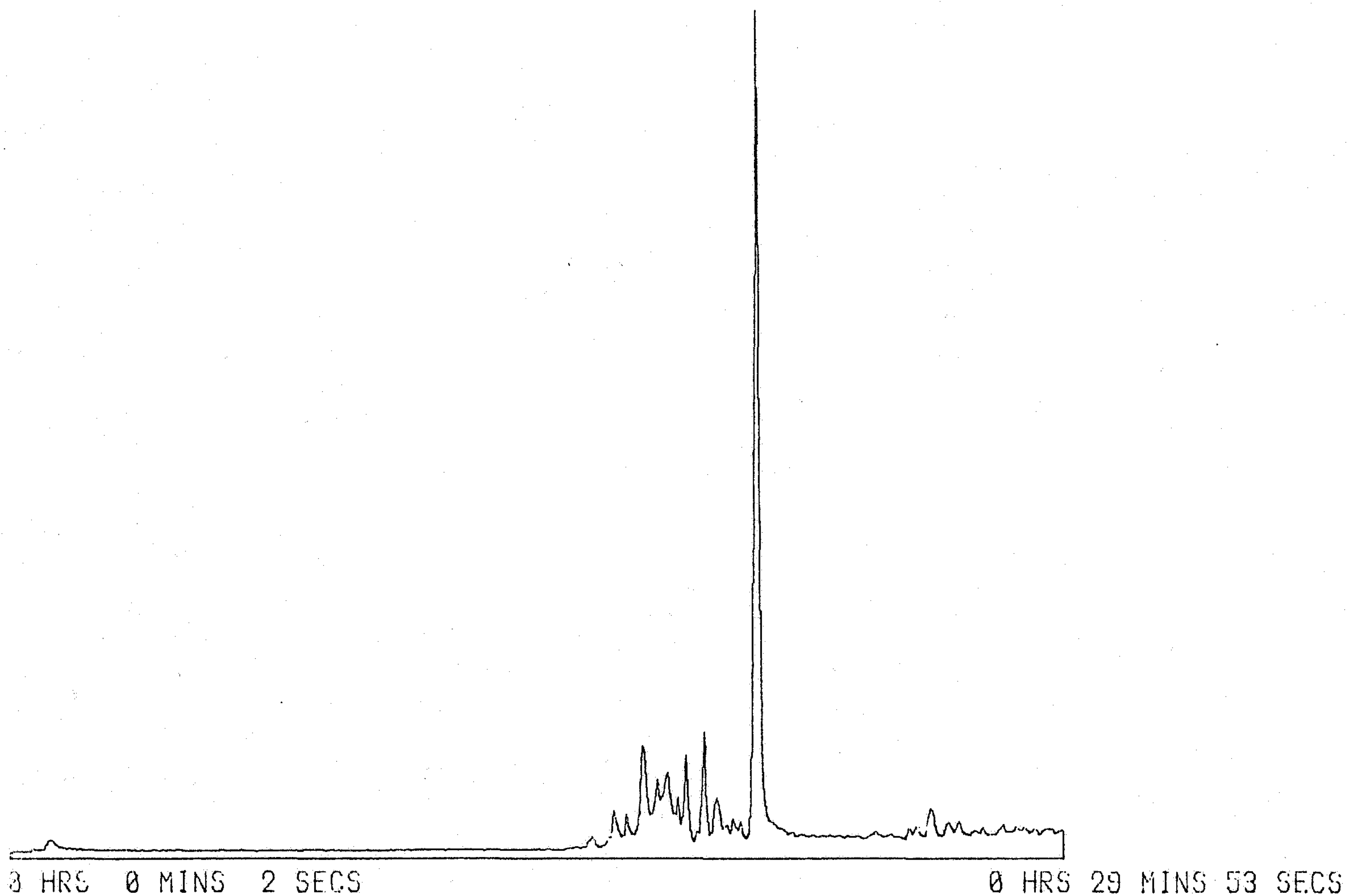


[0.0000] .2L RUN - 1 K1800 AROMATICS
A131S B141S C178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.19	8.23	

CONDENSATE

M/Z = 184



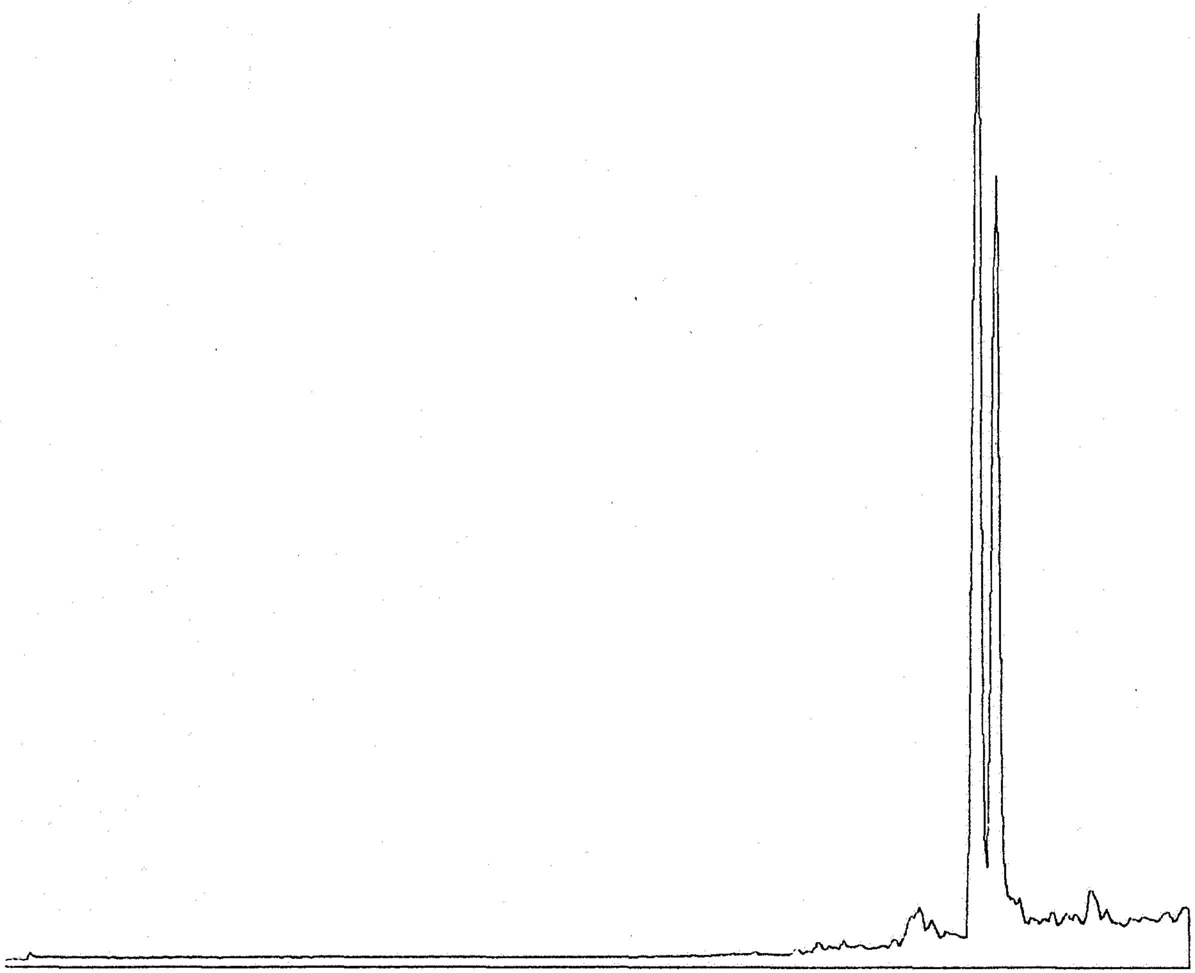
[0.0000] .2L RUN - 1 K1800 AROMATICS

A131S B141S C178S D184S ■192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.19	8.23	

CONDENSATE

M/Z = 192



0 HRS 0 MINS 2 SECS

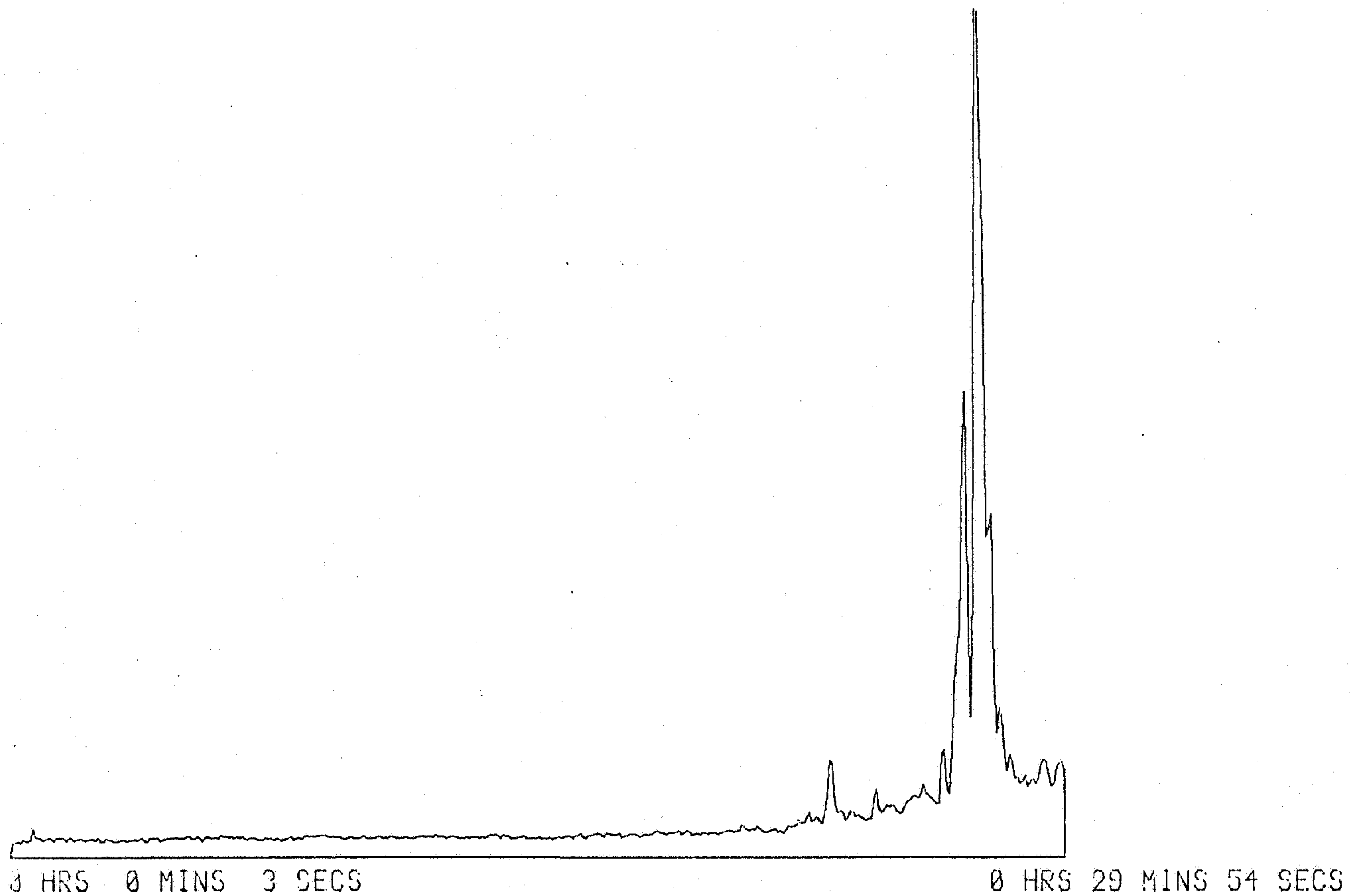
0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 K1800 AROMATICS
A131S B141S C178S D184S E192S ■206S

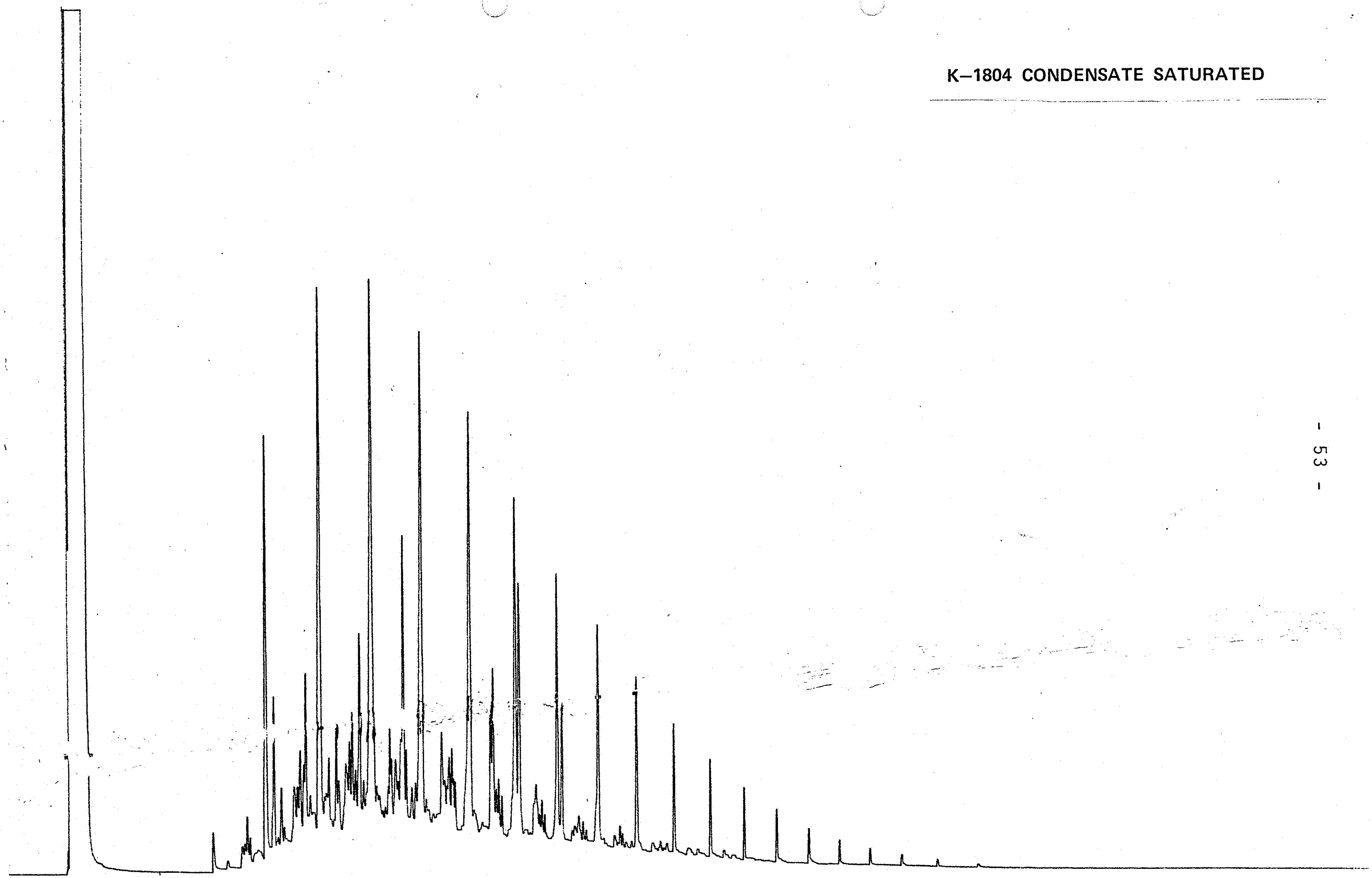
RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:05	1.19	8.23	

CONDENSATE

M/Z = 206



K–1804 CONDENSATE SATURATED

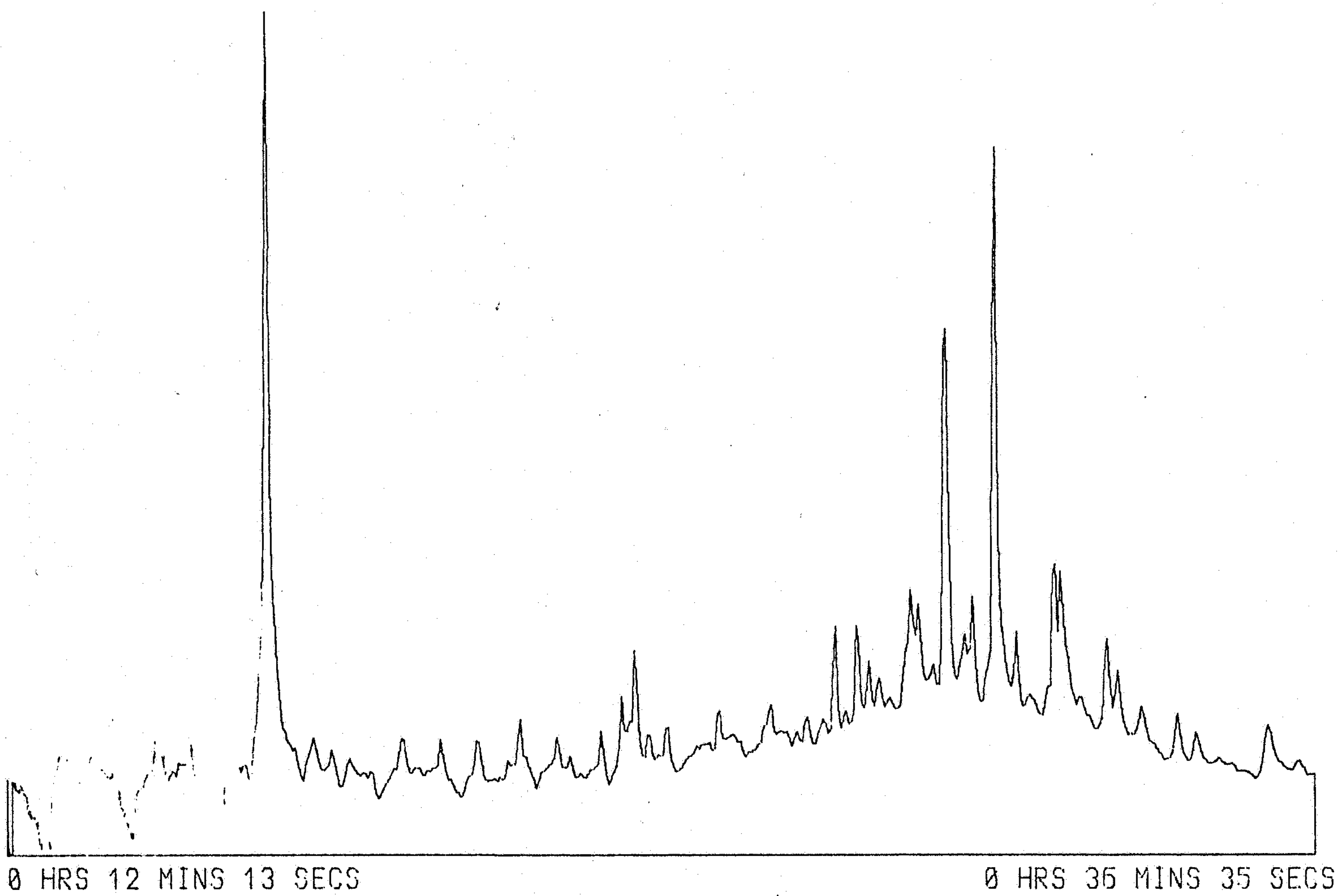


[0.0000] .2L RUN - 1
A181S ■191S C199S D217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:12:15	5.88	50.02	

K–1804 CONDENSATE

M/Z = 191

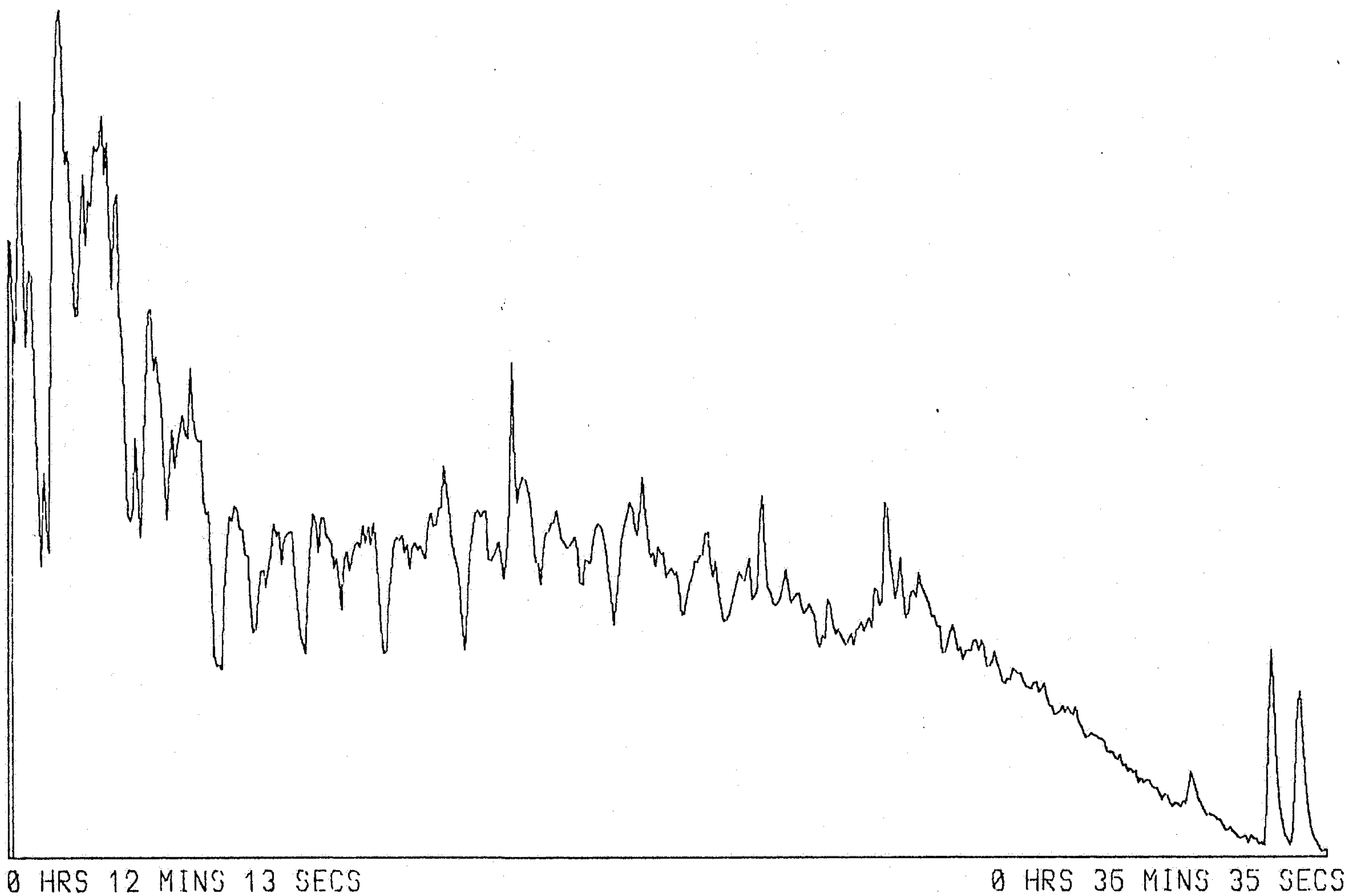


[0.0000] .2L RUN - 1
A181S B191S ▮199S D217S E253S

RETN TIME	HEIGHT	AREA	UNCALIBRATED
0 12:16	5.88	50.02	

K–1804 CONDENSATE

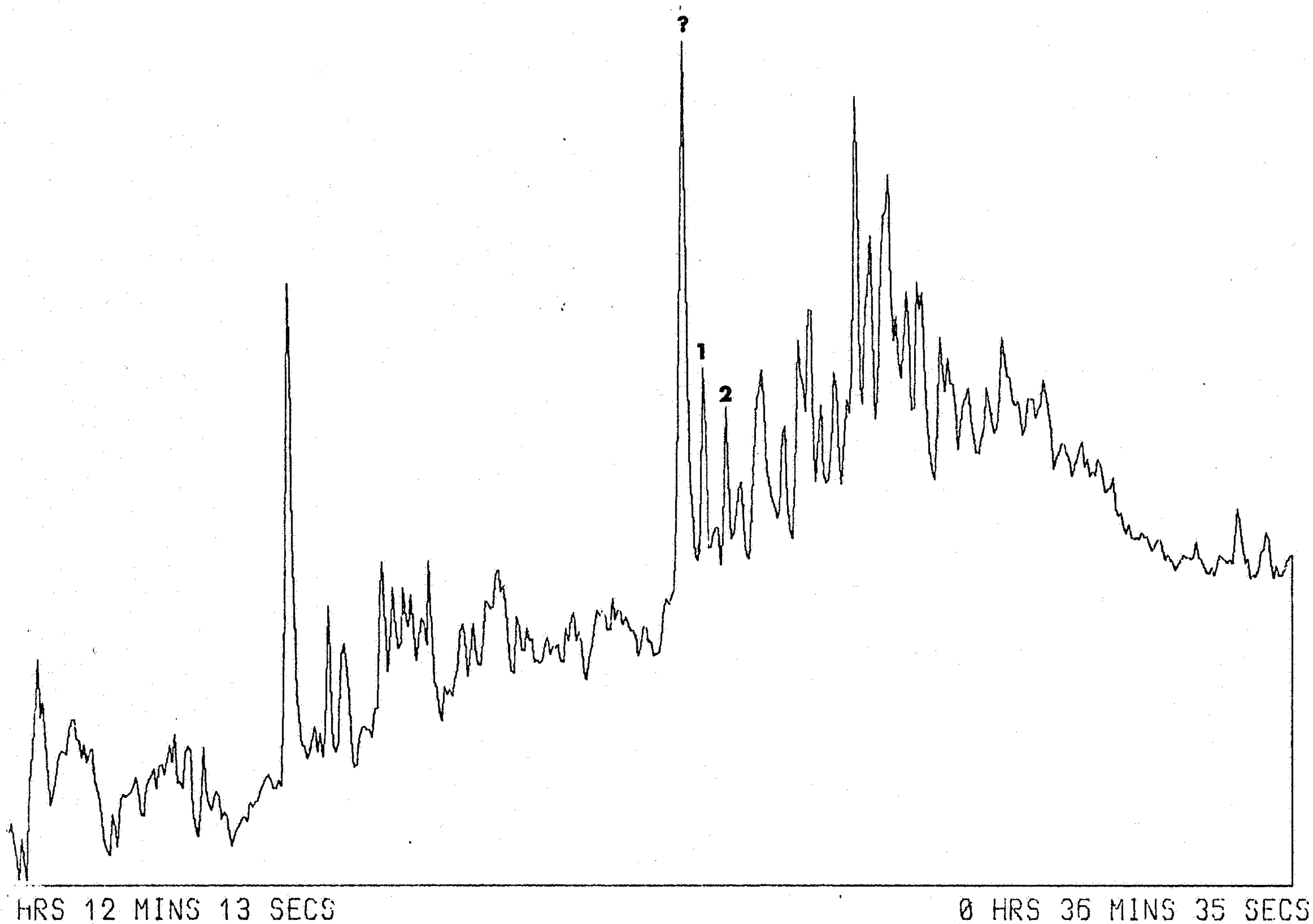
M/Z = 199



[0.0000] .2L RUN - 1
A181S B191S C199S ▮217S E253S
ETN.TIME HEIGHT AREA UNCALIBRATED
0:12:16 5.88 50.02

K–1804 CONDENSATE

M/Z = 217

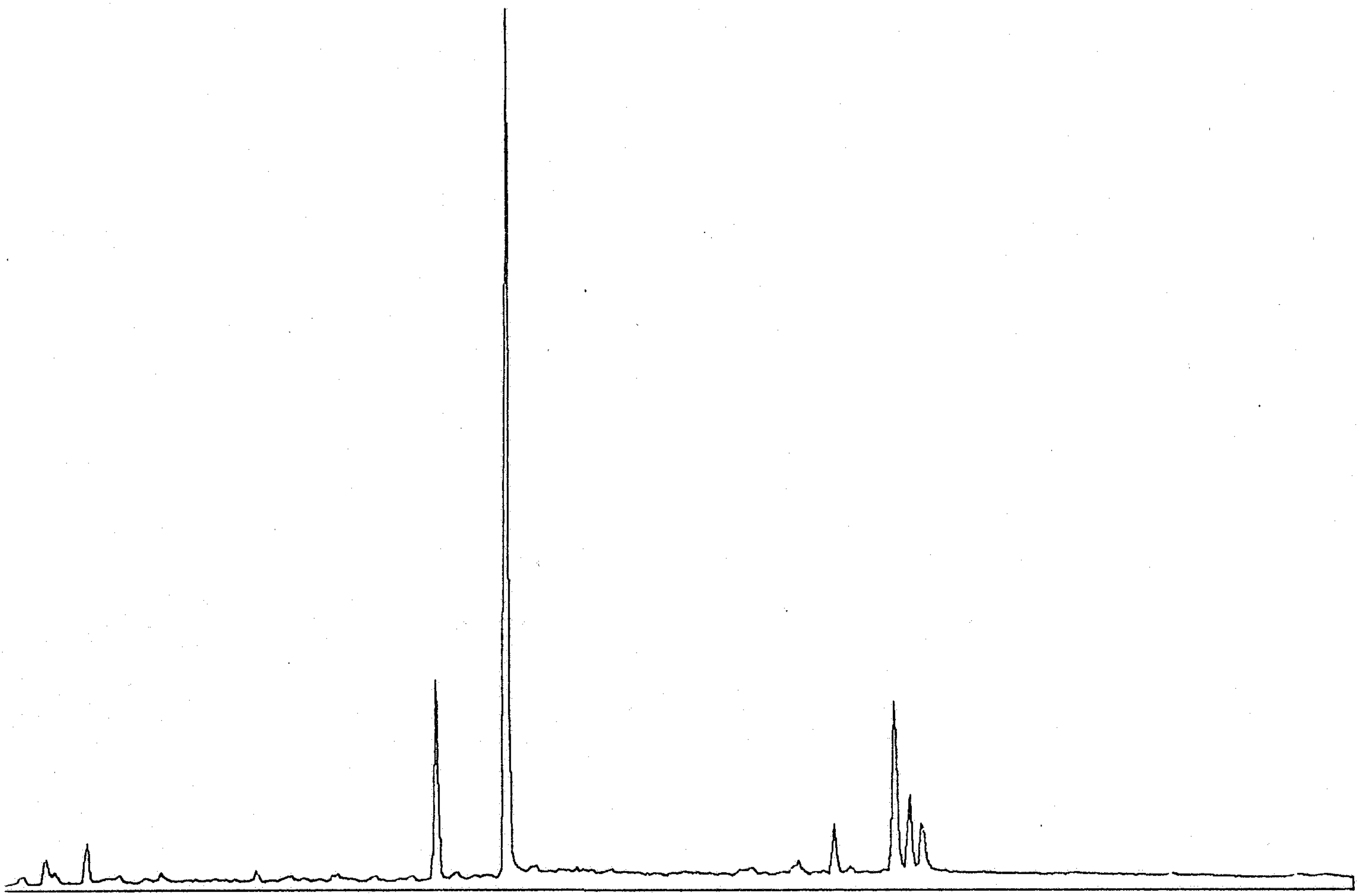


[0.0000] .2L RUN - 1
A181S B191S C199S D217S ▒253S

K-1804 CONDENSATE

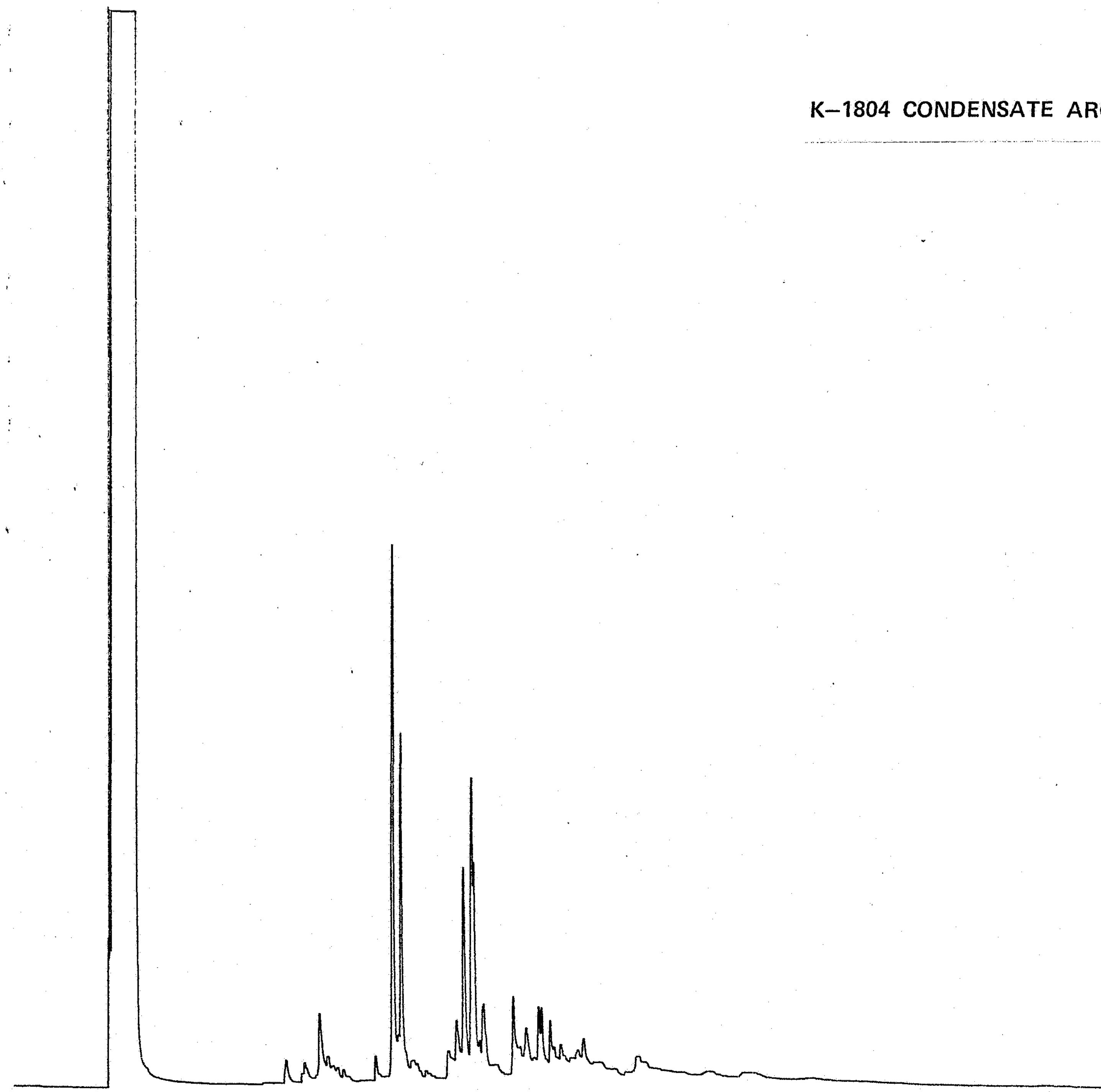
M/Z = 253

ETN.TIME	HEIGHT	AREA	UNCALIBRATED
0 12:16	5.88	50.02	



HRS 12 MINS 13 SECS 0 HRS 36 MINS 35 SECS

K–1804 CONDENSATE AROMATIC

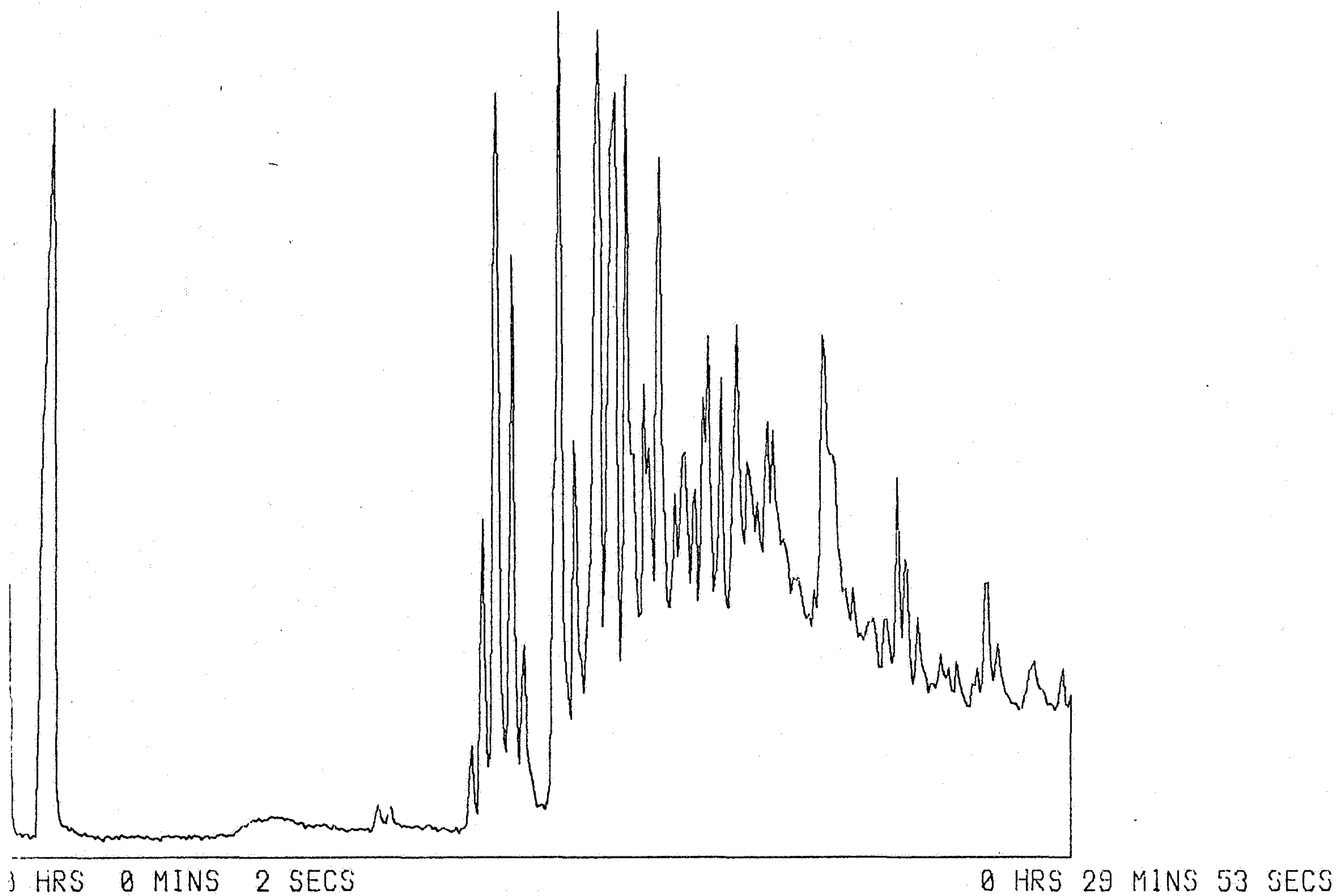


[0.0000] .2L RUN - 1 K1804 AROMATIC
A131S ▮141S C178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00 06	1.23	8.47	

CONDENSATE

M/Z = 141

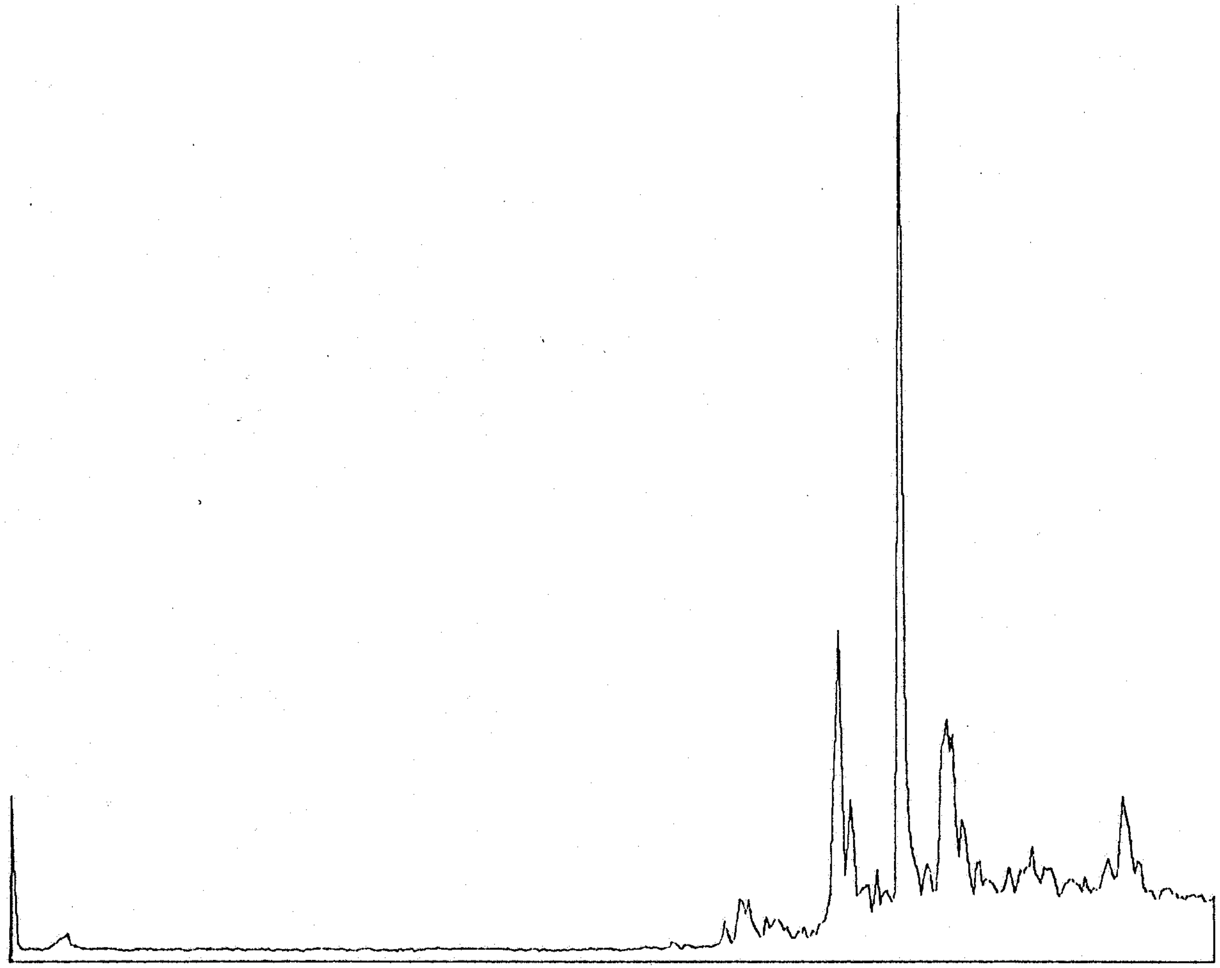


[0.0000] .2L RUN - 1 K1804 AROMATIC
A131S B141S ■178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:05	1.23	8.47	

CONDENSATE

M/Z = 178



0 HRS 0 MINS 2 SECS

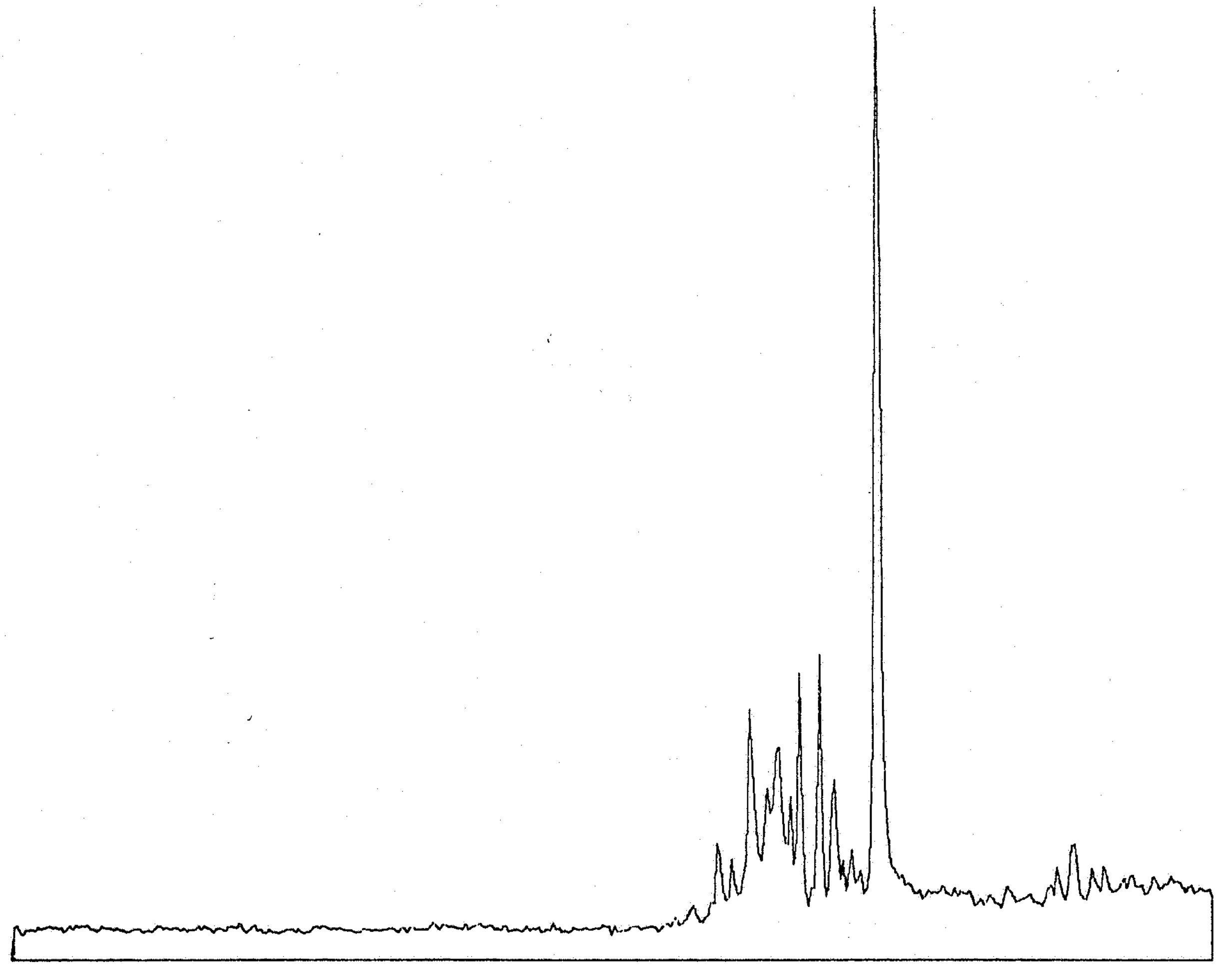
0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 K1804 AROMATIC
A131S B141S C178S ■184S E192S F206S

CONDENSATE

M/Z = 184

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.23	8.47	



0 HRS 0 MINS 2 SECS 0 HRS 29 MINS 53 SECS

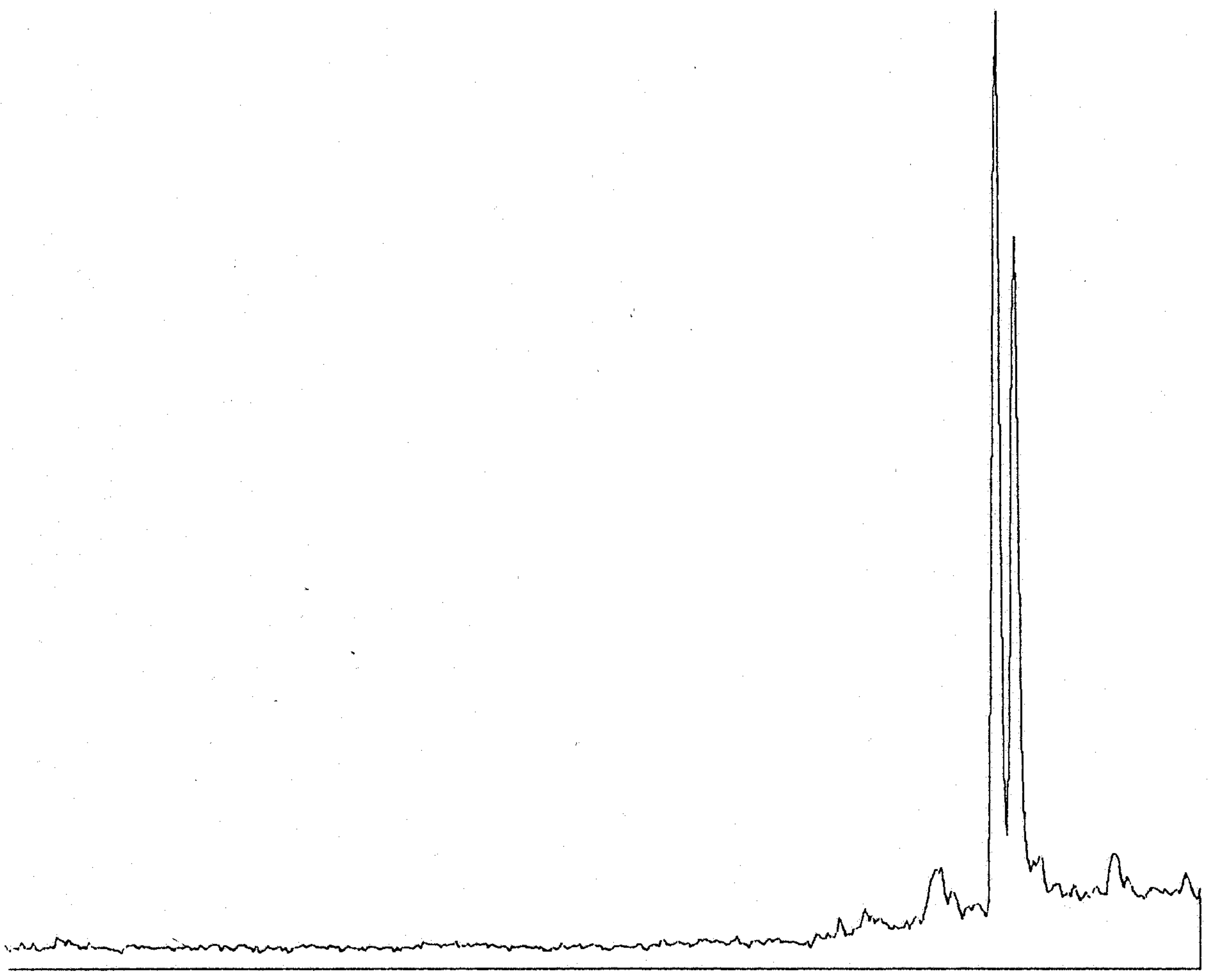
[0.0000] .2L RUN - 1 K1804 AROMATIC

CONDENSATE

M/Z = 192

A131S B141S C178S D184S ▥192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.23	8.47	

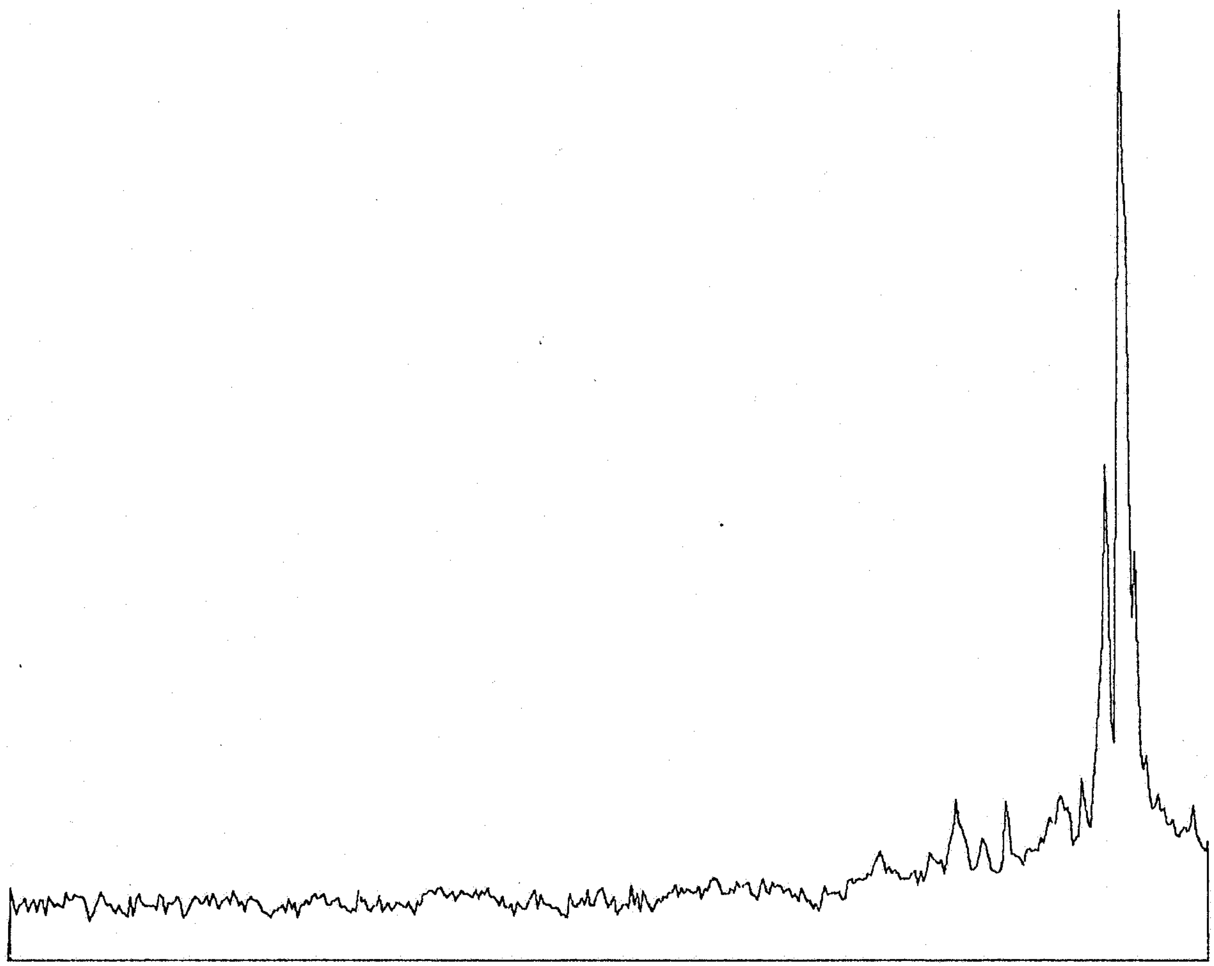


[0.0000] .2L RUN - 1 K1804 AROMATIC
A131S B141S C178S D184S E192S ■206S

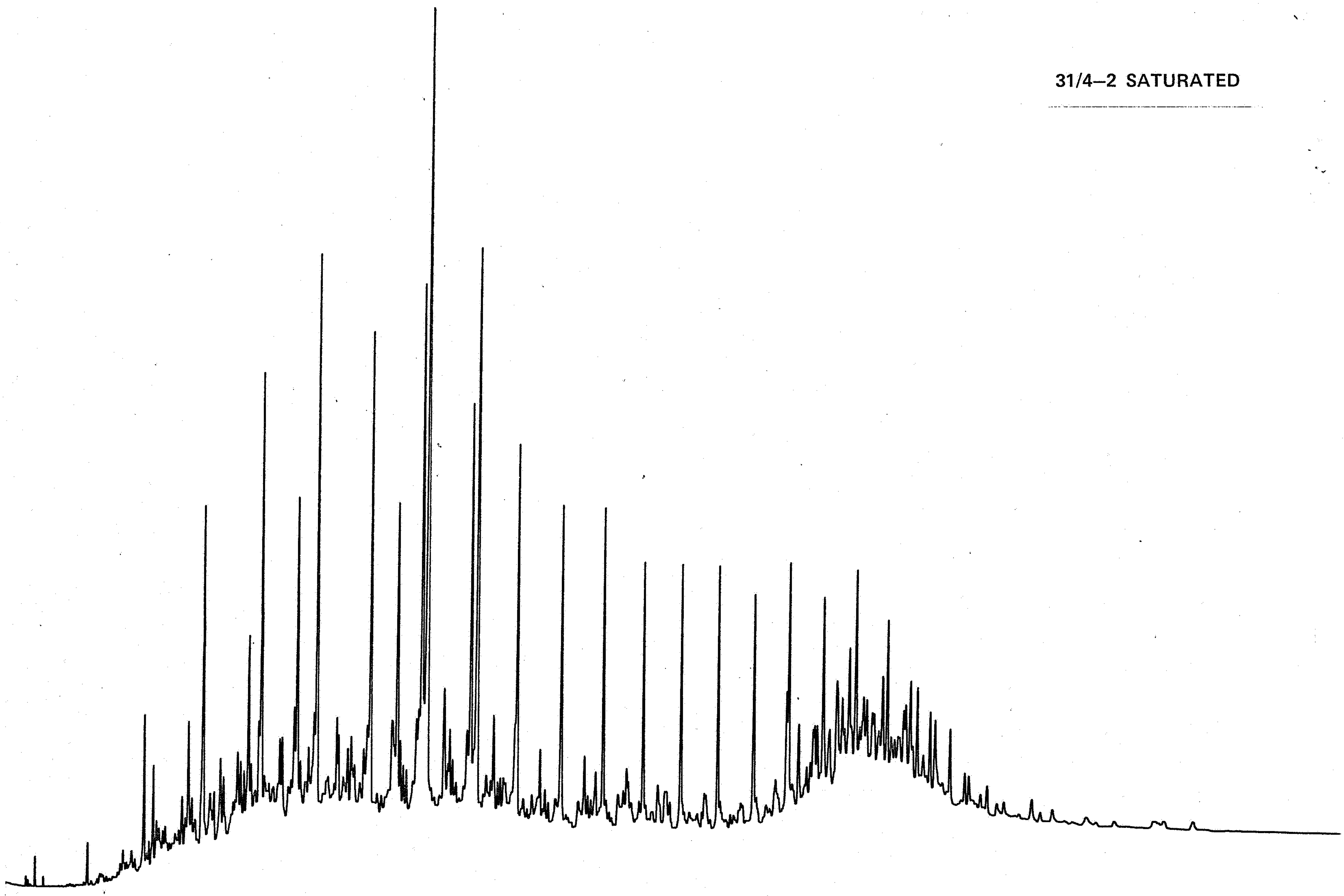
RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:05	1.23	8.47	

CONDENSATE

M/Z = 206



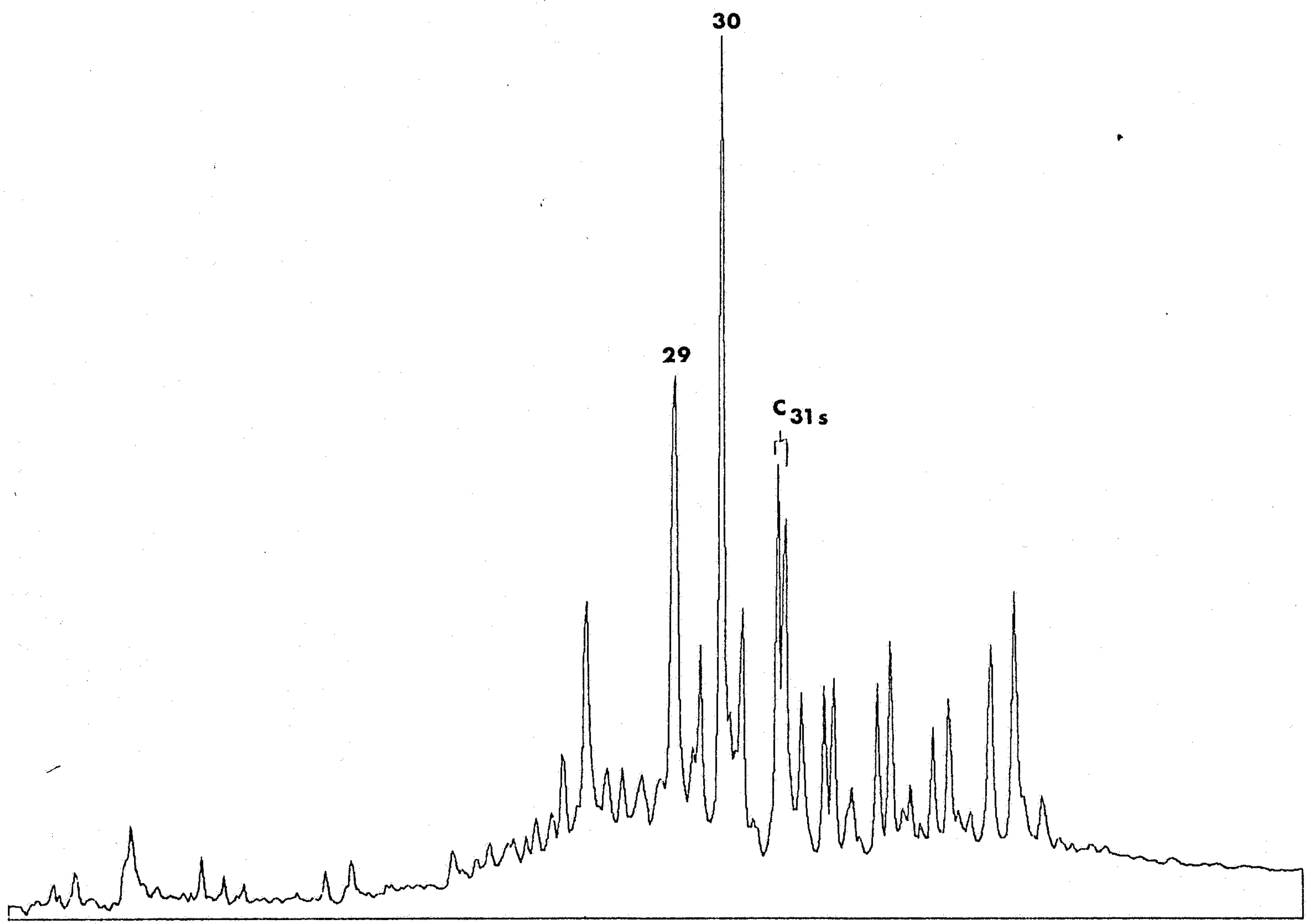
31/4–2 SATURATED



[0.0000] .SD RUN - 1 31/4-2
A181S B191S C197S D217S E253S
RETN.TIME HEIGHT AREA UNCALIBRATED.
0 00 00 0.00 0.00

31/4–2

M/Z = 191

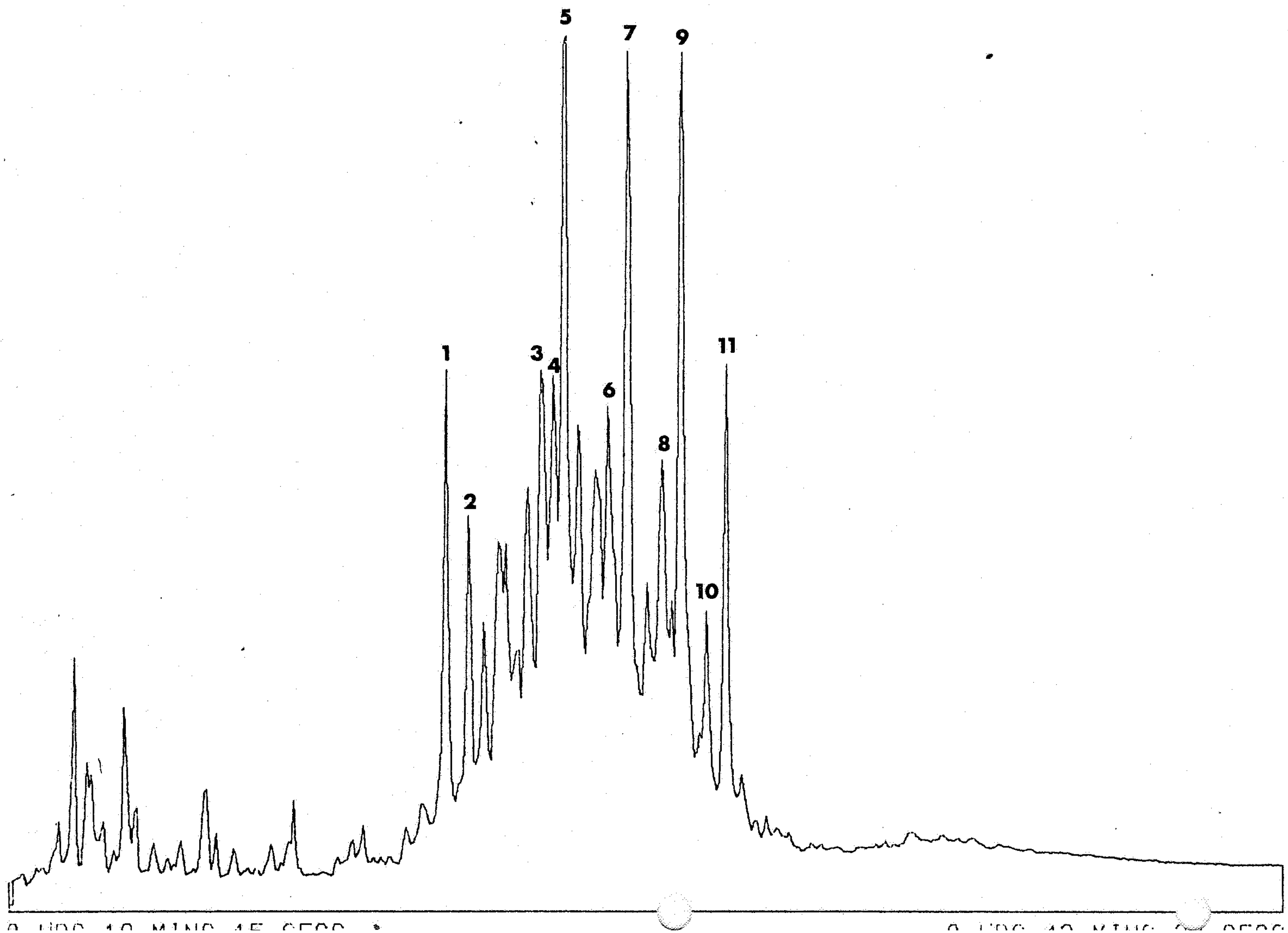


- 65 -

[0.0000] SD RUN - 1 31[illegible]4-2
A181S B191S C197S [illegible]217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:19:21	1.60	13.12	

31/4–2
M/Z = 217



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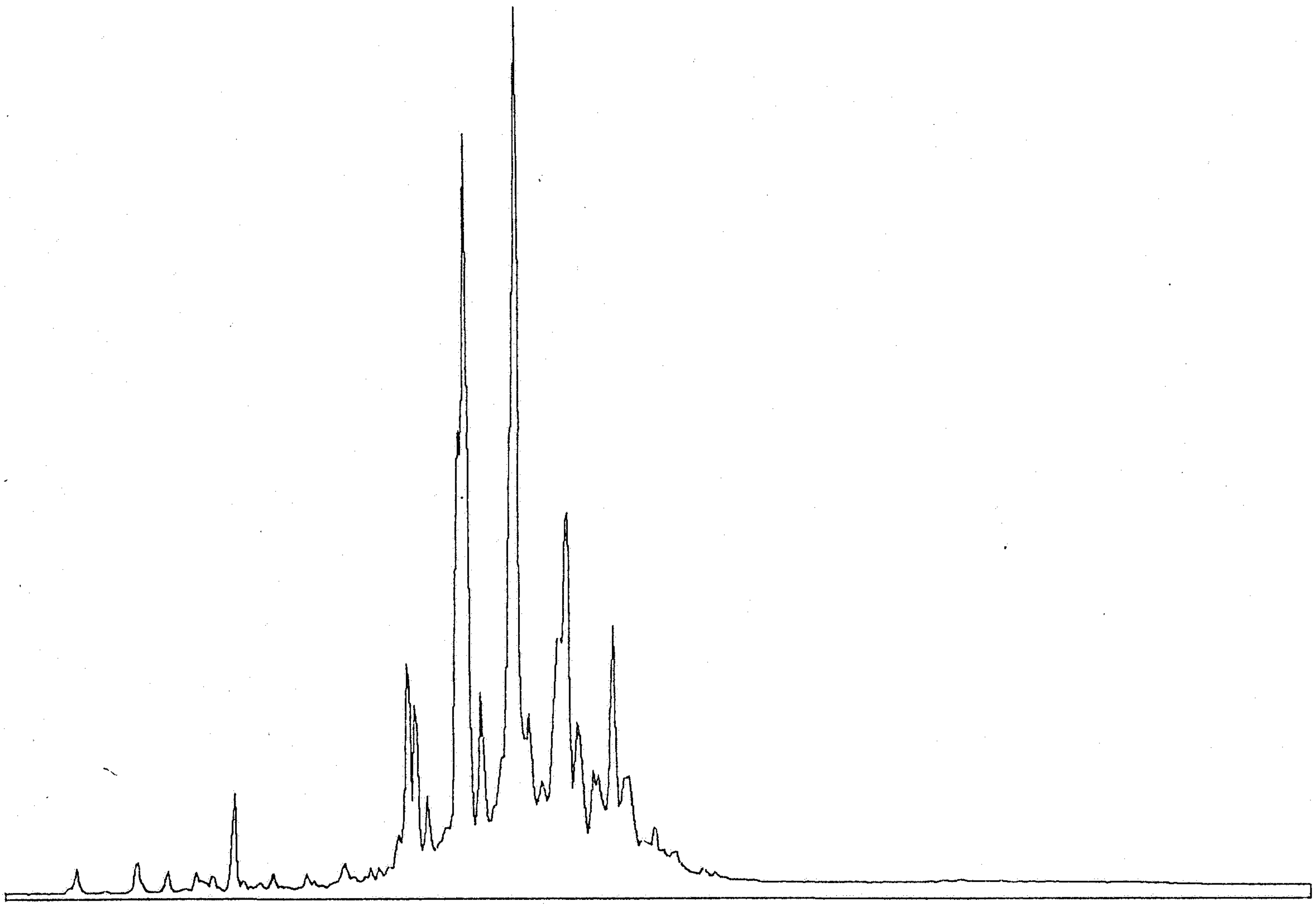
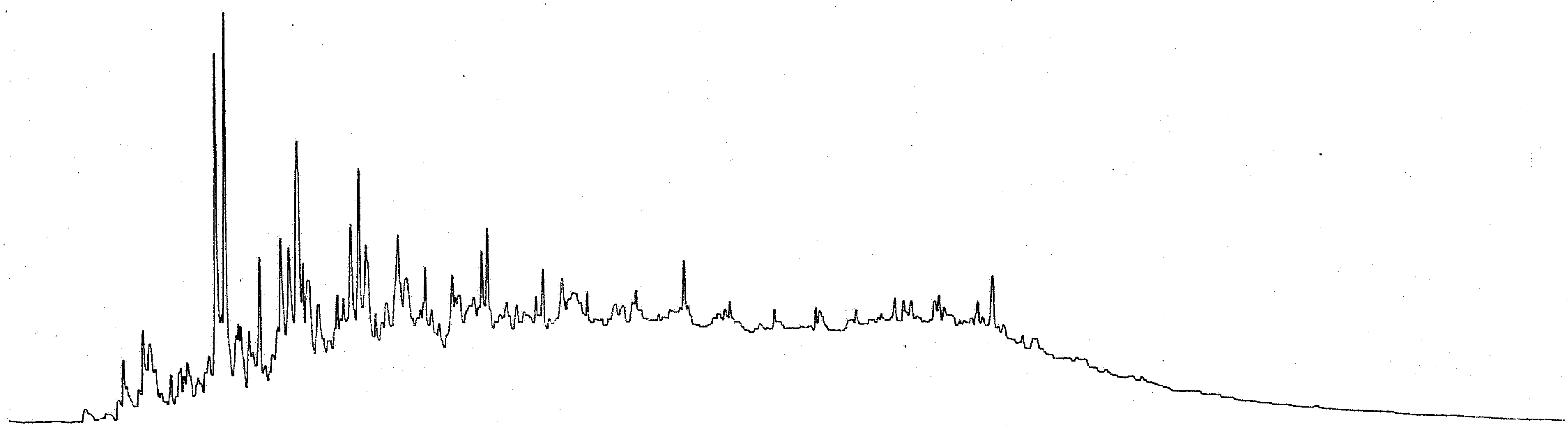
[          0.0000]          .SD  RUN -  1  31■4-2
   A181S B191S C197S D217S ■253S
RETN.TIME     HEIGHT          AREA       UNCALIBRATED.
  0:19'18       0.04          0.11
```

31/4–2

M/Z = 253



31/4–2 AROMATIC



[0.0000] .2L RUN - 1 AROMATICS

A131S B141S C178S D184S E192S F205S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
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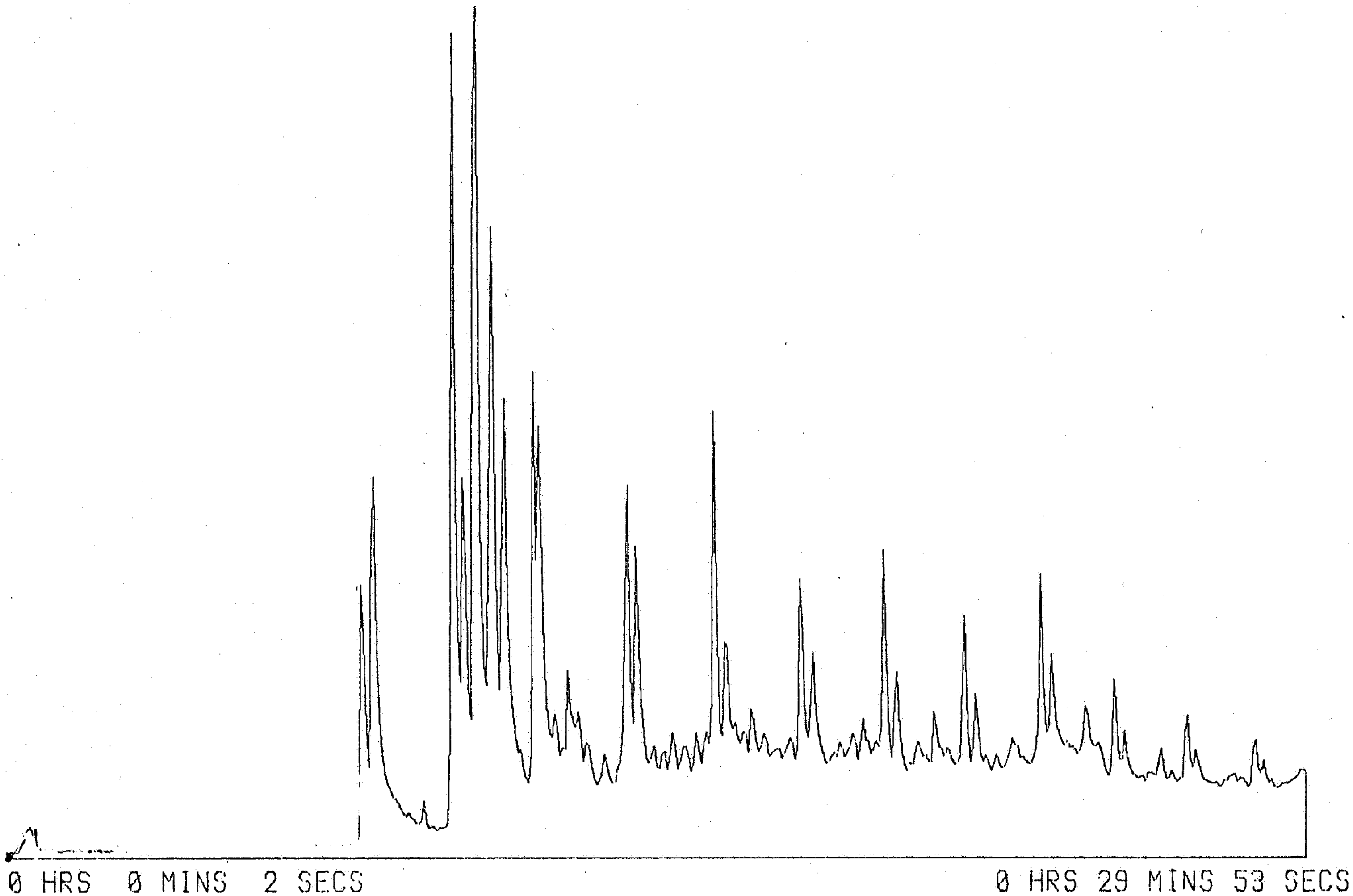
31/4–2

M/Z = 141



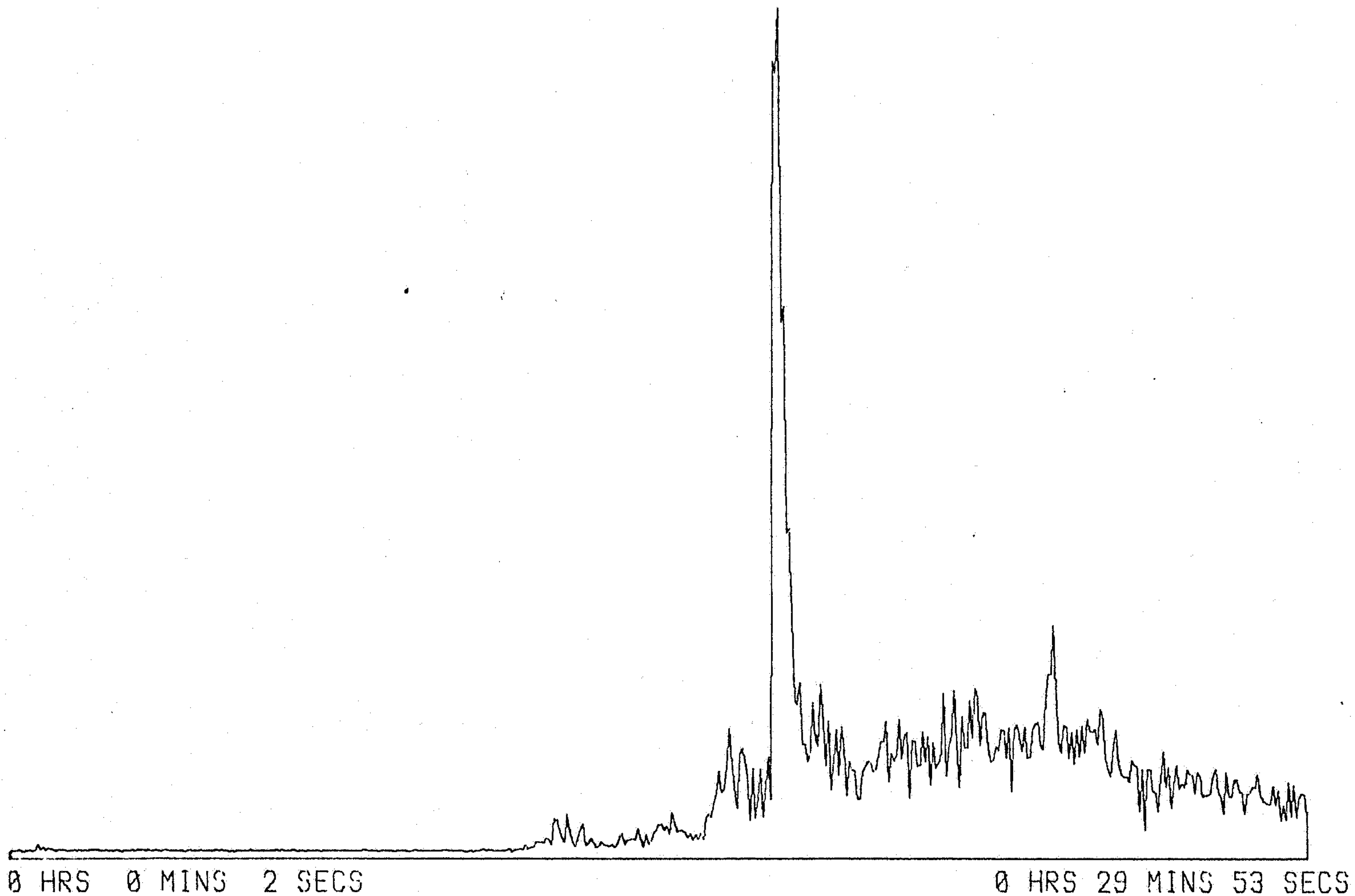
[0.0000] .2L RUN - 1 AROMATICS

31/4-2

M/Z = 178

A131S B141S ▥178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0 00 06	1.49	10.24	



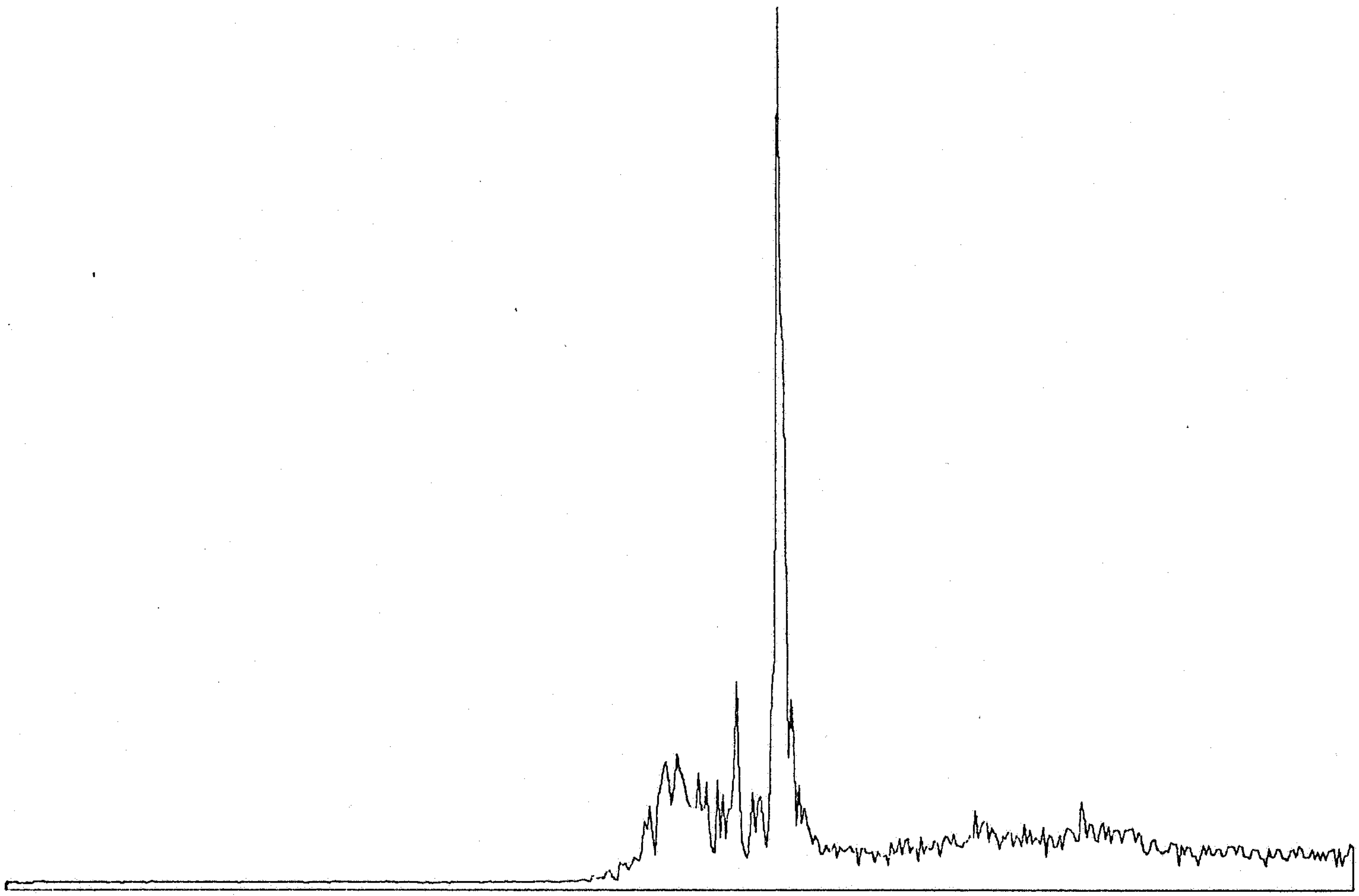
[0.0000] .2L RUN - 1 AROMATICS

A131S B141S C178S D184S E192S F206S

31/4–2

M/Z = 184

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00'06	1.49	10.24	



0 HRS 0 MINS 2 SECS

0 HRS 29 MINS 53 SECS

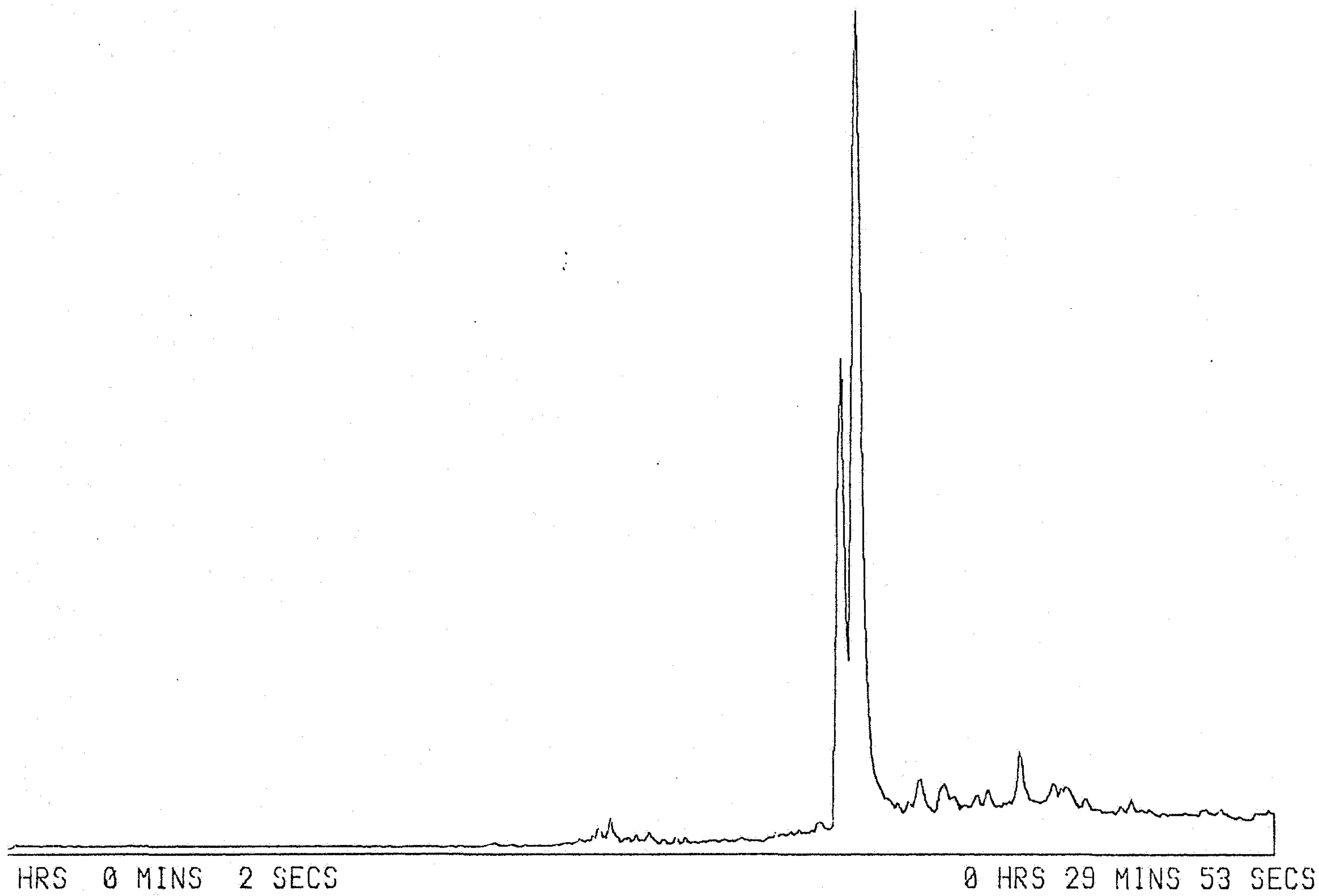
[0.0000] .2L RUN - 1 AROMATICS

A131S B141S C178S D184S ▩192S F206S

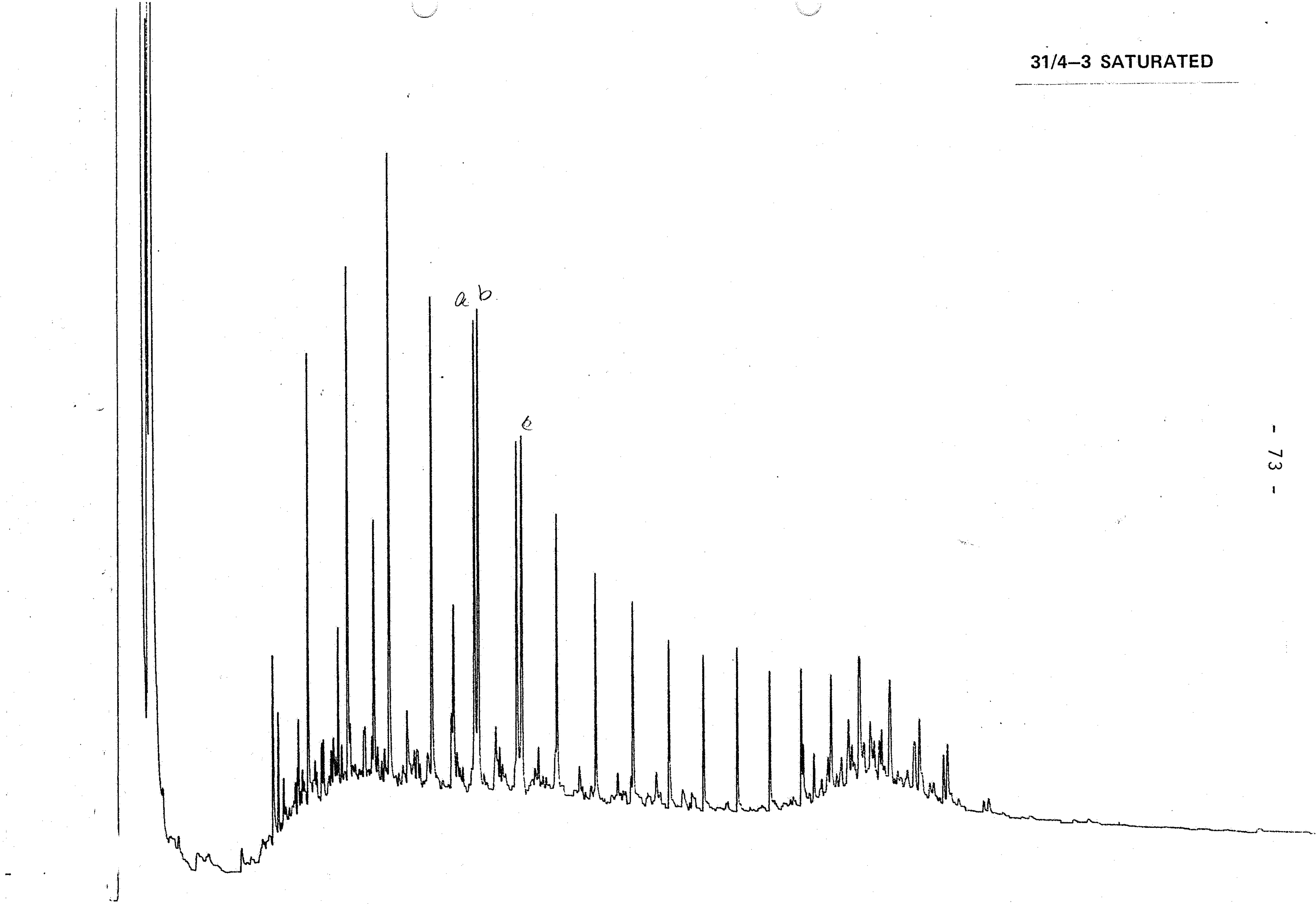
ETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00 06	1.49	10.24	

31/4–2

M/Z = 192



31/4–3 SATURATED

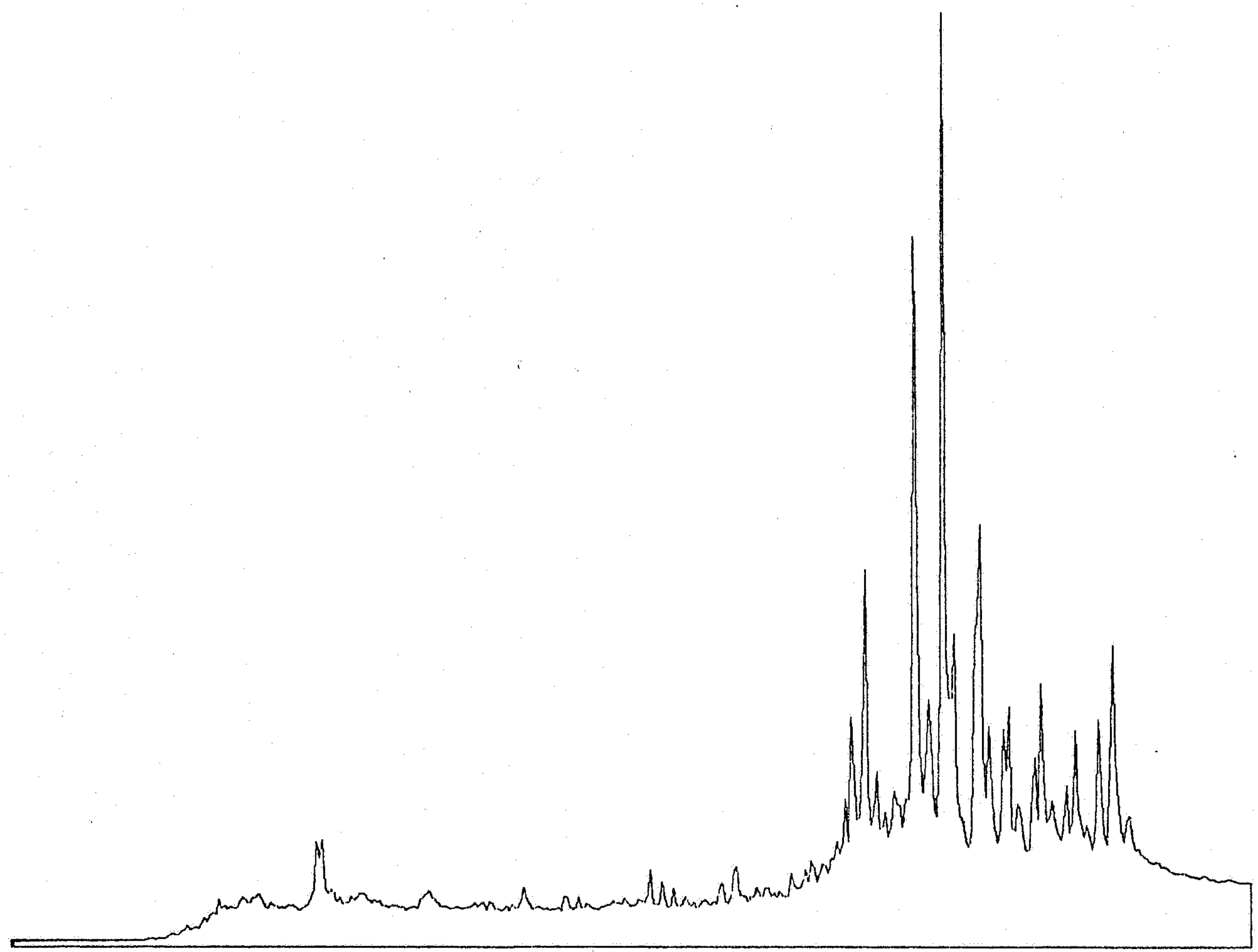


[0.0000] .2L RUN - 1 31/4-3
A181S B191S C197S D217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:01:08	1.91	21.60	

31/4—3

M/Z = 191



0 HRS 1 MINS 2 SECS

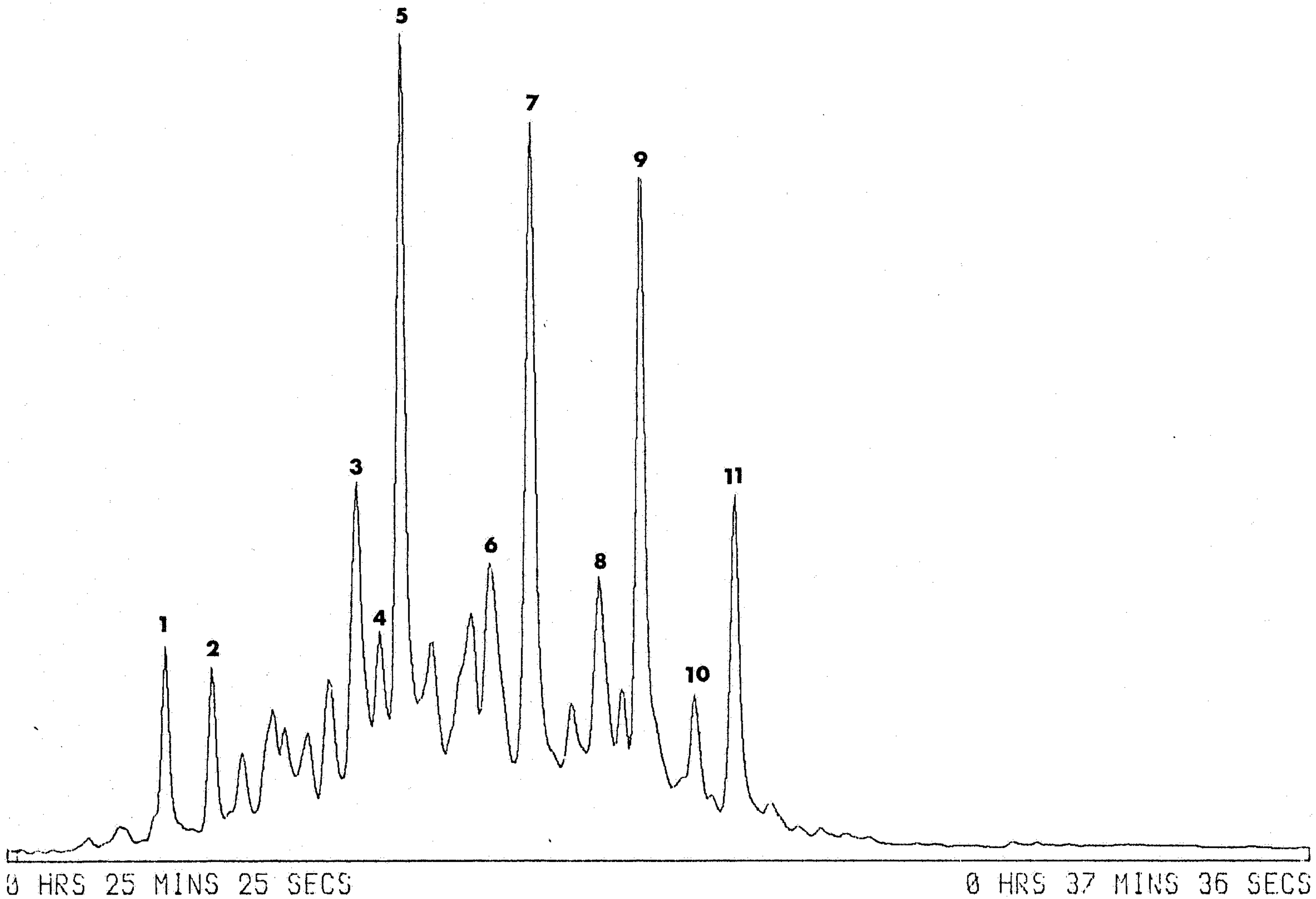
0 HRS 49 MINS 46 SECS

[0.0000] .2L RUN - 1 31■4-3
A181S B191S C197S ■217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:25'25	10.79	72.49	

31/4–3

M/Z = 217

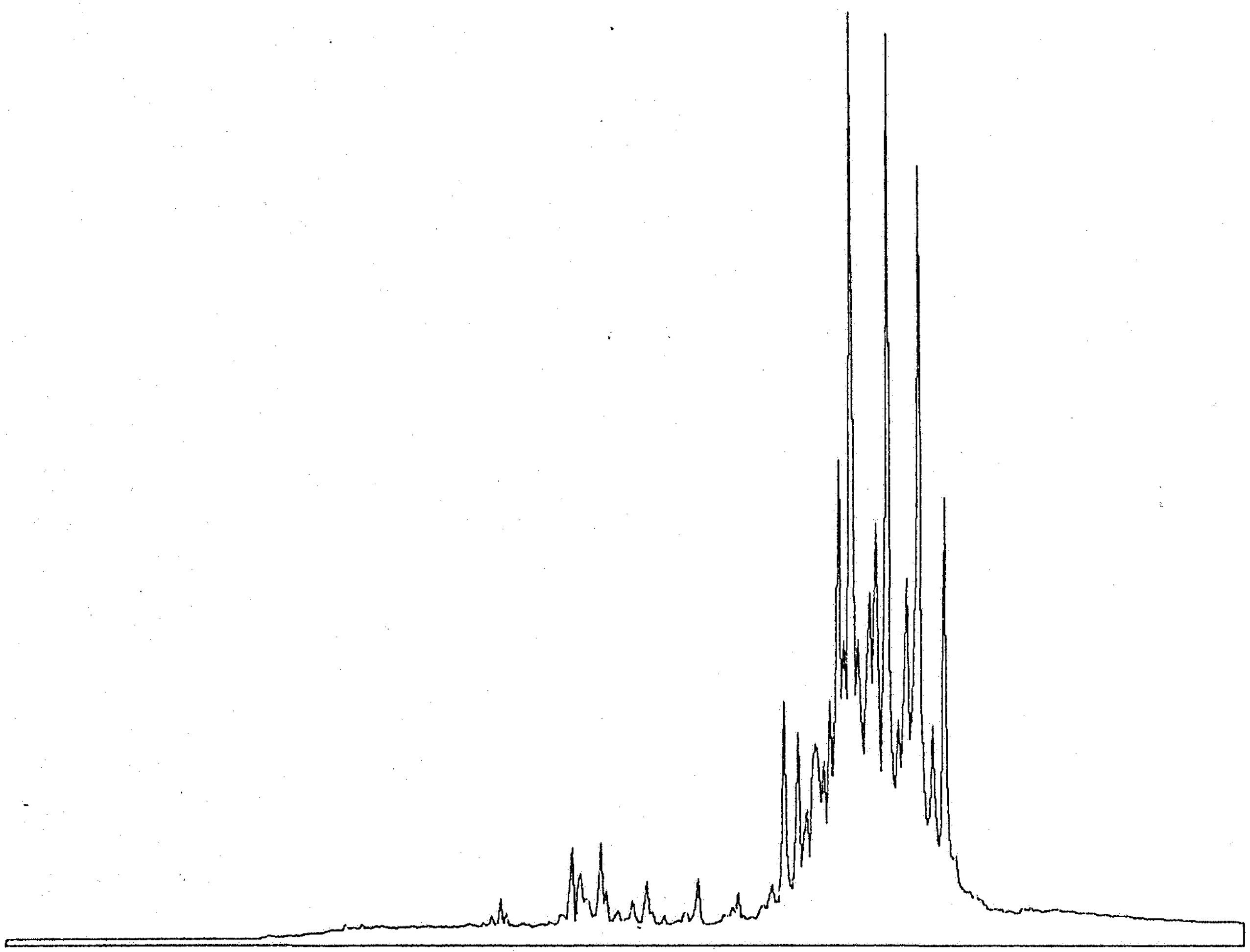


[0.0000] .2L RUN - 1 31■4-3
A181S B191S C197S ■217S E253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:01'08	1.91	21.60	

31/4–3

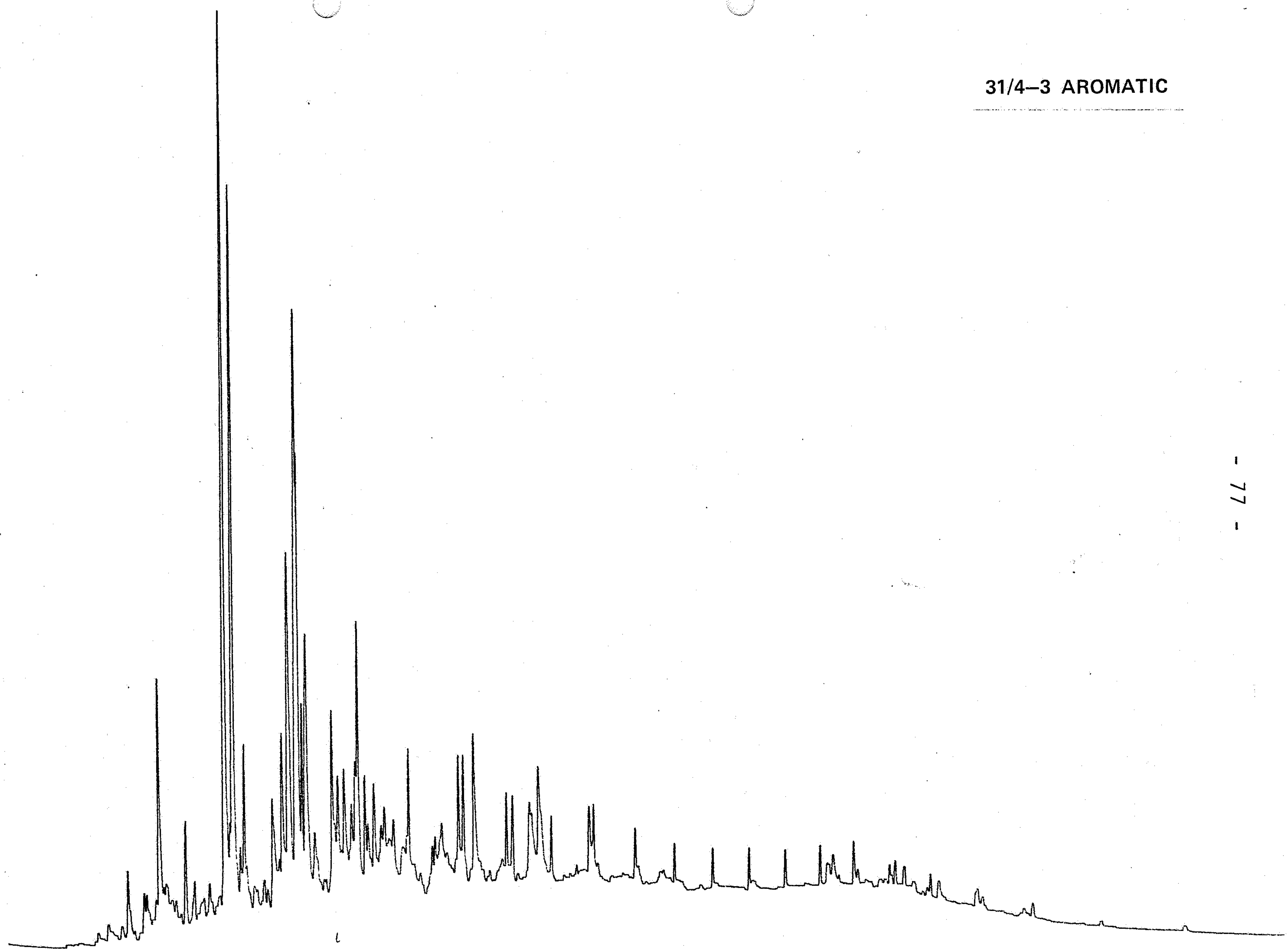
M/Z = 217



0 HRS 1 MINS 2 SECS

0 HRS 49 MINS 46 SECS

31/4–3 AROMATIC



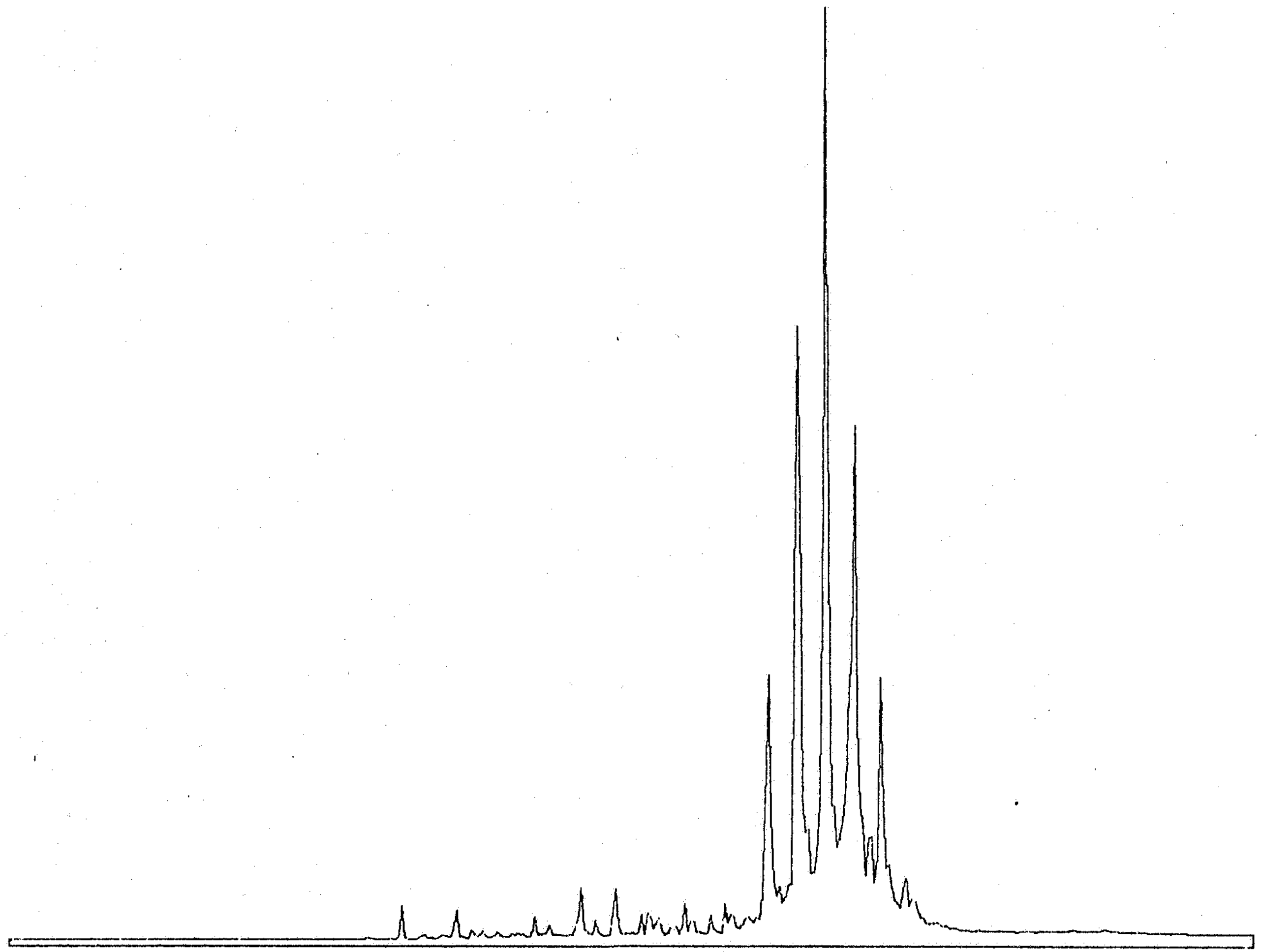
[0.0000] .2L RUN - 1 31▩4-3

A181S B191S C197S D217S ▩253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:01:08	1.91	21.60	

31/4–3

M/Z = 253



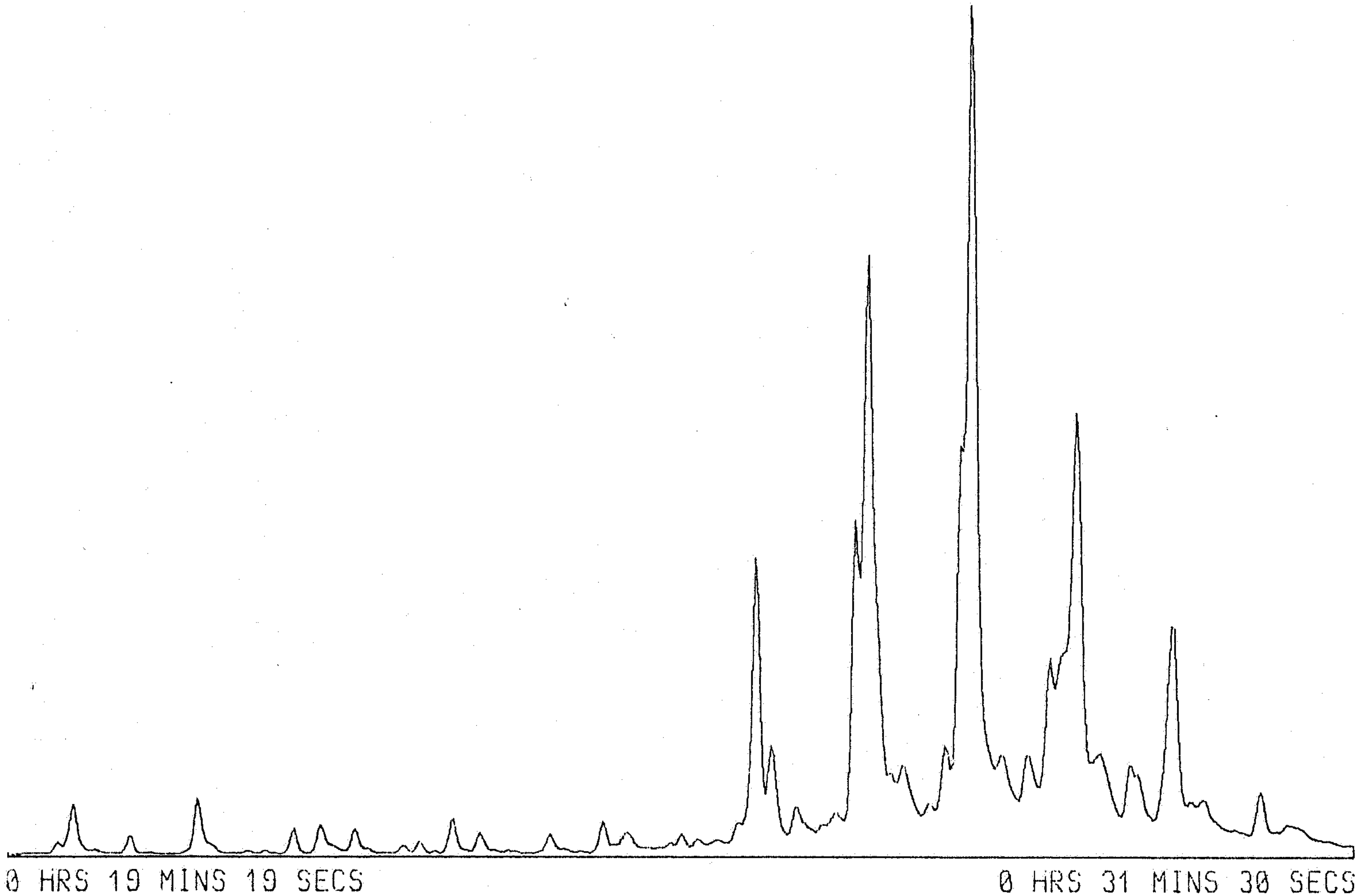
0 HRS 1 MINS 2 SECS

0 HRS 49 MINS 46 SECS

[0.0000] .2L RUN - 1 31/4-3
A181S B191S C197S D217S [illegible]253S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:19 19	2.06	12.51	

31/4–3
M/Z = 253

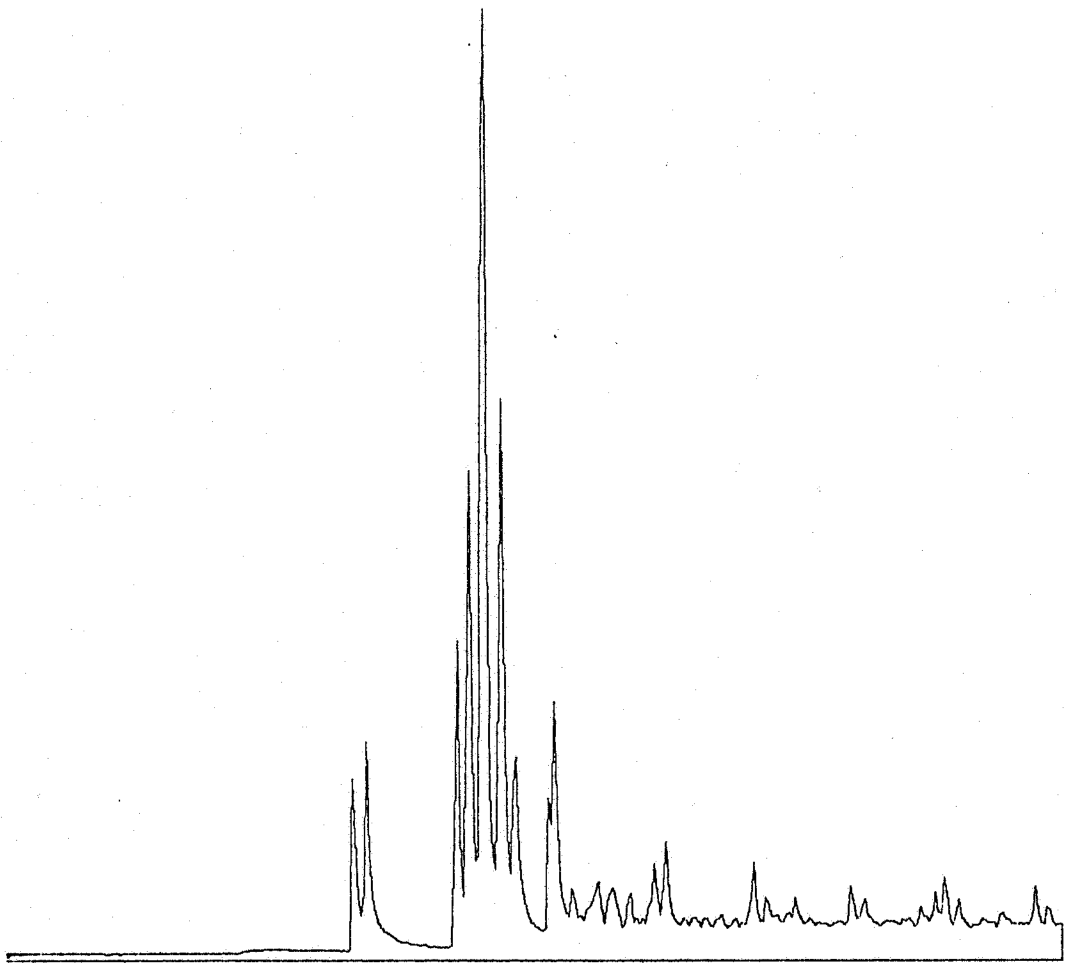


[0.0000] .2L RUN - 1 31/4-3 AROMATIC
A131S B141S C178S D184S E192S F206S

31/4-3

M/Z = 141

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.48	10.28	



0 HRS 0 MINS 2 SECS

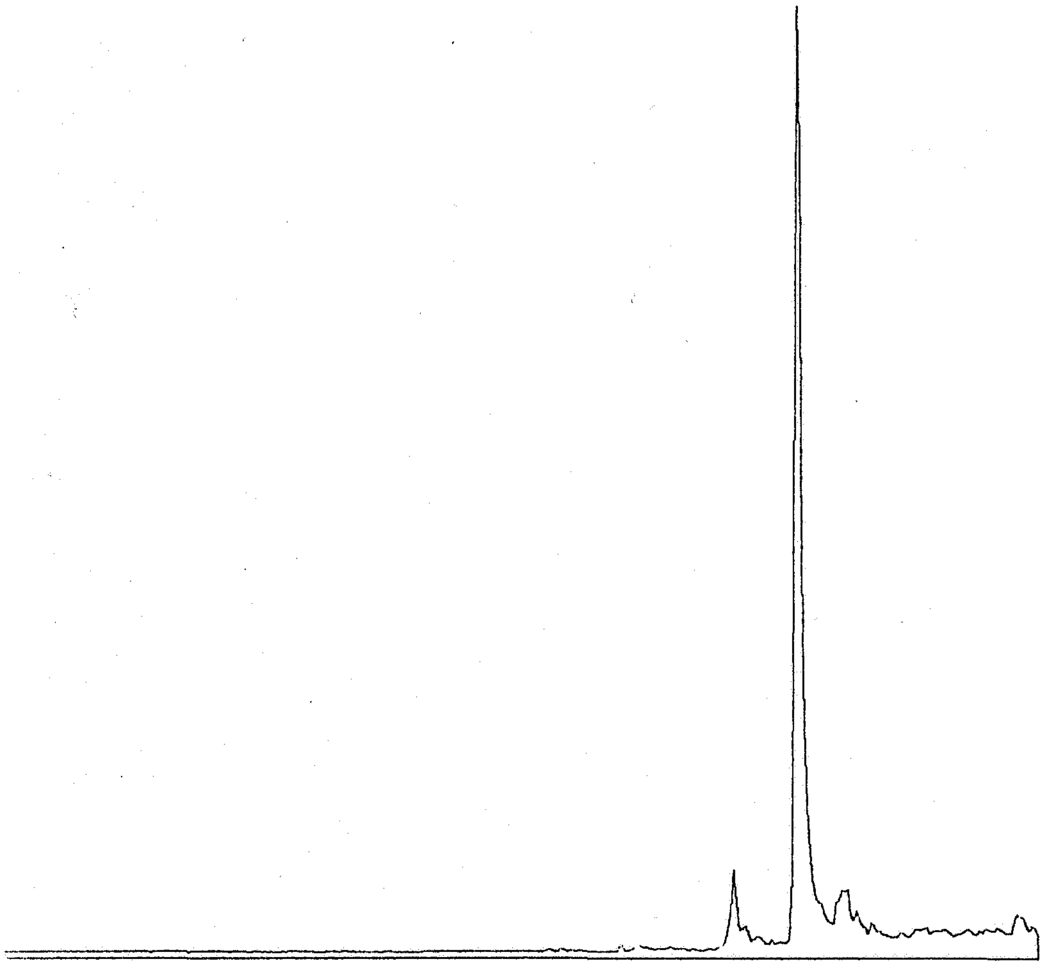
0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 31▒4-3 AROMATIC
A131S B141S ▒178S D184S E192S F206S

TN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:06	1.48	10.28	

31/4-3

M/Z = 178



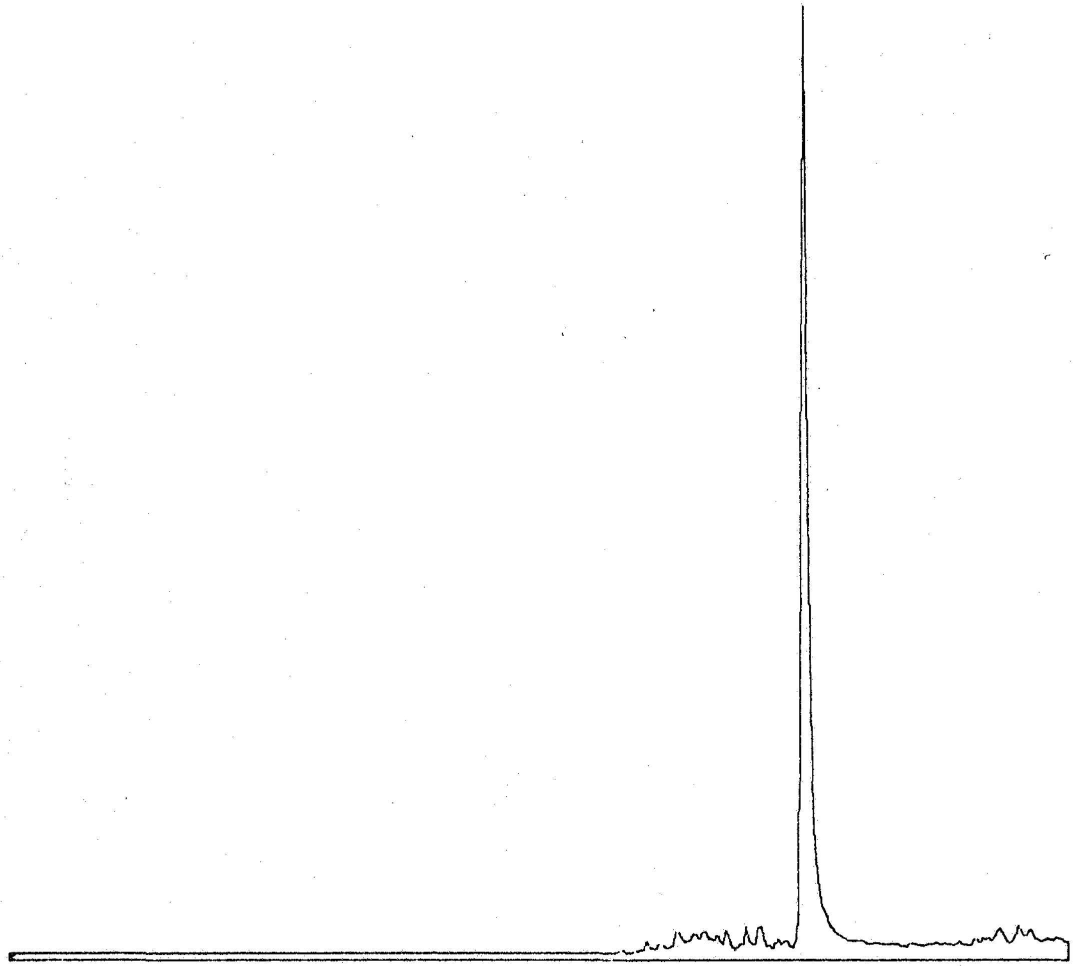
HRS 0 MINS 2 SECS

0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 31■4-3 AROMATIC
A131S B141S C178S ■184S E192S F206S

31/4-3
M/Z = 184

RETN TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:06	1.48	10.28	



0 HRS 0 MINS 2 SECS

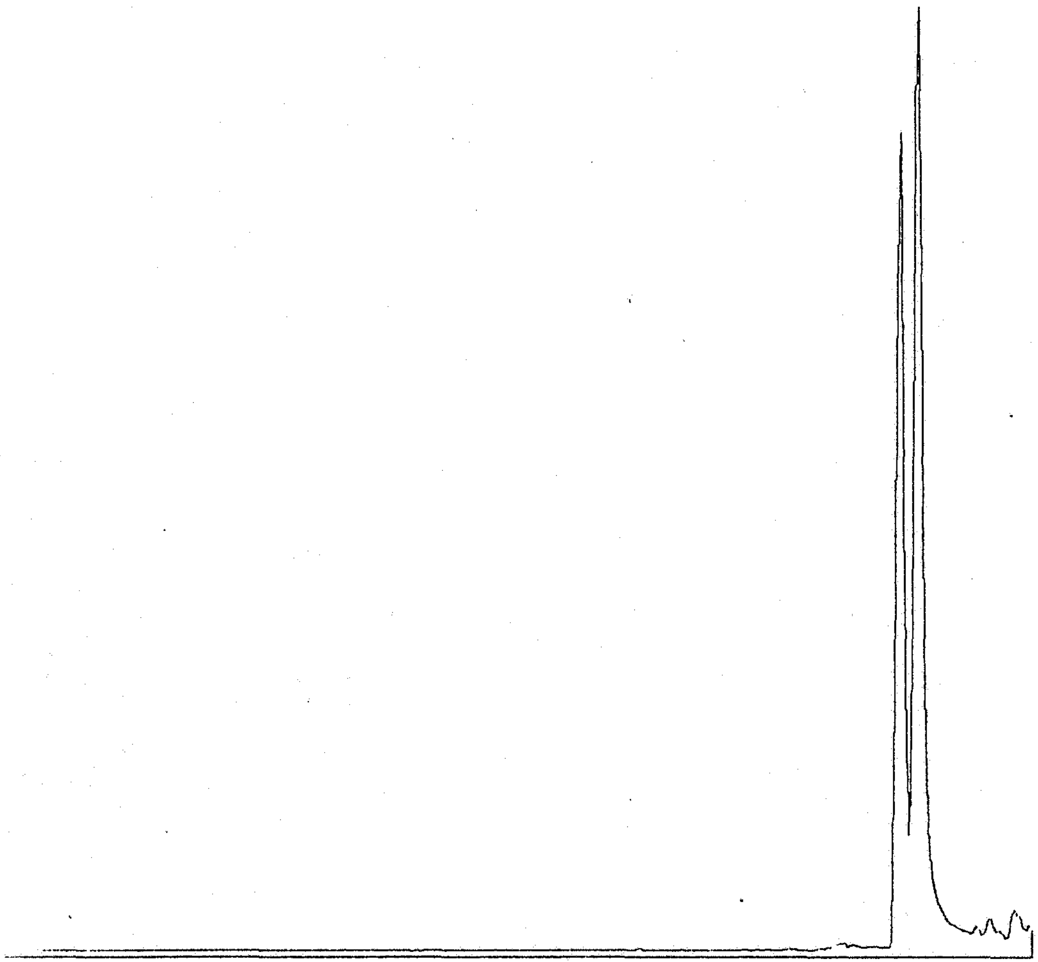
0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 31▩4-3 AROMATIC
A131S B141S C178S D184S ▩192S F206S

RTN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:06	1.48	10.28	

31/4-3

M/Z = 192



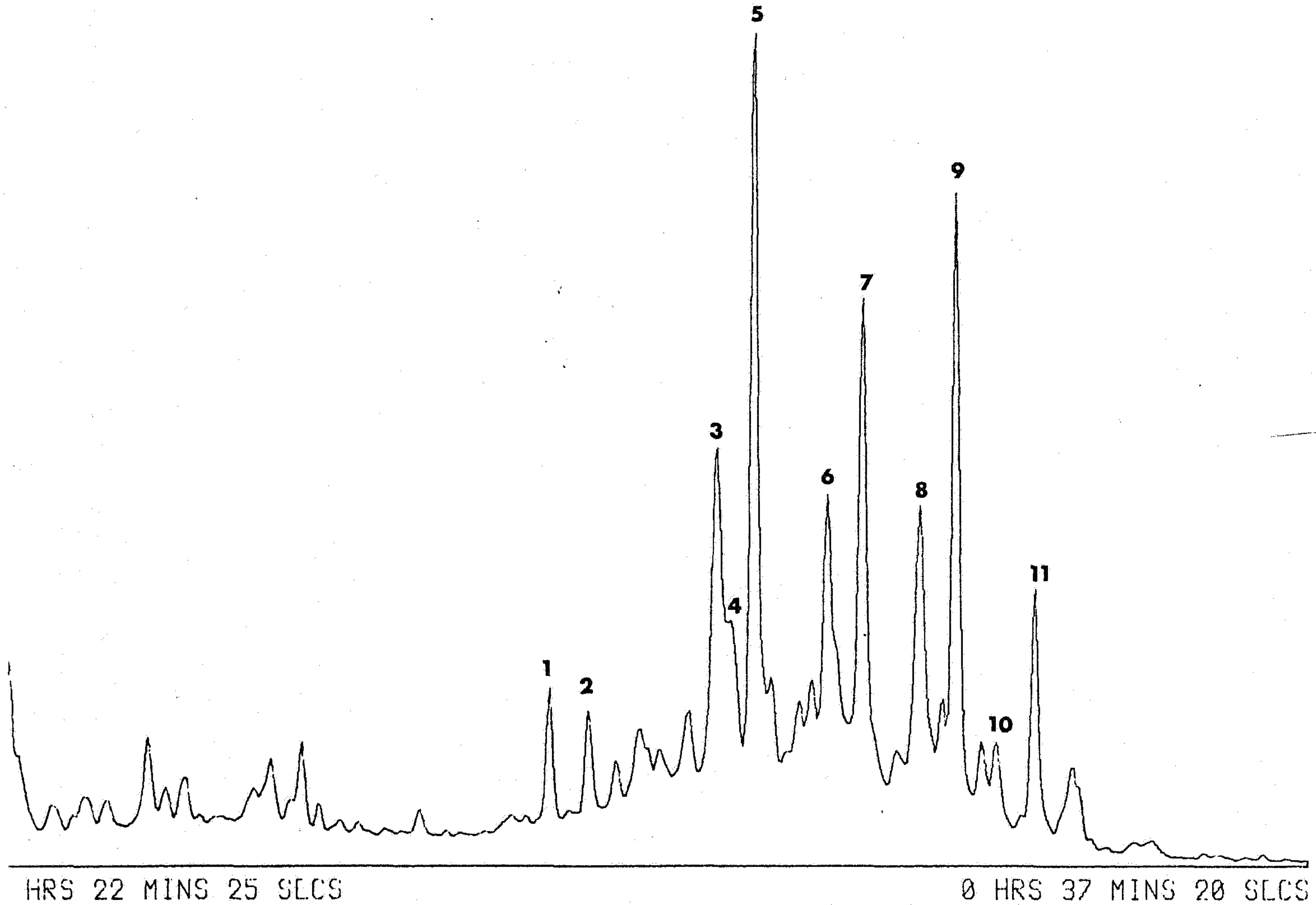
HRS 0 MINS 2 SECS

0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1
A181S B191S C199S ■217S E253S F259S

ETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:22:28	46.76	233.76	

31/2-2 1516 m
K-2875
M/Z = 217

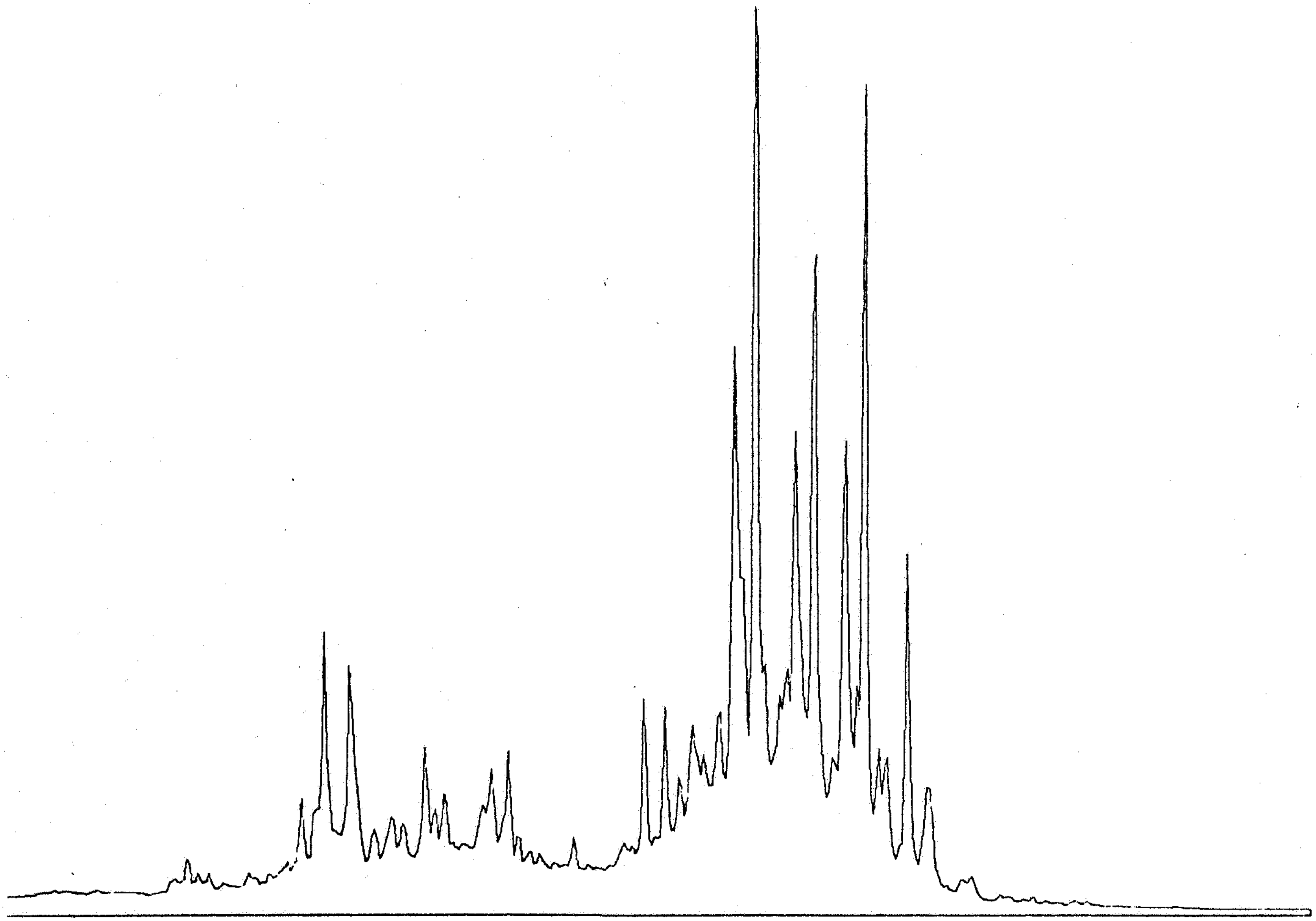


[0.0000] .2L RUN - 1
A181S B191S C199S ⅢD217S E253S F259S
:TN.TIME HEIGHT AREA UNCALIBRATED.
0:15:01 18.77 130.84

31/2-2 1516 m

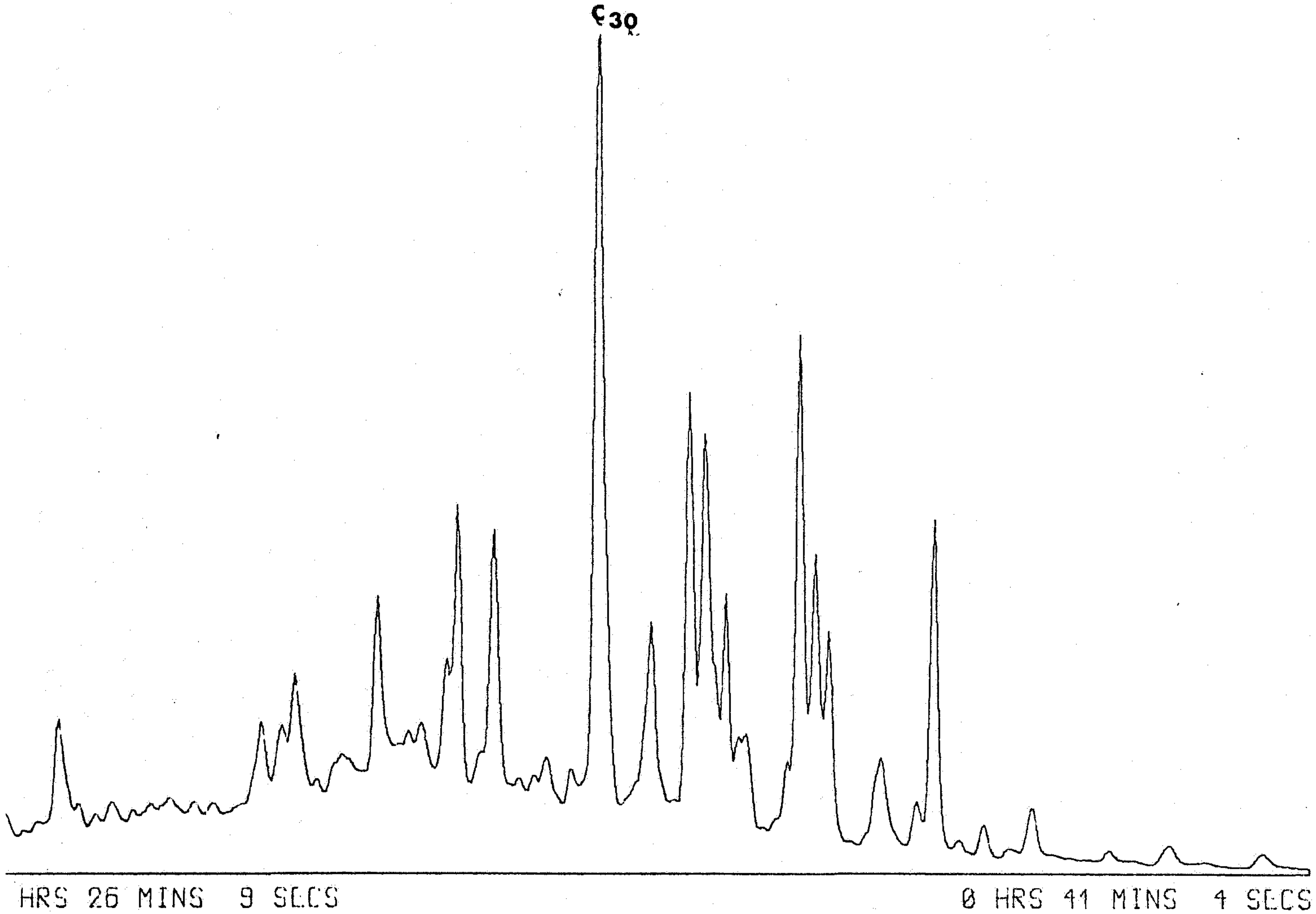
K-2875

M/Z = 217



[0.0000] .2L RUN - 1
A181S B191S C199S D217S E253S F259S
RTN.TIME HEIGHT AREA UNCALIBRATED.
0:26 12 49.58 243.49

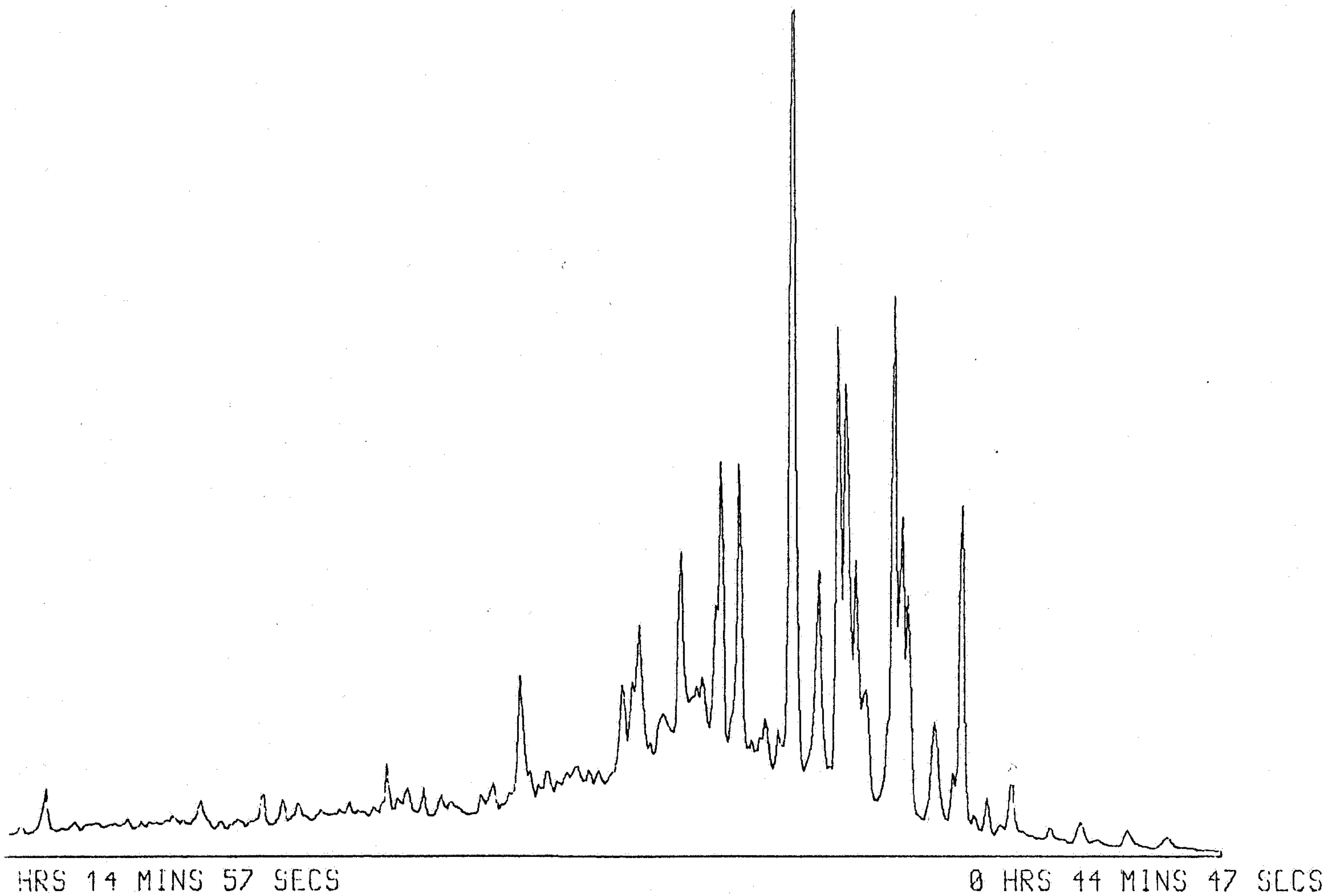
31/2-2 1516 m
K-2875
M/Z = 191



31/2–2 1516 m
K–2875
M/Z = 191

[0.0000] .2L RUN - 1
A181S B191S C199S D217S E253S F259S

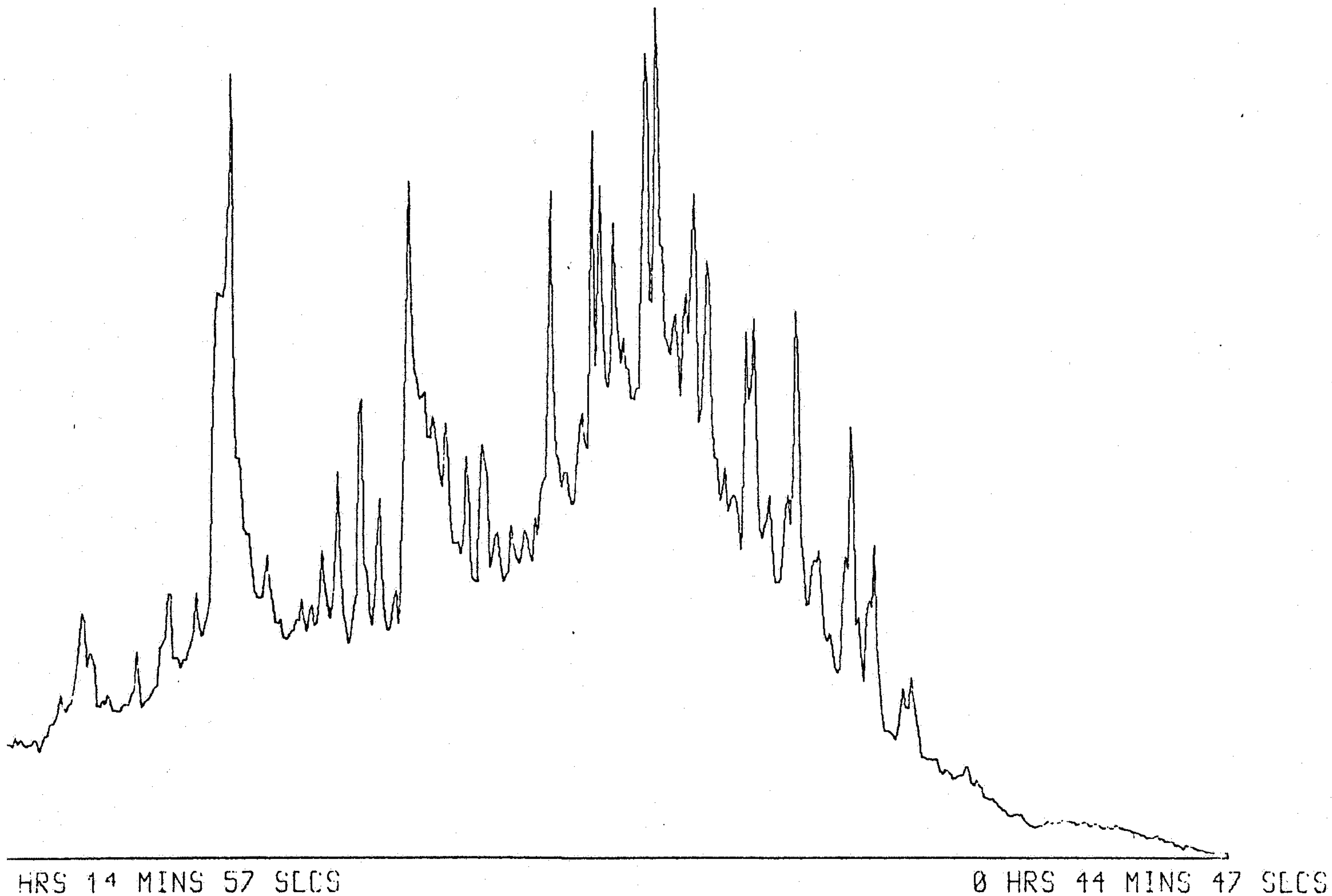
RTN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:15:01	18 77	130.84	



[0.0000] .2L RUN - 1
A181S B191S ⓜ199S D217S E253S F259S

:TN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:15:01	18.77	130.84	

31/2-2 1516 m
K-2875
M/Z = 199



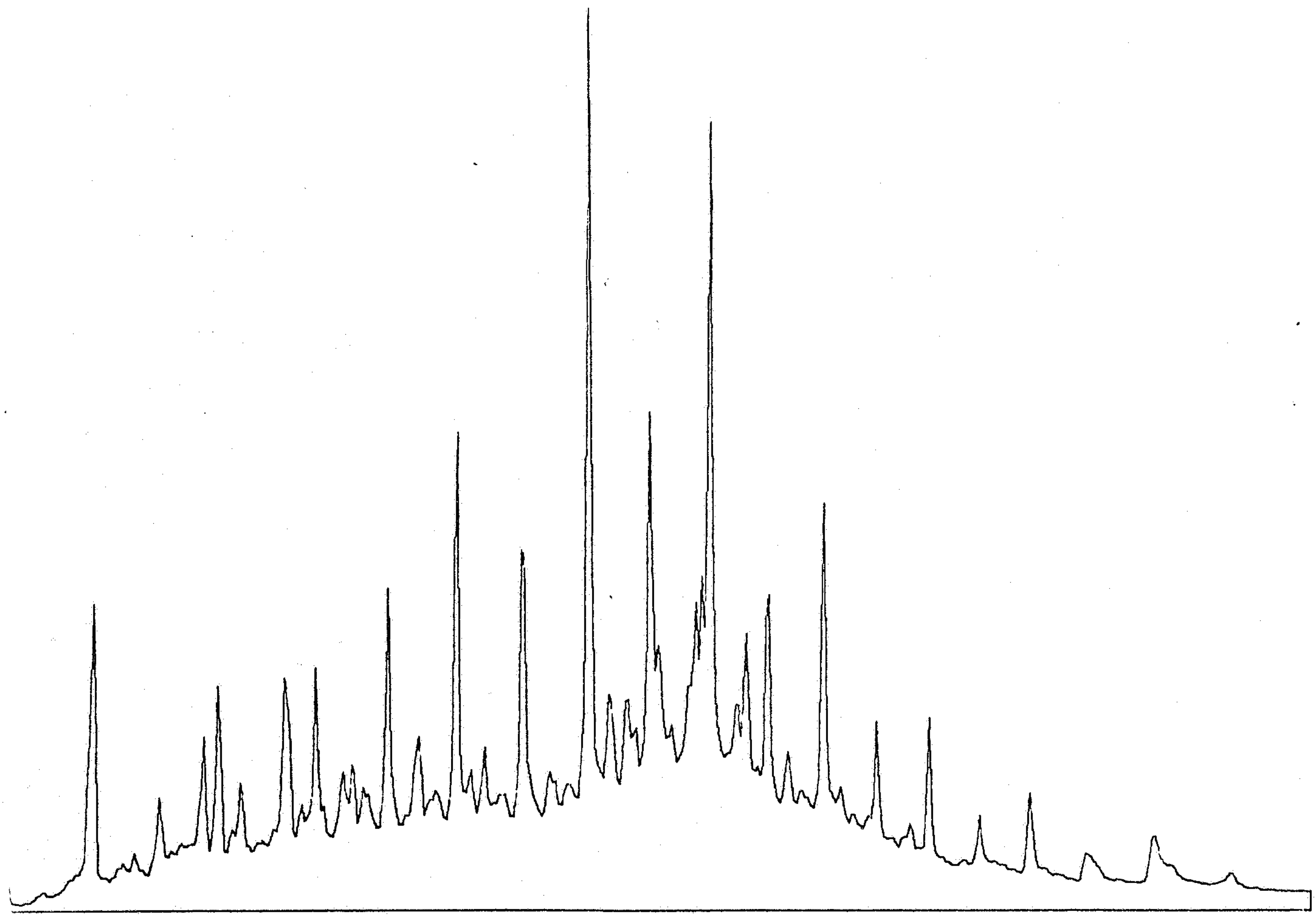
[0.0000] .2L RUN - 1
A181S B191S C199S D217S E253S F259S

ETN TIME	HEIGHT	AREA	UNCALIBRATED
0:15:01	18.77	130.84	

31/2-2 1516 m

K-2875

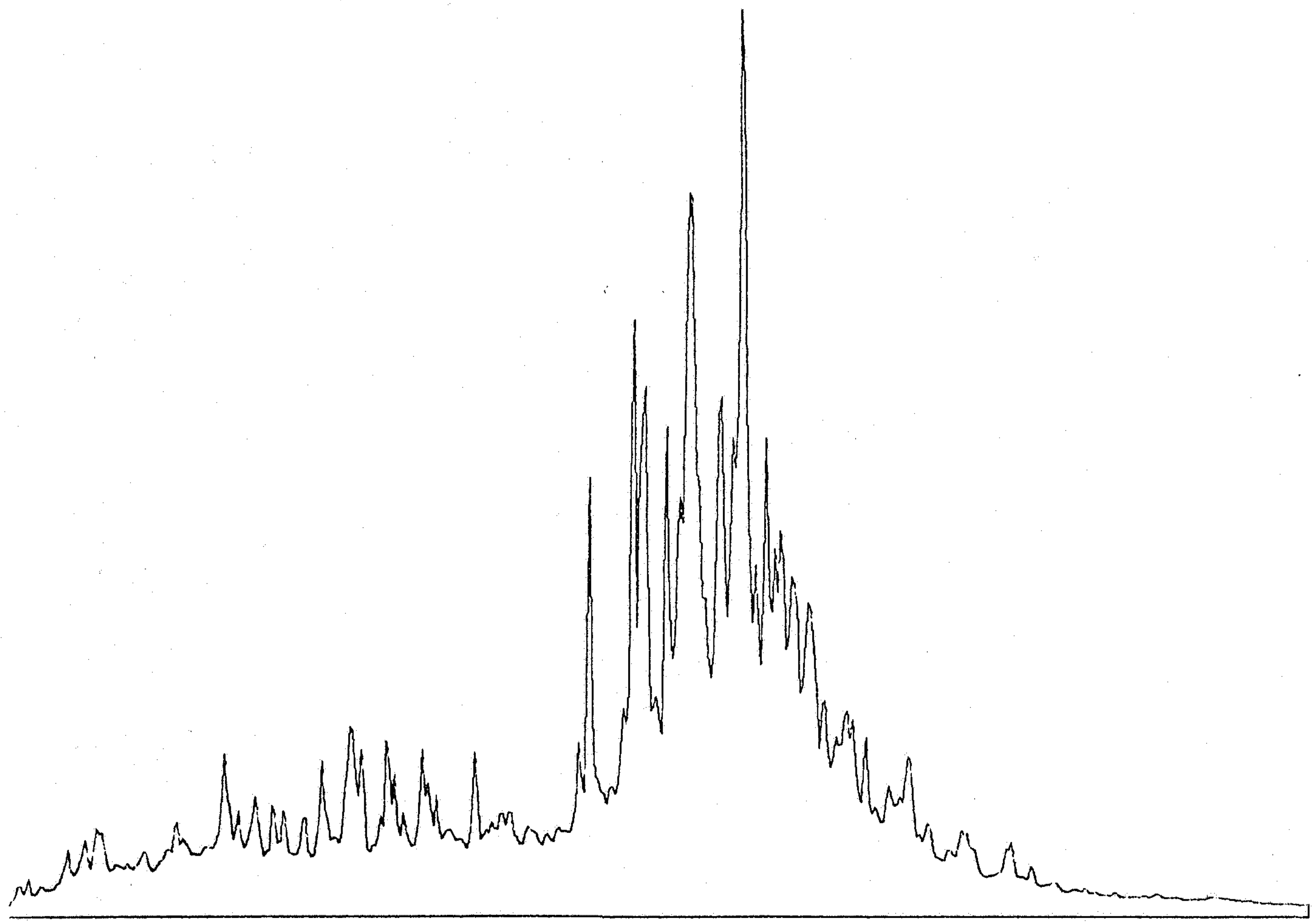
M/Z = 253



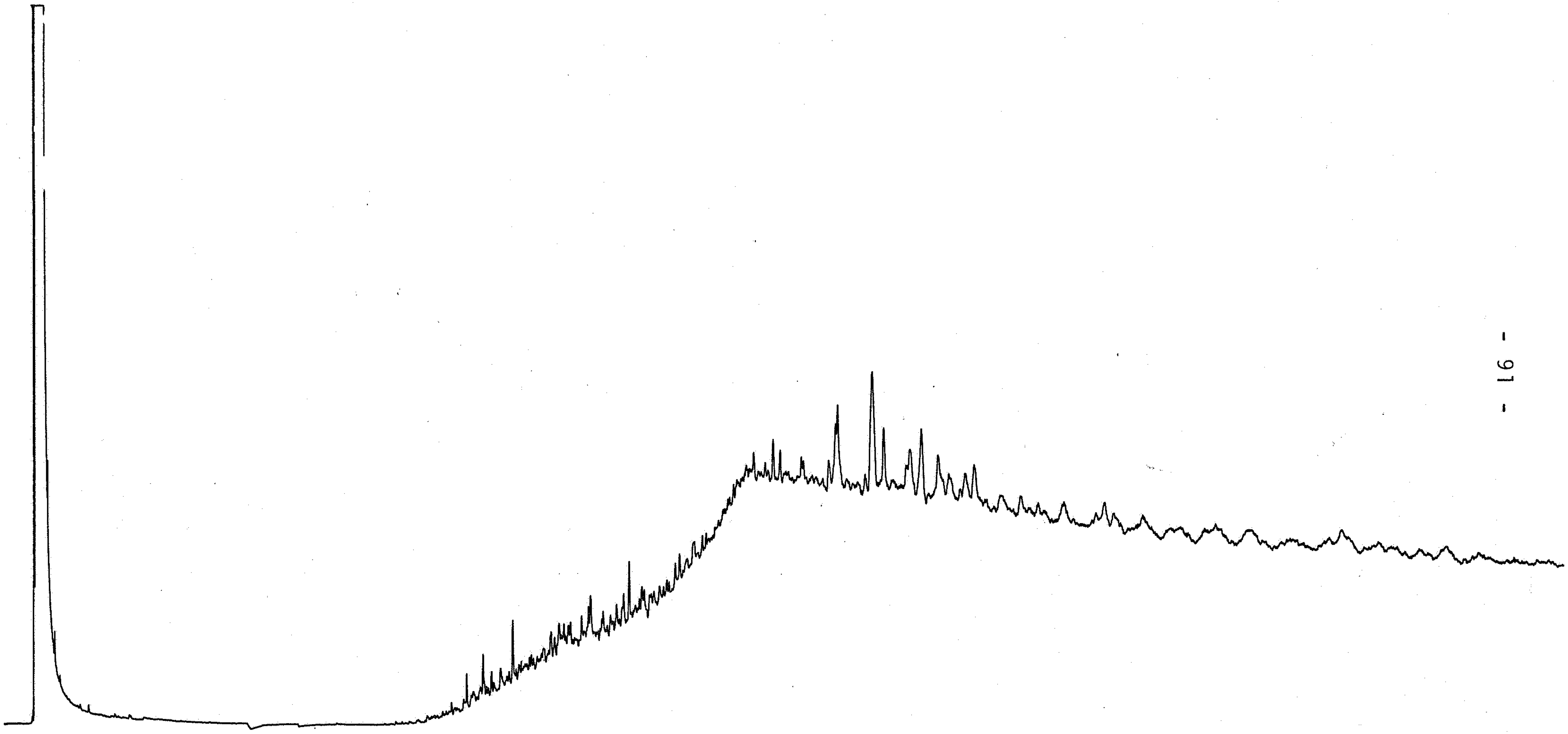
[0.0000] .2L RUN - 1
A181S B191S C199S D217S E253S ■259S

ETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:15:01	18.77	130.84	

31/2-2 1516 m
K-2875
M/Z = 259



31/2–2 1516 m AROMATIC

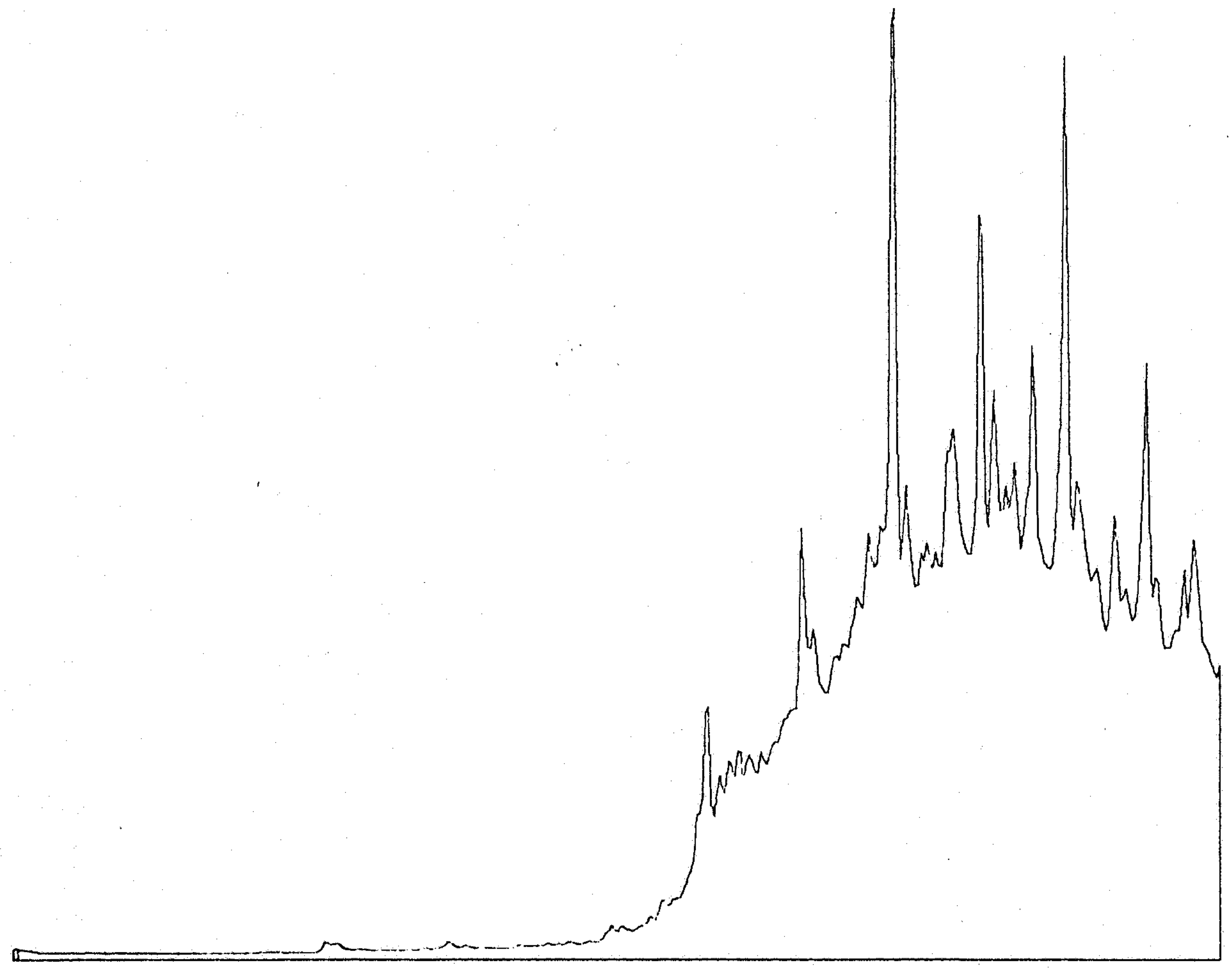


[0.0000] .2L RUN - 1 2875 AROMATICS SAMPLE 2
A131S B141S C178S D184S L192S F206S

31/2–2 1516 m

M/Z = 141

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:02	1.91	19.34	



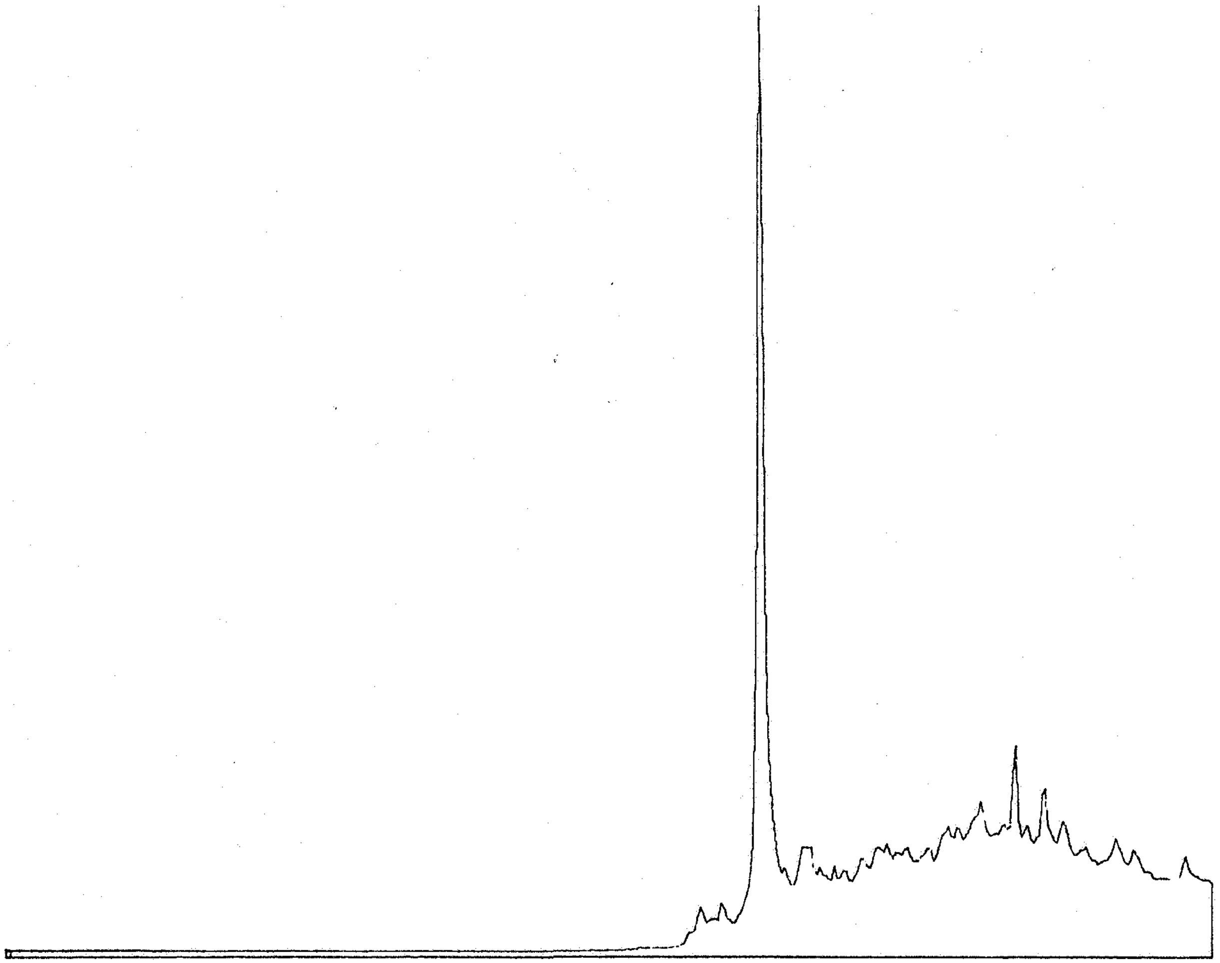
31/2–2 1516 m

M/Z = 178

[0.0000] .2L RUN - 1 375 AROMATICS SAMPLE 2

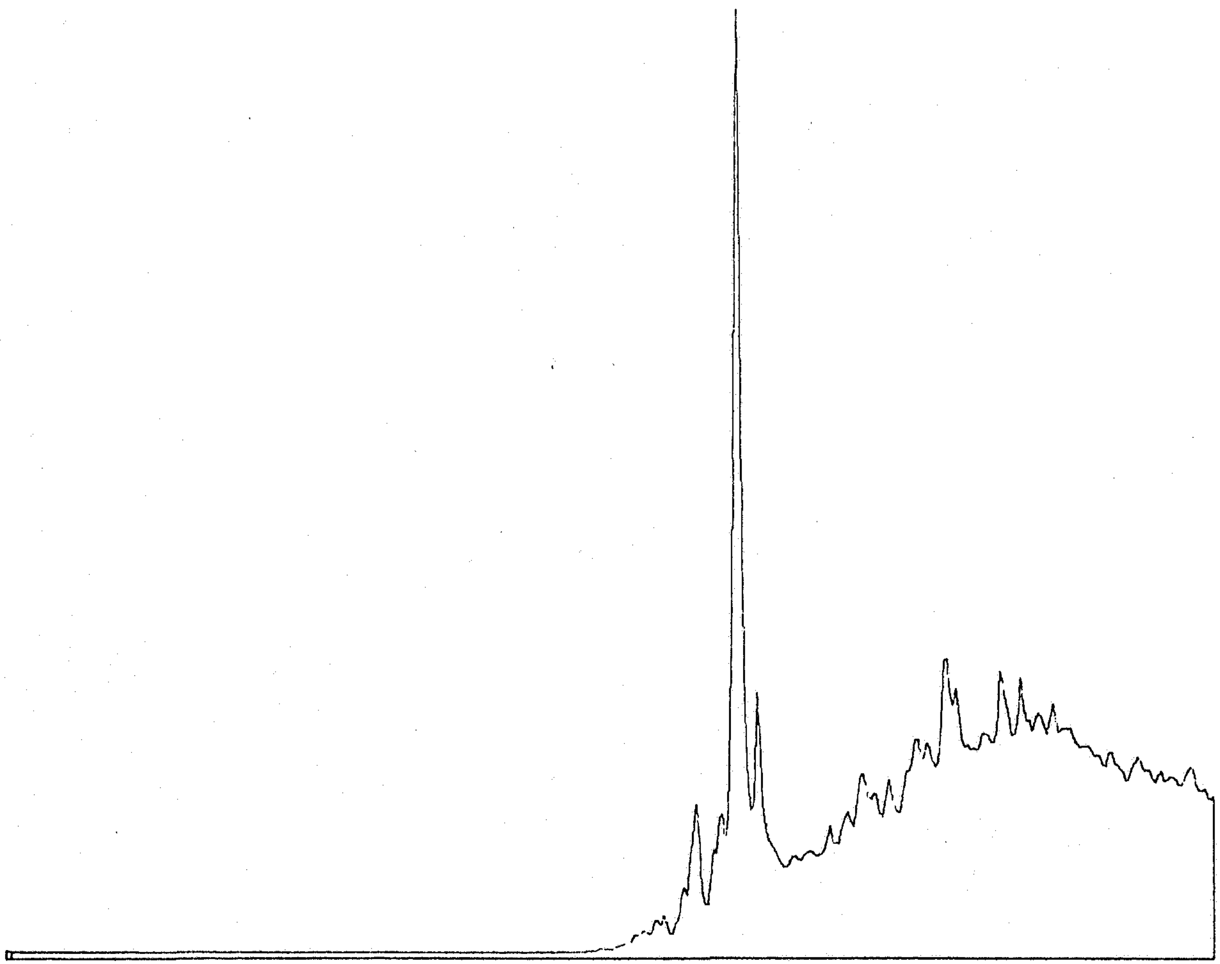
A131S B141S C178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:02	1.91	19.34	



[0.0000] .2L RUN - 1 2875 AROMATICS SAMPLE 2
A131S B141S C178S D184S E192S F206S
RETN.TIME HEIGHT AREA UNCALIBRATED.
0:00:02 1.91 19.34

31/2-2 1516 m
M/Z = 184

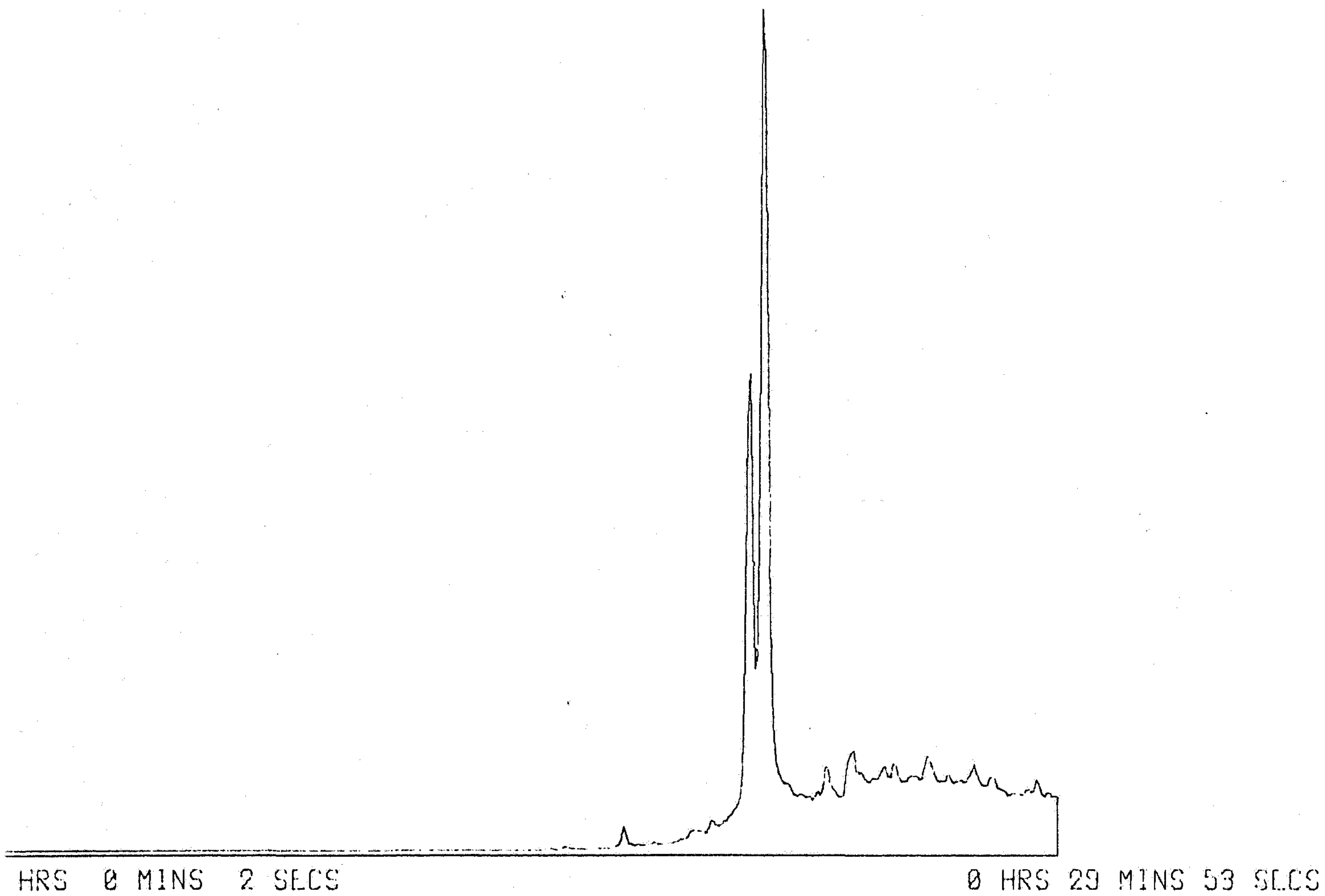


31/2–2 1516 m

M/Z = 192

[0.0000] .2L RUN - 1 2875 AROMATICS SAMPLE 2
A131S B141S C178S D184S E192S F206S

ETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:00:02	1.91	19.34	

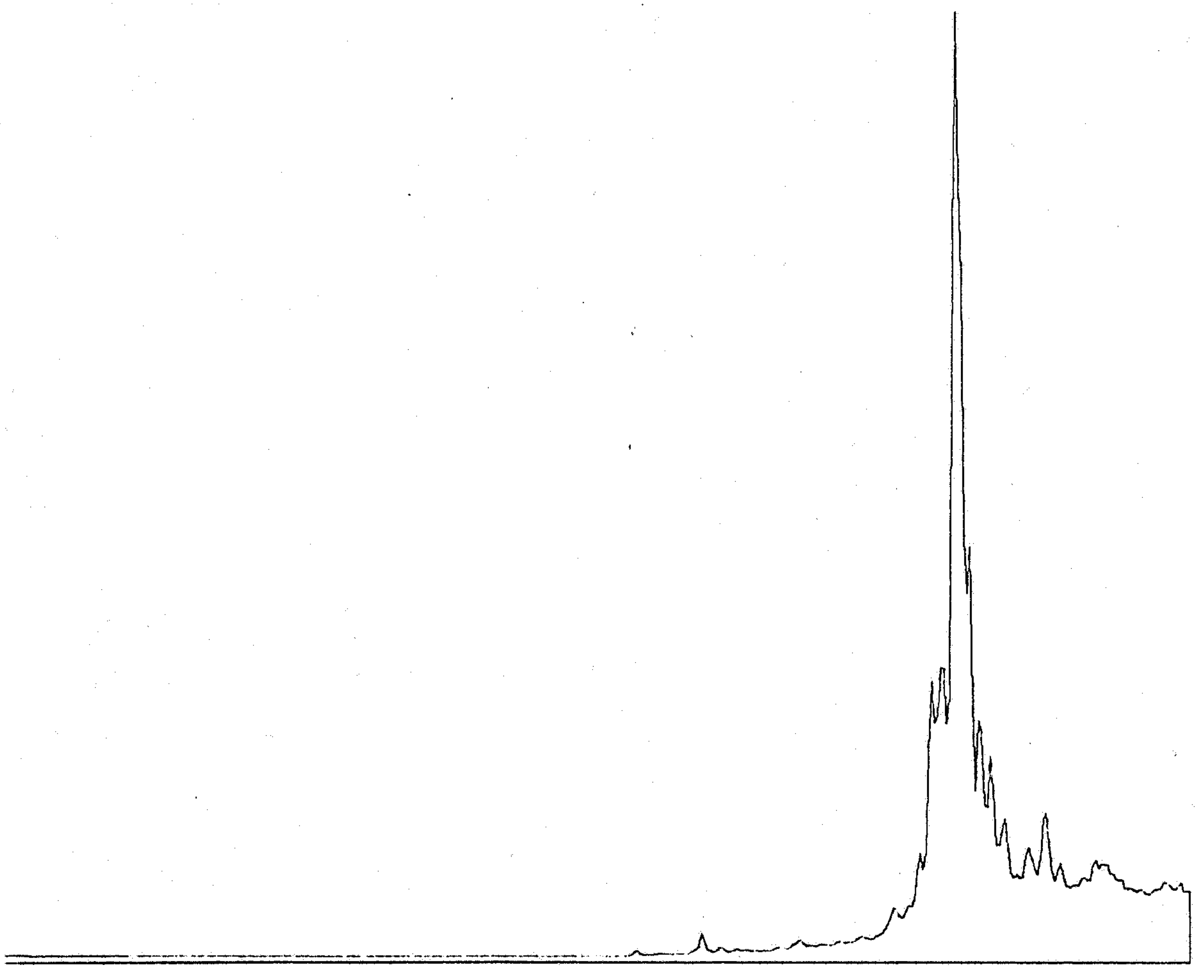


[0.0000] .2L RUN - 1 2875 AROMATICS SAMPLE 2
A131S B141S C178S D184S E192S ■206S

31/2-2 1516 m

M/Z = 206

ETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0 00 02	1.91	19.34	



[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2

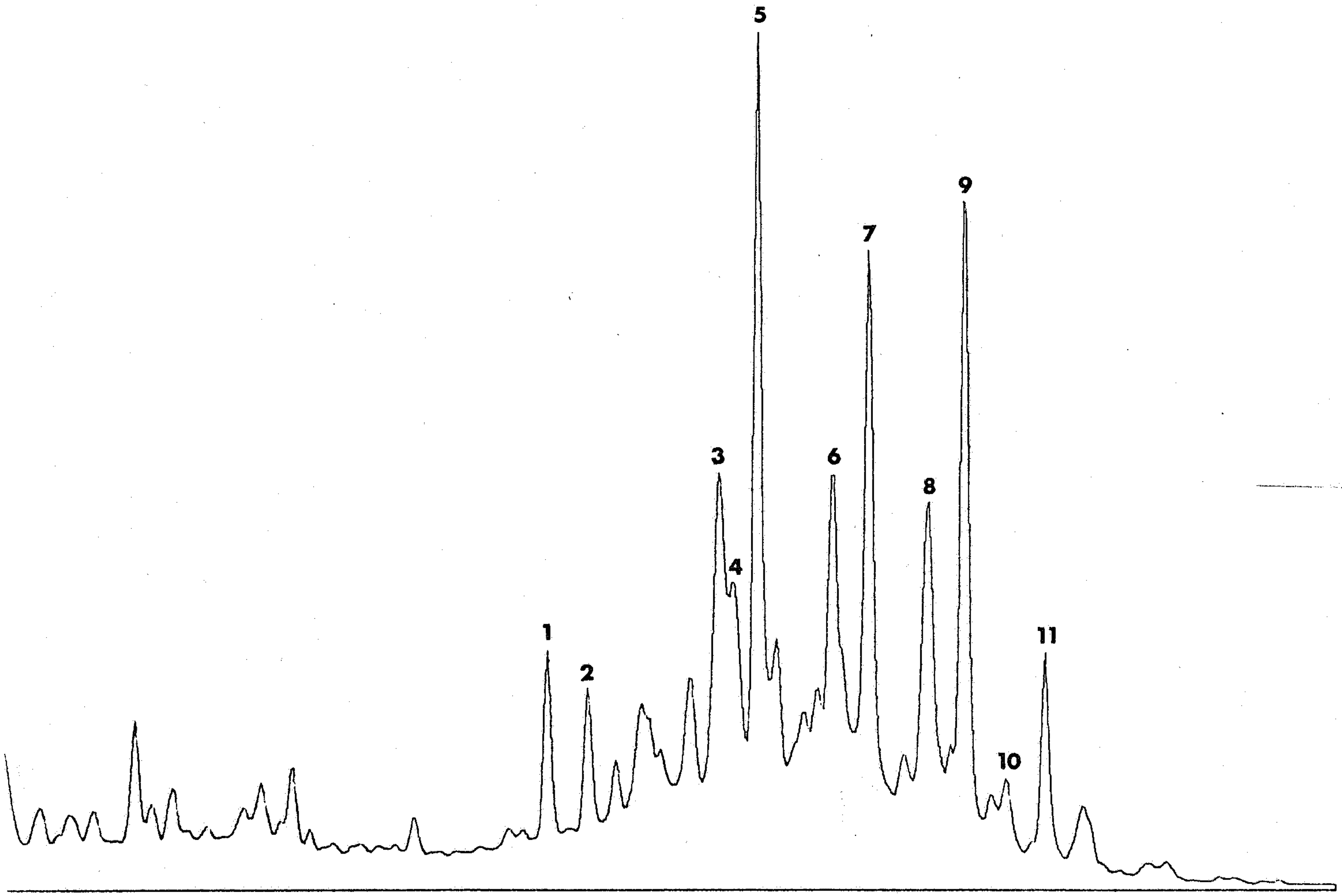
A181S B191S C199S D217S E253S F259S

RTN.TIME HEIGHT AREA UNCALIBRATED.

0:22:28 169.84 1073.02

31/2-2 1537 m

M/Z = 217

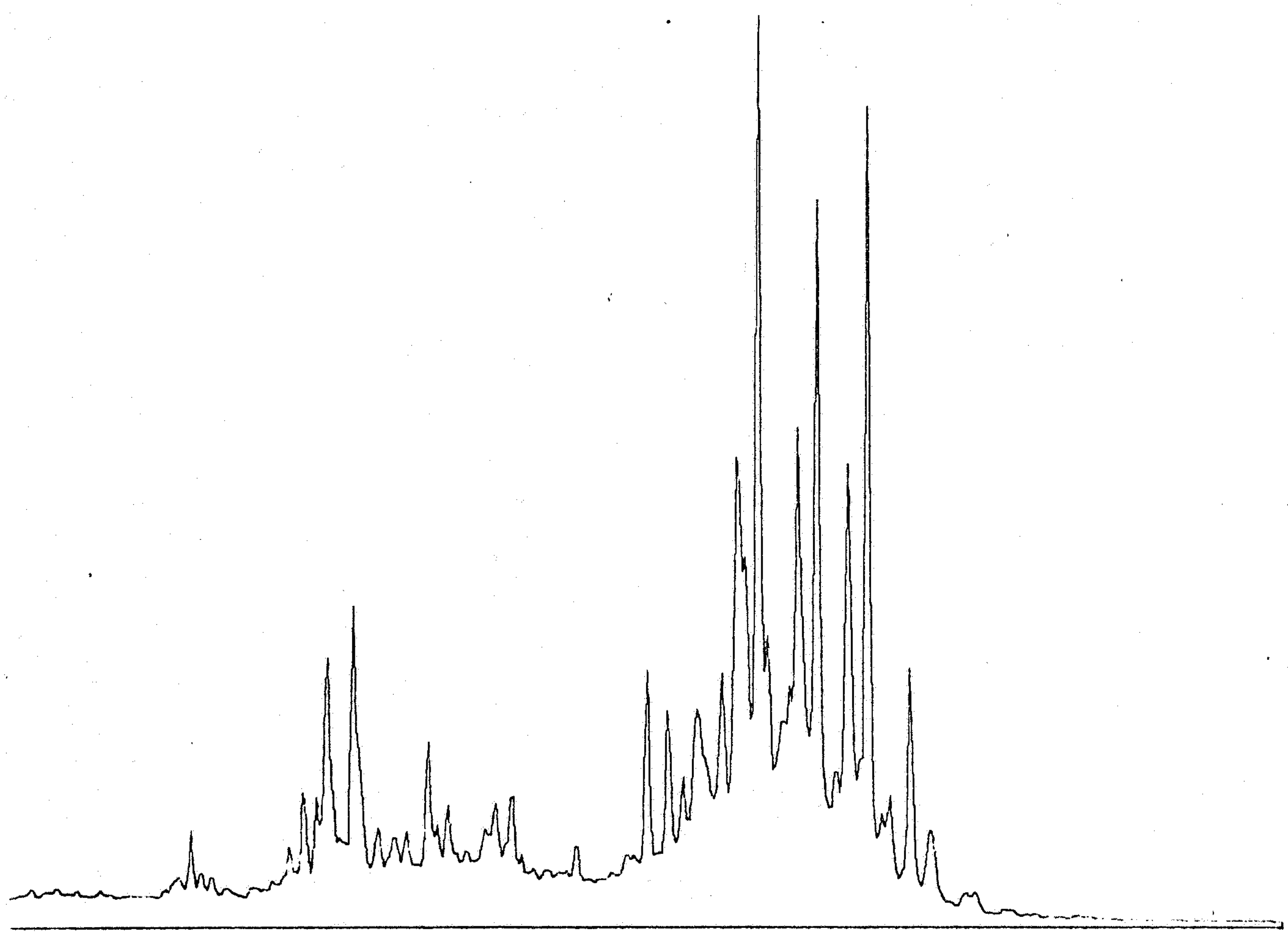


HRS 22 MINS 25 SECS 0 HRS 37 MINS 20 SECS

[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2
A181S B191S C199S ■217S E253S F259S
ETN.TIME HEIGHT AREA UNCALIBRATED.
0:15:05 14.15 144.27

31/2-2 1537 m

M/Z = 217



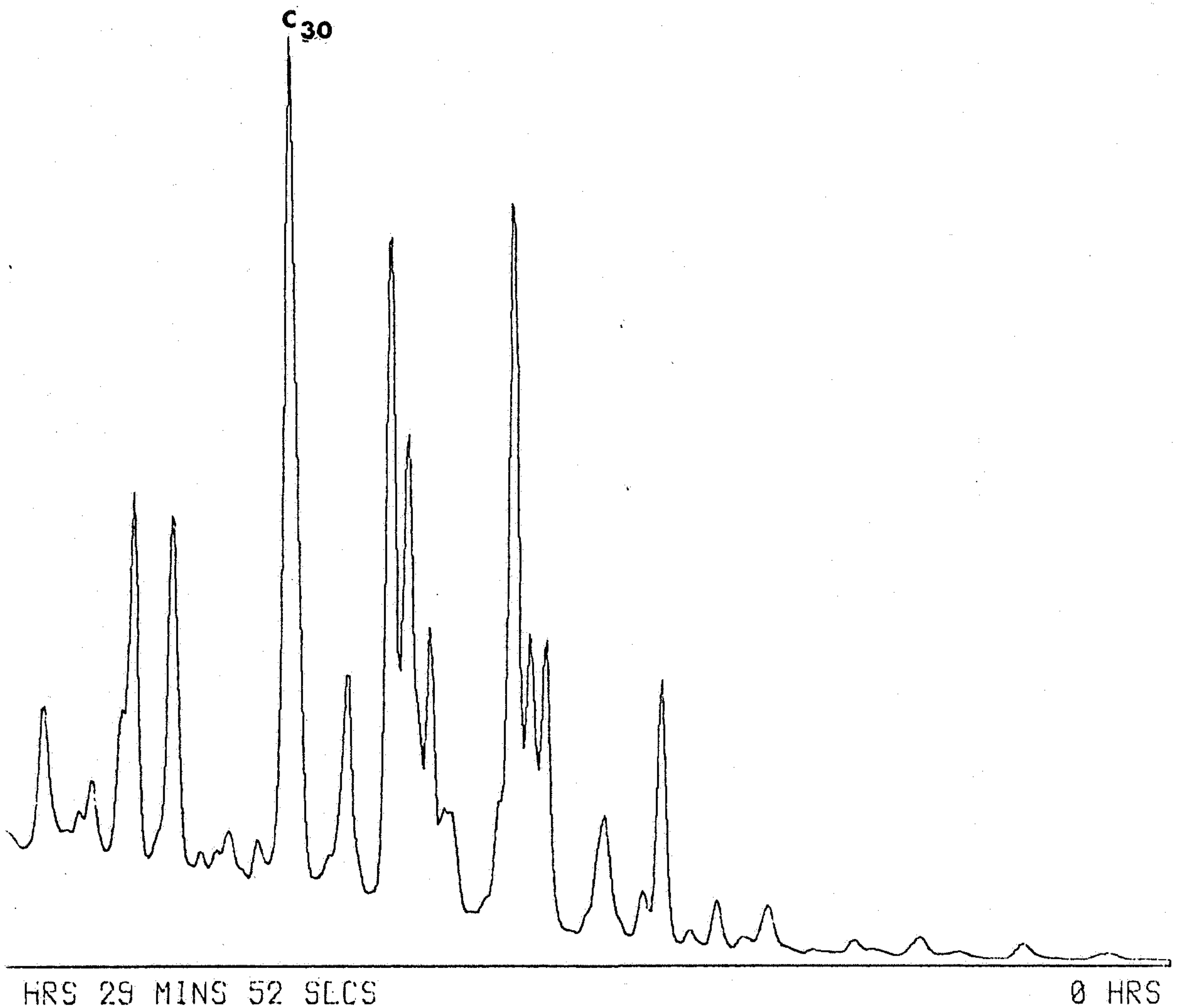
HRS 14 MINS 58 SECS

0 HRS 44 MINS 48 SECS

[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2
A181S B191S C199S D217S E253S F259S
ETN.TIME HEIGHT AREA UNCALIBRATED.
0:29:59 106.19 851.75

31/2-2 1537 m

M/Z = 191



Ɪ 0.0000Ɪ .2L RUN - 1 2876 SATURATES SAMPLE 2

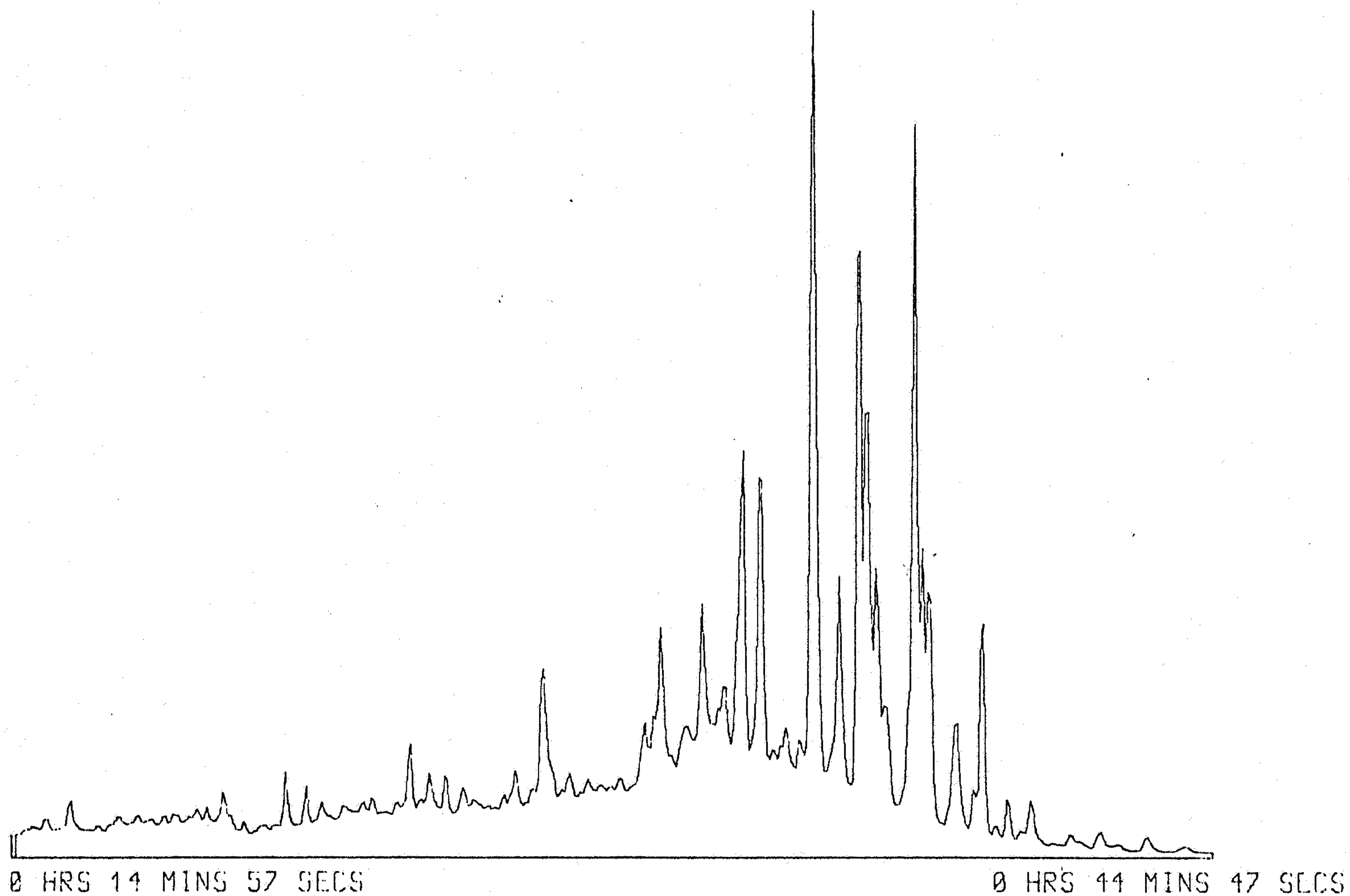
A181S ▥191S C199S D217S E253S F259S

RETN.TIME HEIGHT AREA UNCALIBRATED.

0:15:05 14.15 144.27

31/2-2 1537 m

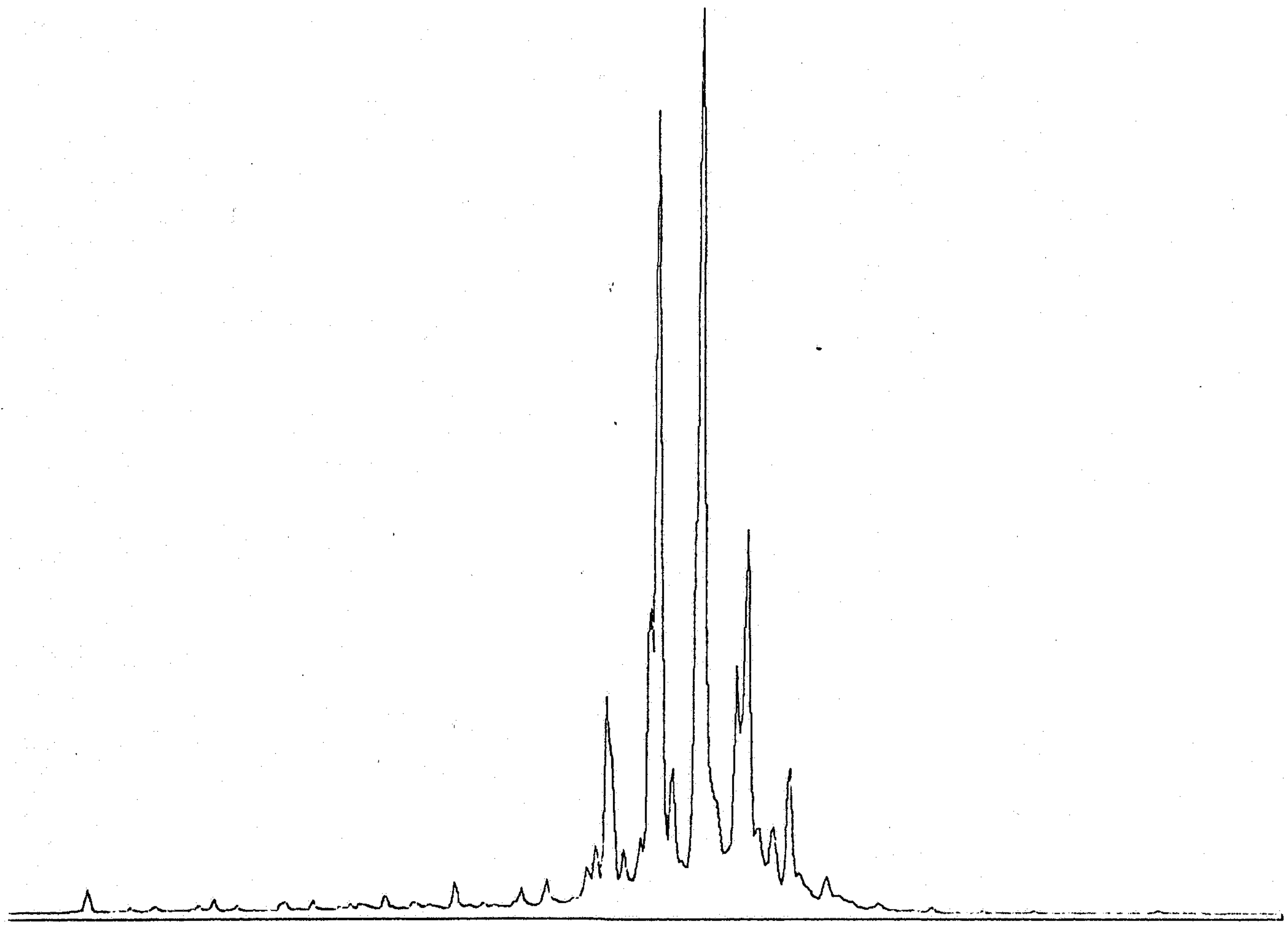
M/Z = 191



[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2
A181S B191S C199S D217S E253S F259S
ETN.TIME HEIGHT AREA UNCALIBRATED.
0:15:05 14.15 144.27

31/2-2 1537 m

M/Z = 253



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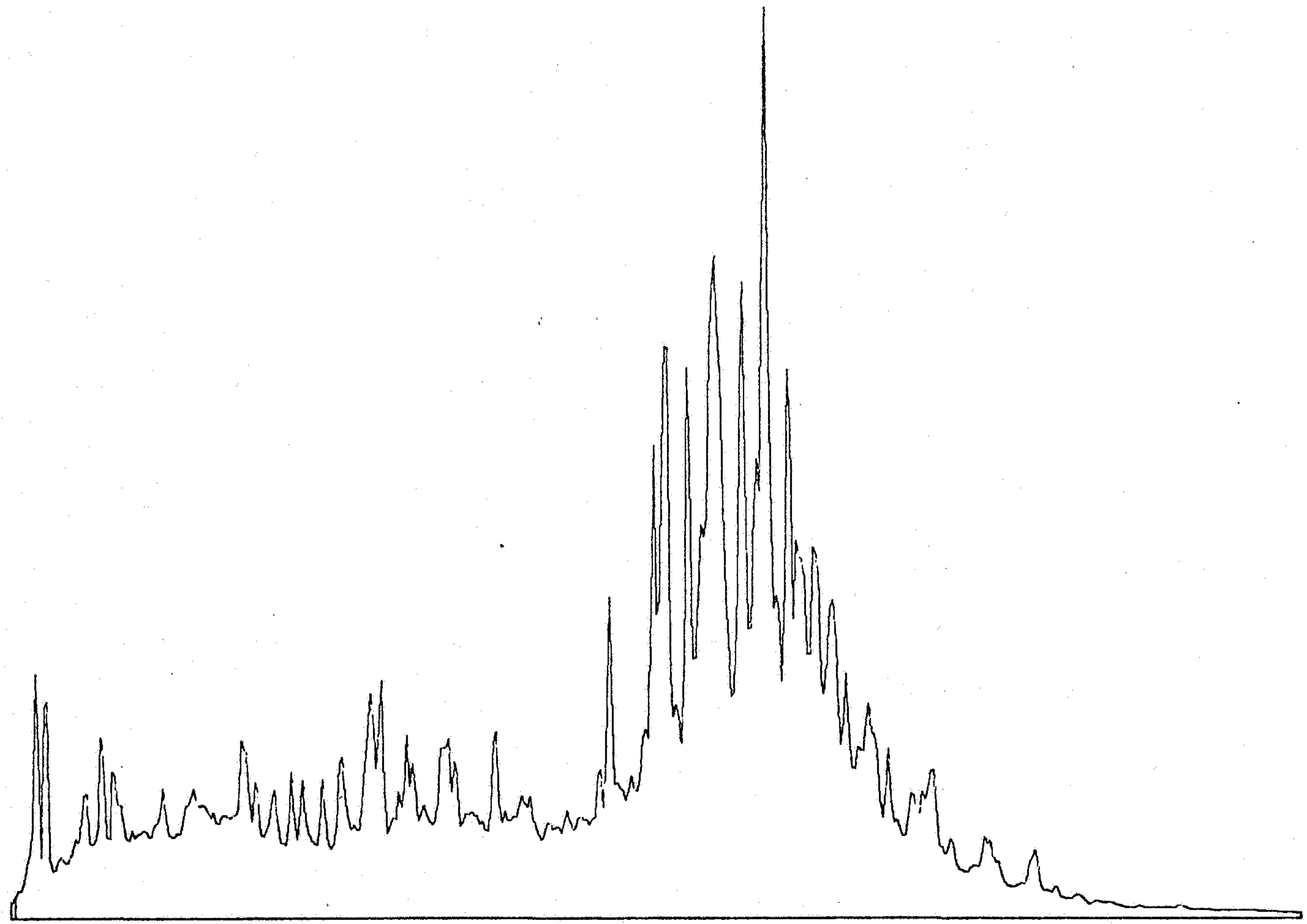
[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2

31/2-2 1537 m

A181S B191S C199S D217S E253S M259S

M/Z = 259

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0:15:05	14.15	144.27	



0 HRS 14 MINS 58 SECS

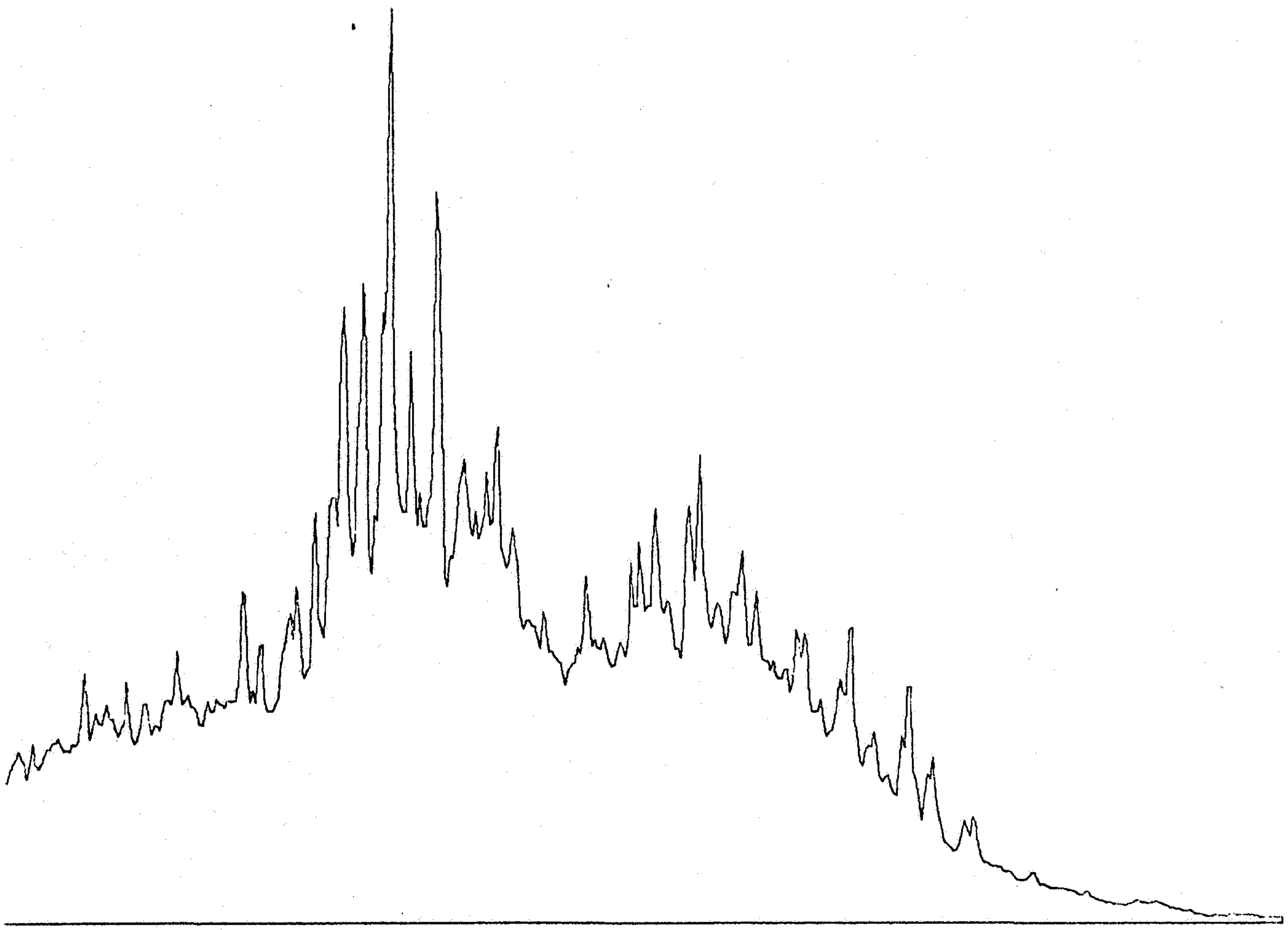
0 HRS 44 MINS 48 SECS

[0.0000] .2L RUN - 1 2876 SATURATES SAMPLE 2
A181S B191S M199S D217S E253S F259S

31/2-2 1537 m

M/Z = 199

ETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:15:05	14.15	144.27	



HRS 14 MINS 57 SECS 0 HRS 44 MINS 47 SECS

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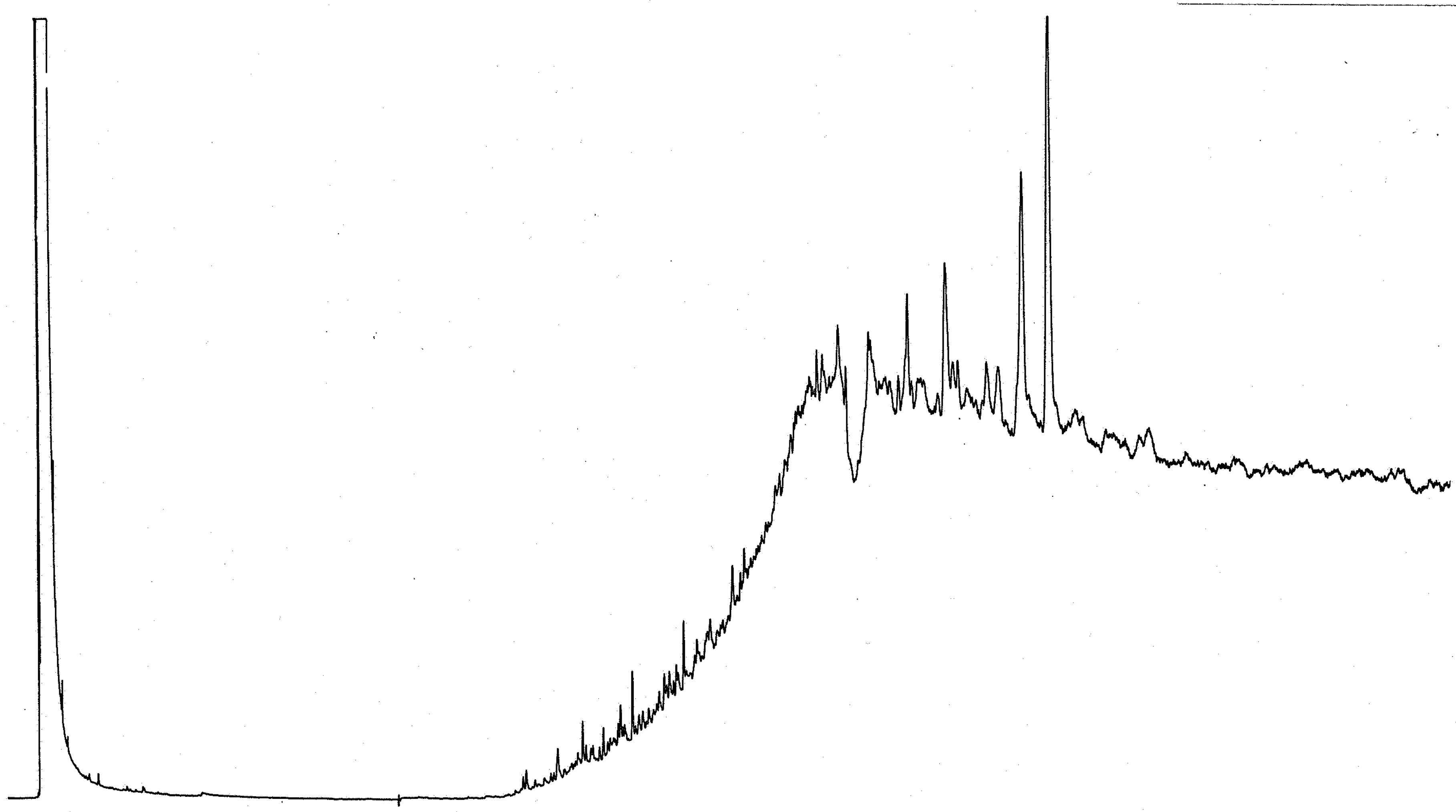
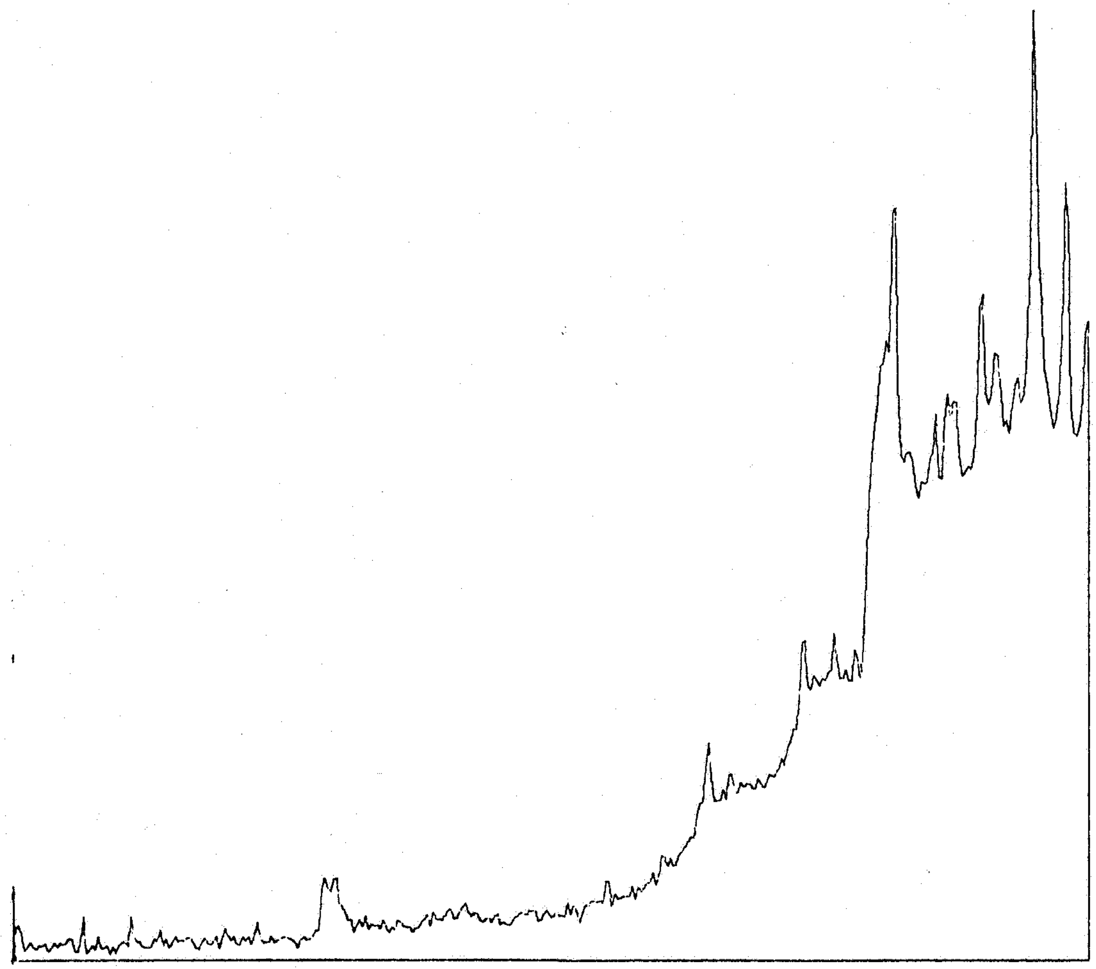
31/2–2 1537 m AROMATIC



[0.0000] .2L RUN - 1 2875 AROMATICS SAMPLE 2
A131S B141S C178S D184S E192S F206S
RETN.TIME HEIGHT AREA UNCALIBRATED.
0:00:03 1.36 9.53

31/2–2 1537 m
M/Z = 141



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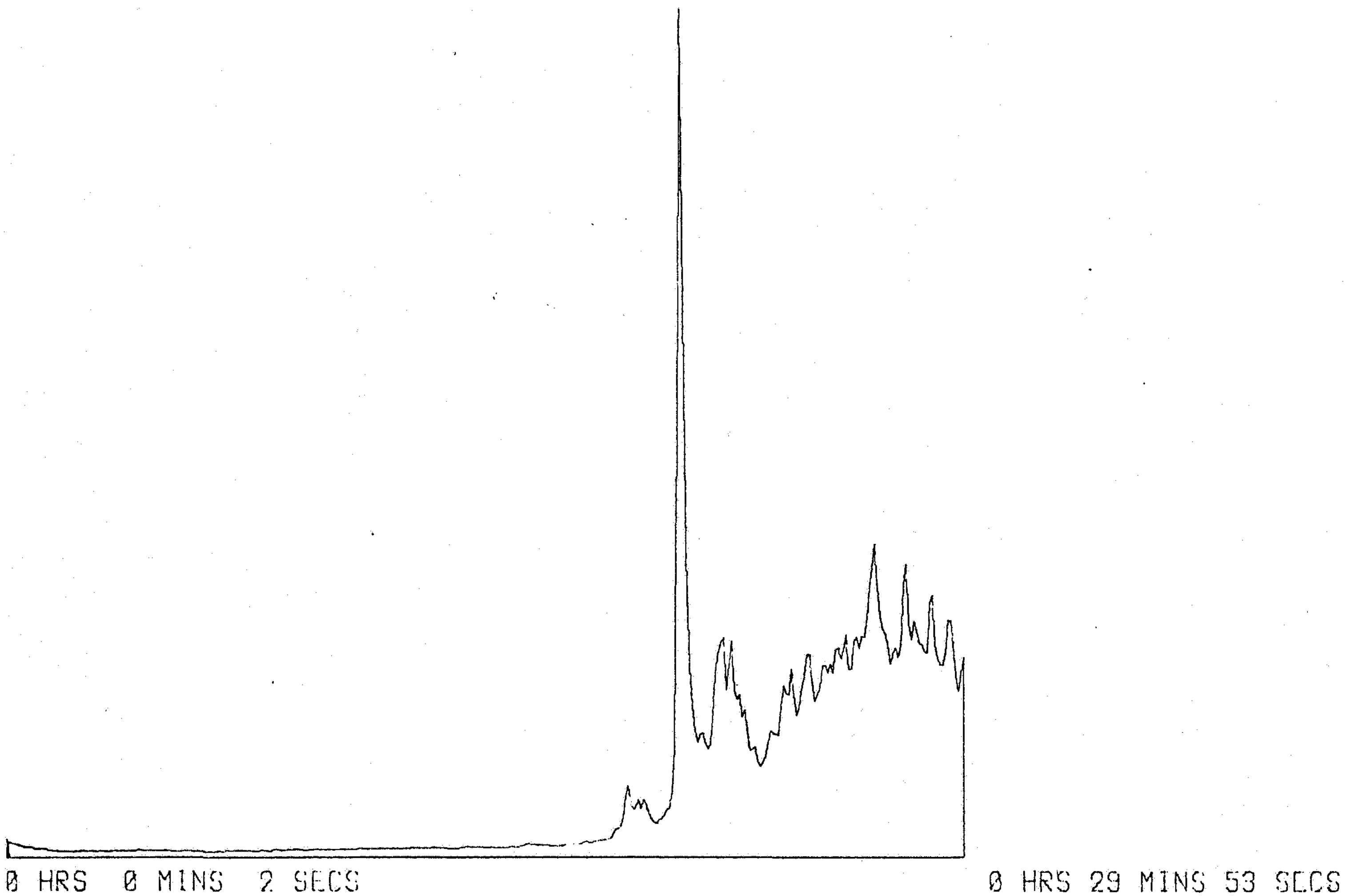
[0.0000] .2L RUN - 1 2876 AROMATICS SAMPLE 2
A131S B141S ▮178S D184S E192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:03	1.35	9.53	.

31/2–2 1537 m

M/Z = 178

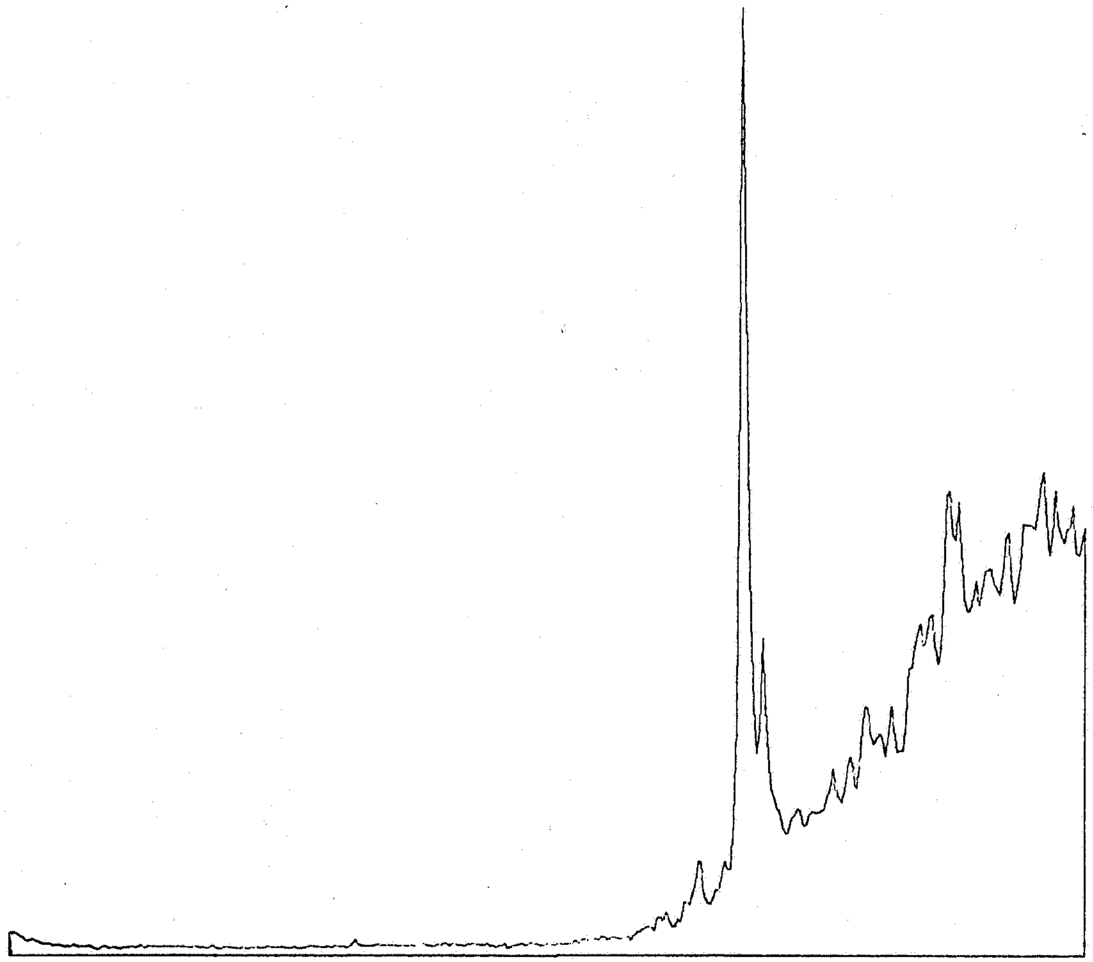


[0.0000] .2L RUN - 1 2876 AROMATICS SAMPLE 2
A131S B141S C178S ▩184S L192S F206S

RETN.TIME	HEIGHT	AREA	UNCALIBRATED.
0 00:03	1.35	9.53	

31/2-2 1537 m

M/Z = 184



0 HRS 0 MINS 2 SECS

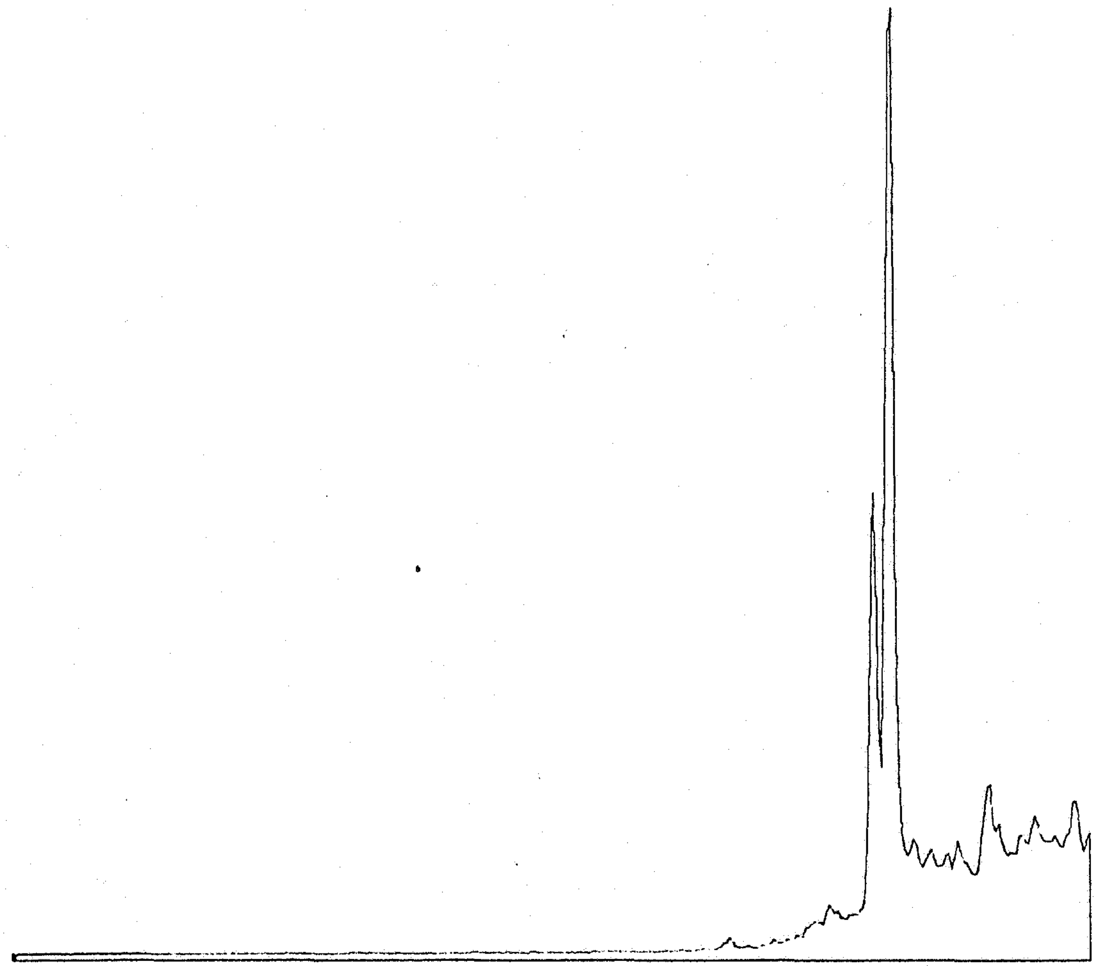
0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 2876 AROMATICS SAMPLE 2
A131S B141S C178S D184S ▩192S F206S

31/2—2 1537 m

M/Z = 192

RETN.TIME	HEIGHT	AREA	UNCALIBRATED
0:00:03	1.36	9.53	



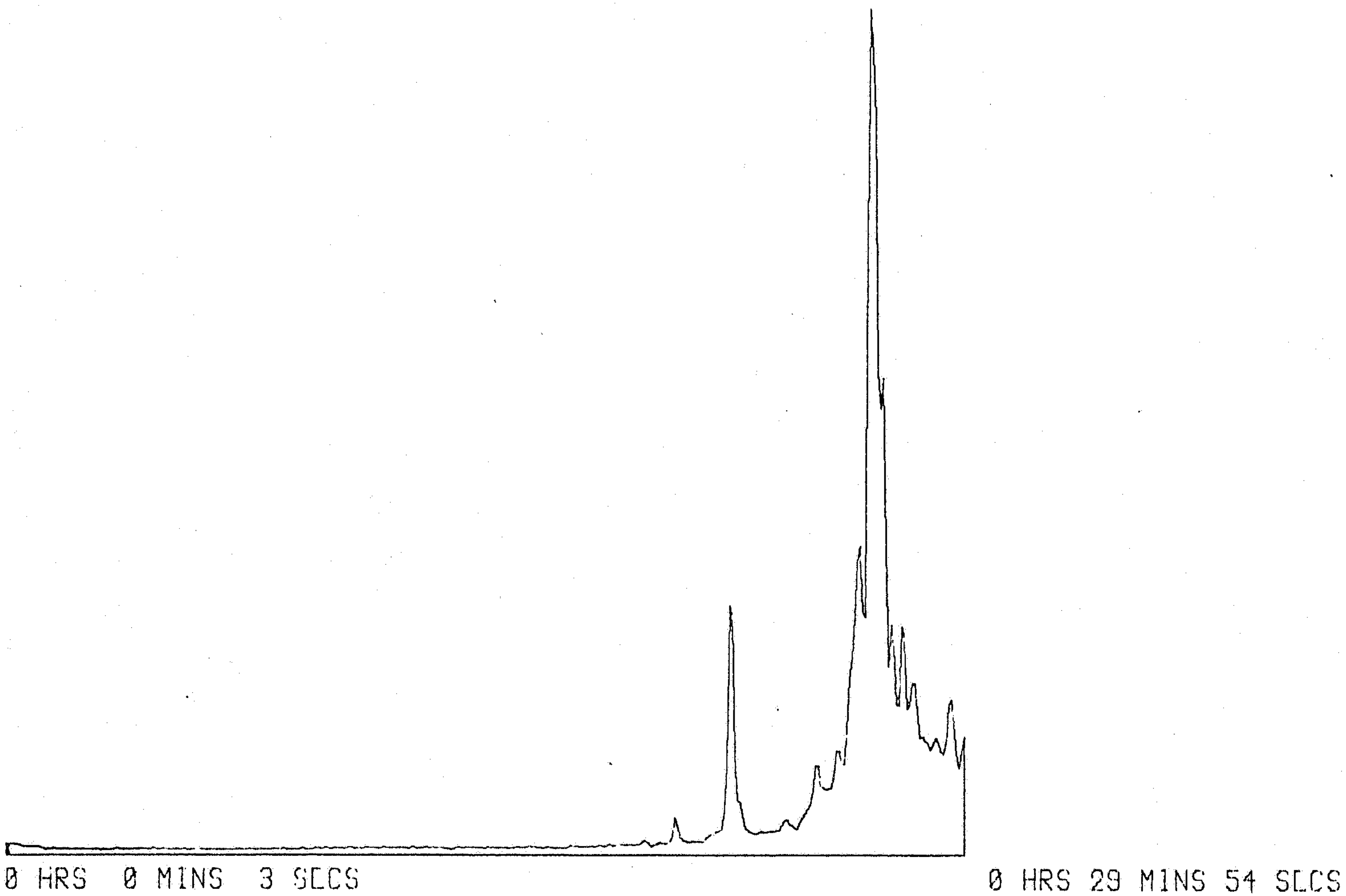
0 HRS 0 MINS 2 SECS

0 HRS 29 MINS 53 SECS

[0.0000] .2L RUN - 1 2876 AROMATICS SAMPLE 2
A131S B141S C178S D184S E192S W206S
RETN.TIME HEIGHT AREA UNCALIBRATED.
0:00:03 1.36 9.53

31/2–2 1537 m

M/Z = 206



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P A R T   T W O

BIOSTRATIGRAPHIC STUDIES

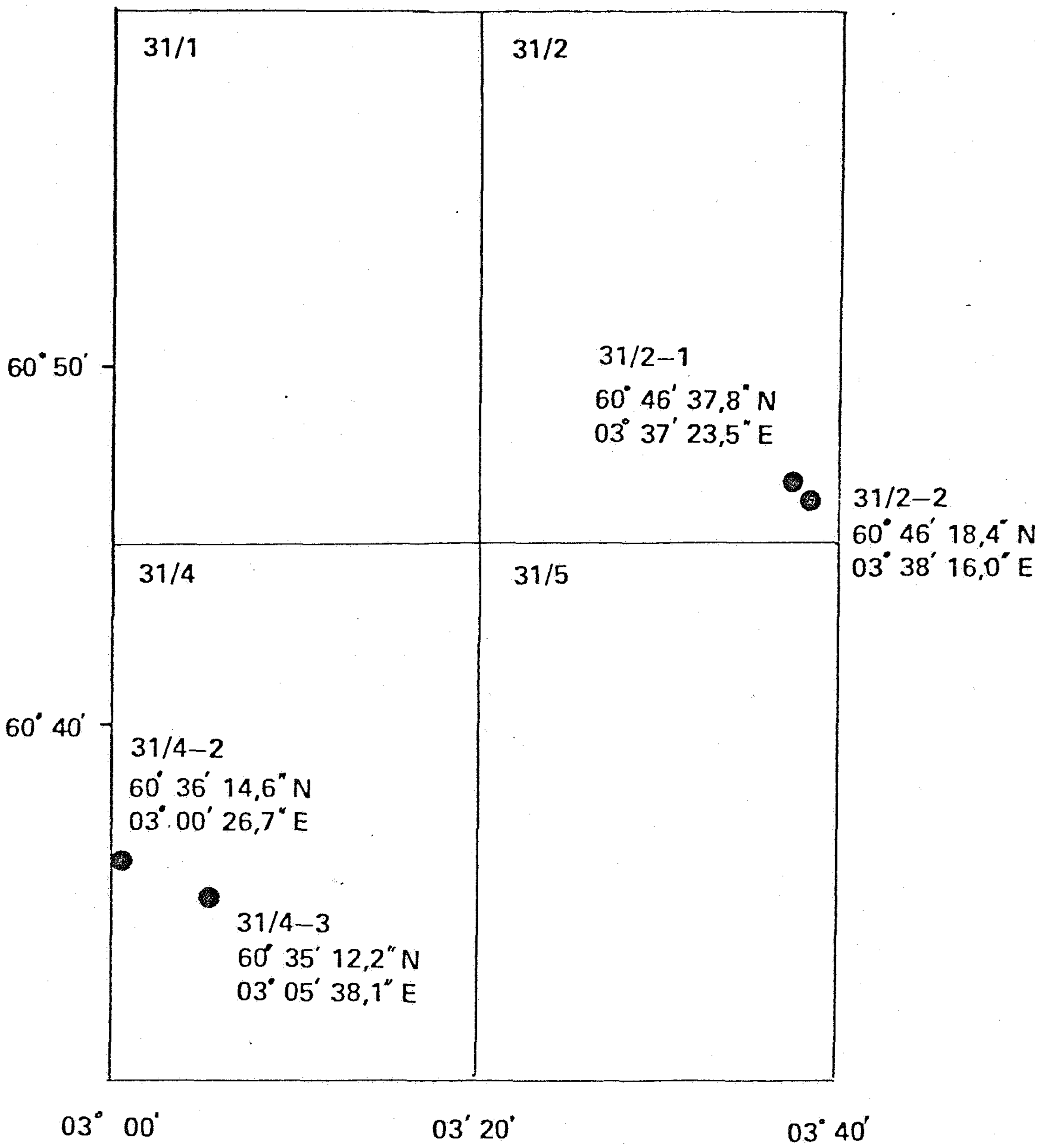
OBJECTIVES:

A: Age determination of the hotshale horizon in wells 31/2-1 and 2 and 31/4-2 and 3.

B: Assessment of the hotshale as a correlation factor.

Figure 1

POSITION OF WELLS



INTRODUCTION

This study involves palynological investigations of the age of "radioactive" lithological units in four wells from the northern part of the Norwegian North Sea (fig. B1). Material from wells 31/4-2, 31/4-3 and 31/2-1 was supplied by Norsk Hydro for whom the study was carried out. Use of data from well 31/2-2, recently analysed by IKU was courteously permitted by A/S Norske Shell. The analyses were carried out by Aarhus and Bell. Correlation, synthesis and coordination of the biostratigraphic study was carried out by Bell.

Quality, quantity and coverage of samples varies very considerably from well to well, but is generally good in wells 31/4-3 and 31/2-2 and rather poor in wells 31/4-2 and 31/2-1. The thickest of the "hot shale" sequences under consideration, as defined by log data received is in well 31/2-2. This well also has the best sample coverage and is therefore the most suitable for comparison with other sections.

DESCRIPTION OF INDIVIDUAL WELLS

Well 31/2-2

"Hot shale" sequence as defined: 1483 - 1543 = 60 m thickness. Material: 16 sidewall cores and 7 core chips. Fossil preservation: fair to excellent, mostly good.

0000 - 1465.5 m Early Hauterivian to Valanginian

Palynology

The 1465.5 m sidewall represents the lowest occurrence of Kleithriasphaeridium corrugatum and Ctenidodinium elegantulum. Pseudoceratium pelliferum is also not recorded below this level. These species conbined with the presence of Tubotuberella apatela and the occurrence of Pareodinia dasyforma immediately below suggest an Early Hauterivian or Valangian age. The palynological dating is confirmed by nannofossil evidence (see IKU report 0-264/1).

1472 - 1479 m Late Berriasian

Palynology

The record of Pareodinia dasyforma (simple spined variety) at 1479 m indicates an age no younger than Berriasian. The occurrence of Batioladinium micropodum (granulate variety) at 1479 m further suggests an age no older than Late Berriasian down to at least this level.

1481 - 1519.5 Berriasian to Late Portlandian

Palynology

The more or less regular and at times common occurrence of Pareodinia dasyforma indicates a Berriasian to Late Portlandian age. The exact position of the Jurassic/Cretaceous boundary cannot be easily determined on the basis of dinoflagellate cysts as significant (and moreover, reliably identifiable) floral breaks occur just above (Late/Middle Berriasian) and just below (Early/Late Portlandian) the boundary. The most significant aspects of the dinoflagellate assemblages are Sirmiodinium grossi (fairly common to abundant throughout), Wallodinium krutzschi, Pareodinia dasyforma, Apteodinium granulatum, Endoscrinium pharo (sporadic) and Egmontodinium torynum/ E. sp. A Davey 1979. Of these species P. dasyforma, which has a base around the Late/Early Portlandian boundary, is probably the most reliable stratigraphic index. Most other species tend to suggest that most of this interval may be in the younger part of the proposed age range though are not conclusive. Endoscrinium pharo is generally more typical of the Berriasian, though does extend down into the Portlandian. Egmontodinium torynum (sensu stricto) likewise is a Berriasian species though the distinction between this and Egmontodinium sp. A Davey 1979, which Davey records from the Late Portlandian, is not clear cut and the two may be synonymous.

It should, however, be pointed out that stratigraphic control (i.e. palynologically investigated, well-dated sections) is not good in the Late Portlandian. Nontheless, it is significant that the Early Portlandian suite of species is not recorded from this interval. The exception is the record of a single specimen of Senoniasphaera jurassica at 1493.5 m. This is thought to be due either to reworking or that the species continues in low numbers into the Late Portlandian.

1521.07 - (?)1556 m Early Portlandian to Late Kimmeridgian

Palynology

The 1521.07 m sidewall represents the first downhole record of an Early Portlandian/Late Kimmeridgian suite of species. Both Dinopterygium dimorphum and Senoniasphaera jurassica (which occurs regularly below this level) are recorded from this sample. Also of note is the occurrence of Gonyaulacysta perforans at 1521.07 m and below, and Ctenidodinium panneum at 1525.06 m and below. Prolixosphaeridium granulosum also occurs fairly consistently through most of the interval. Aspects of this species suite are present down to the 1543.5 m sidewall.

The base of the interval is somewhat uncertain. There is a distinct lithological change at 1543.5 m from claystone (above) to sandstone (below) containing only impoverished assemblages. The upper few metres of the sandstone at least seem to be no older than Late Kimmeridigan (possibly Early Portlandian!). The occurrence of Ctenidodinium culmulum at 1552 m indicates that the age at this depth is no older than Late Kimmeridgian. Below this depth the evidence is less convincing. The 1556 m core chip yielded Muderongia sp. 'A' Davey 1979 which probably does not extend lower than Late Kimmeridgian. It seems logical on the basis of the rather sparse palynoflora to include the uppermost few metres of the sandstone within this interval. The record of Gonyaulacysta jurassica at 1443.5 m is anomalous and may be due to reworking.

Well 31/2-1

Hot shale sequence as defined: 1414 - 1439.5 m = 25.5 m thickness. Material: 5 cuttings samples. Fossil preservation: fair to moderate.

Remarks

Only five samples were available from the "hot shale" interval together with two samples above and five samples below the specified interval. All samples were cuttings. Very limited amounts of material were available and recovery in some samples was poor. Tertiary and Late Cretaceous contamination is evident in some samples. In view of the relatively poor sample material, lack of sidewall/core control and lack of control from higher in the well the suggested biostratigraphy must necessarily be rather tentaive.

0000 - 1390 m Indeterminate

Palynology

Few cysts were recovered from this interval. Ceratiopsis boloniensis / pannucea, Hystrichosphaeridium tubiferum and Palaeocystodinium cf. rhomboides testify to the presence of Late Cretaceous/Early Tertiary deposits in the well, though these are probebly caved at this level. The presence of Pterospermopsis spp. could indicate an earliest Cretaceous/latest Jurassic age. This genus is particularly common around the Jurassic/Cretaceous boundar, though is not restricted to deposits of this age.

1402 m ?Early Cretaceous

Palynology

The presence of Sirmiodinium grossi and Dingodinium alberti could be taken as evidence of an Early Cretaceous age. S. grossi ranges down into Middle Jurassic strata. The base of D. alberti is somewhat uncertain.

1414 m: no recovery

1420 - 1426 m Berriasian to Late Portlandian

Palynology

The record of Pareodinia dasyforma at 1426 m indicates, if in situ (i.e. not caved), an age no younger than Berriasian. This species has a base around the Late/Early Portlandian boundary. The presence of Bourkidinium? sp. (an undescribed species with trumpet like polar processes) lends some support to this dating. This species was recovered from well 31/2-2 at 1489,5 m, also of Berriasian/Late Portlandian age.

1432? - 1456? m Early Portlandian to Late Kimmeridgian

Palynology

The limits of this interval are uncertain though the occurrence of Senoniasphaera jurassica and Gonyaulacysta perforans at 1438 m can be taken as evidence of an Early Portlandian/Late Kimmeridgian age. The records of Gonyaulacysta longicornis at 1432 m, and Muderongia sp. A Davey 1979 at 1456 m could suggest that the interval extends to at least this level. However, additional evidence is lacking and the interval limits must be regarded tentatively.

1468 - 1492 m Indeterminate Late Jurassic

Palynolgy

The three samples represented by this interval are contaminated by Late Cretaceous/Tertiary material. However, Sirmiodinium grossi, Oligosphaeridium cf. pulcherimum, Dingodinium sp., Scriniodinium sp. and Apteodinium nuciforme were recorded suggesting a Late Jurassic, probably Kimmeridgian age.

Well 31/4-3

Hot shale sequence as defined: 2011 - 2018 m = 7 m thickness. Material: 4 sidewall cores, 2 cuttings samples. Fossil preservation: mostly good.

2011.5 - 2015 m Late Berriasian

Palynology

The presence of Pareodinia dasyforma in the 2011.5 m sidewall and below indicates an age probably no younger than Berriasian. The record of Pseudoceratium pelliferum at 2011.5 to 2015 m further implies an age no older than Late Berriasian down to at least this level. Together, these occurrences infer a Late Berriasian age between 2011.5 and 2015 m.

2016.5 m Berriasian to Late Portlandian

Palynology

P. dasyforma was again recorded from this sample infering an age no older than Late Portlandian. This sample could be of similar age to the above interval though the presence of Egmontodinium polyplacophorum may indicate a slightly older age, possibly around the Late/Early Portlandian boundary. It should be noted, however, that forms similar to E. polyplacophorum (and intermediate forms) are known from slightly younger strata.

2020/24 (cuttings) - 2034 m Early Portlandian to Late/Middle Kimmeridgian

Palynology

Pareodinia dasyforma is not recorded from sidewalls below 2016.5 m (though does occur in cuttings) suggesting a pre-Late Portlandian age. The presence of Senoniasphaera jurassica in the 2020/24 m cuttings sample and the 2030 m sidewall, which also yielded Dinopterygium dimorphum, suggests and Early Portlandian or Kimmeridgian age. Moreover, as a number of elements normally associated with at least the upper part of the Early Portlandian are lacking, the interval may be of Kimmeridgian (Late/Middle) age. An Early Portlandian age is not excluded.

Well 31/4-2

Hot shale sequence as defined: 2146 - 2171 m = 25 m thickness.
Material: 8 cuttings samples + bulk geochemistry samples.
Fossil preservation: poor.

Remarks

Sidewalls shot in the vicinity of this interval yielded consistently Late Cretaceous, probably Maastrichtian palynological assemblages. This is thought to be due to misfiring of the gun. They are therefore not considered in the following account. The cuttings also gave rather poor results, containing large amounts of sapropelic material, poor preservation (often very poor) and Late Cretaceous caving.

The stratigraphy between identifiable Late Cretaceous deposits and the hot shale is rather confused. There is evidence (usually not in situ!) of the presence of more than one geological period in this interval. We have not though, managed to identify with certainty exact depths and interval limits. This may be due to very thin remnants or lenses of differing ages, thinner than the (contaminated) cuttings can resolve. We have attempted to summarize at least in part, some of the epochs represented by the fossils recorded though we have not been able to place these within definitive intervals.

2050 - 2115 m Maastrichtian to Late Campanian

For details on the evidence for the dating of this interval see IKU report 0-239, Biostratigrapy of Norsk Hydro (N) 31/4-2 p. 9.

2115? - 0000 ?Turonian to ?Cenomanian

Nannofossils

A nannofossil assemblage characterising the level near to the Turonian-Cenomanian boundary is recorded from the 2115 m sidewall. As the sidewall depths are unreliable we cannot be certain of the interval limits, though this is presumably below 2115 m. For details see IKU report 0-239, appendix II p. 45.

Palynology

The records of Achomosphaera sagena at 2140 m, (possibly caved), an uncertain record of Palaeohystrichophora infusoroides at 2134 m and Carpodinium obliquicostatum at 2160 m (caved) suggest the presence of Middle Cretaceous, possibly Late Albian to Turonian, at some level in the well.

0000 - 0000 m Neocomian

Nannofossils

At 2194 m a highly characteristic Nannoconus association of probable Hauterivian-Barremian age is recorded. At this level the assemblage is certainly caved. For details see IKU report 0-239 p. 10-11 & appendix II p. 47.

0000 - 0000 m Berriasian to Late Portlandian

Palynology

The index fossil Pareodinia dasyforma is recorded (caved) at 2372 m. This suggests the presence of Berriasian to Late Portlandian deposits at some level in the well.

2146? - 2170 m ?Early Portlandian to Late/Middle Kimmeridgian

A single specimen of Gonyaulacysta longicornis is recorded from the 2146 m cuttings. This could indicate an Early Portlandian or Late Kimmeridgian age. Other evidence is rather weak and fossil preservation poor. Three very questionable records of Pseudoceratium pelliferum are made between 2160-2170 m. These are Late Berriasian and younger species. Preservation is so poor that it is impossible to be certain of the identification. This dating clashes with the suggested dating for this interval. As there is one suggestion of Neocomian strata in the well their presence could be due to caving. A questionable specimen of Dinopterygium dimorphum is also recorded at 2170 m. D. dimorphum has a top in the Early Portlandian and extends down into the Kimmeridgian. A bulk sample from 2158-2178 m, prepared as a part of the organic geochamical investigation yielded Heslertonia pellucida and Egmontodinium polyplacophorum both of which have tops in the Early Portlandian. The latter specimen has well developed and entire lists and as such is distinct from Egmontodinium sp. A Davey 1979 and E. torynum. E. polyplacophorum is not thought to extend lower than the Late/Middle Kimmeridgan.

CORRELATION

Suggested correlation of the units defined is presented in figure 6, Fossil evidence is outlined in the figure text. The correlations are based on fossil occurrence/non-occurrence. It is important to point out some of the limitations of such correlations. As noted, the non-occurrence of fossil species is a factor taken into account, though in many circumstances we have little control on "non-occurrence" which may be due to poor material. This could result in some of the intervals being more or less synonymous, for example, the Berriasian/Late Portlandian of well 31/4-3. This is based on the absence of Late Berriasian forms in the single sidewall core constituting this interval. The sample could be of Late Berriasian age, though in the absence of Late Berriasian forms we do not feel justified in including this with the Late Berriasian immediately above. Nevertheless, it seems fairly clear that the bulk of the interval described as Berriasian/Late Portlandian in 31/2-2 (c.38 m) is very much reduced (or absent) in 31/4-3.

The relatively good sidewall/core control available in wells 31/4-3 and 31/2-2 is lacking in wells 31/4-2 and 31/2-1. The correlations are thus considerably more tentative. In well 31/4-2, due to problems of questionable sidewall depths and the poor cuttings samples, we have not been able to confidently identify Late Berriasian or Berriasian/Late Portlandian. However, the presence of caved specimens of the index fossil for these intervals, Pareodinia dasyforma, does suggest the possibility of a thin deposit of this age, presumably in the vicinity of, or slightly above 2146 m.

In 31/2-1 recovery in the upper part of the hotshale unit is poor though the record of P. dasyforma at 1420 m does suggest the presence of Berriasian or Late Portlandian deposits at or close to this level. A tentative correlation is therefore proposed.

The distinction between Late Portlandian/Berriasian and Early Portlandian/Late Kimmeridgian in 31/2-2 is fairly clear, and takes place around the middle of the hotshale unit as defined. This is drawn between the base of P. dasyforma (1519.5 m) and the top of Senoniasphaera jurassica (1521.07 m) and associated species. This floral break may in fact be slightly lower than the Late/Early Portlandian boundary sensu stricto though the break is a convenient marker which for the purpose of this study is taken as representing in practical terms the approximate position of the Late/Early Portlandian boundary. This floral break is also fairly clear in 31/4-3 though a number of species normally associated with S. jurassica make their first downhole occurrence slightly lower (e.g. Dinopterygium dimorphum). Also of note is that there are fewer species typical of latest Kimmeridigan/Early Portlandian in well 31/4-3 though as there are only two sidewalls and two cuttings from this interval (compared with 11 in 31/2-2) this is perhaps not unusual. Nevertheless, reasonably good correlation of this floral break is apparent between 31/2-2 and 31/4-3 (correlation lines 3A-3B in fig. 6).

Correlation is less certain with wells 31/4-2 and 31/2-1. In 31/4-2 the record of Gonyaulacysta longicornis at 2146 m represent some evidence, albeit rather weak, of Early Portlandian/Kimmeridgian. Less useful, but nevertheless positive evidence is the record of Eymontodinium polyplacophorum in the bulk organic geochemistry sample from 2158/2178 m. In well 31/2-1 the evidence is somewhat more positive and consists of the occurrence of G. longicornis at 1432 m, S. jurassica at 1438 m and Muderongia sp. A Davey 1979 at 1456 m.

The base of the Early Portlandian - Late/Middle Kimmeridgian interval as drawn in this study is somewhat incidental and may not represent a true time plane. In 31/2-2 the base does not seem to be coincident with the change in lithology which takes place around 1540-1545 m. At least the upper few metres of the sandstone belong on grounds of floral similarity to this interval as is evidenced by the occurrence of Ctenidodinium culmulum at 2147 m, Muderongia sp. A Davey 1979 at 1556 m and Pterospermopsis p. together with an uncertain record of Ctenidodinium panneum also at 1556 m. Below 1556 m, there is little convincing evidence and hence we delimit the downward extension to 1556 m.

In 31/4-3 the lower limit is placed at the lowermost occurence of Senoniasphaera jurassica. This species probably continues down into Middle and possibly Early Kimmeridgina deposits but is most common in Late Kimmeridgian and Early Portlandian deposits.

In 31/4-2 the interval is underlain by Oxfordian deposits and in 31/2-1 by indeterminate Late Jurassic.

Figur 6: (in enclosure)

1A/1B: Top Late Berriasian in 31/2-2 & 31/4-3 by top P.dasyforma.

1C : Presence of Berrasian/Late Portlandian suspected on the basis of (caved) P.dasyforma.

2A : "Late" Berrasian in 31/2-2 defined by presence of P.dasyforma and lowermost occurence of B.micropodum.

2B : "Late" Berrasian in 31/4-3 defined by presence of P.dasyforma and lowermost occurence of B.micropodum and P.pelliferum.

2C : As 1C.

3A : Berriasian/Late Portlandian and Early Portlandian/Late Kimmeridgian boundary in 31/2-2 defined by base P.dasyforma and top S.jurassica, D.dimorphum and Ct. panneum.

3B : As 3A but in 31/4-3 defined by base P.dasyforma and top S.jurassica only.

3C : As 1C.

3D : As 3A, boundary is suggested on the basis of P.dasyforma at 1426, G. longicornis at 1432 and S.jurassica at 1438 m.

4A : Limit of Early Portlandian/Late Kimmeridgian extended down to lowermost records of Muderongia sp. A Davey 1979 and Ct. culmulum.

4B : Lower limit uncertain, S. jurassica occurs at 2034 m.

CONCLUSIONS

The hot shale units in these wells represents a highly distinctive stratigraphic horizon easily recognisable on electric wire logs. The formation differs consderably in thickness from well to well (c. 7 m - 70 m) and falls within the same broad age range: Late Kimmeridgian to Late Berrasian, in each of the wells. In detail however, there are minor, but significant inconsistencies in the ages of the formation from well to well. In view of the value of this unit in correlation and the emphasis normally placed on log correlations the following questions seem to beg an answer:

1. What is the cause of the apparent variation in age and is this a result of differing interpretations of fossil data?
2. What is the value of hot shale in correlation and does it represent a uniform, age synchronous stratum?

The origin of "hot shales" is not fully understood though is thought to be due at least in part to formation of a stratified water column, anoxic bottom conditions and concentration of radioactive minerals by micro-organisms (see Degens & Stoffers and others in J. geol. Soc. London, v. 137 1980). That is: particular environmental conditions which may or may not have been stable over considerable areas for shorter or longer periods of time.

Whilst it must be admitted that correlation of the four wells involved in this study is far from satisfactory and that a number of the proposals are questionable, the data does enable the main points of interest, as formulated above to be answered. The good sidewall and core coverage of wells 31/4-3 and 31/2-2 make these particuarly suitable. We make the following observations:

1. The upper part of the hot shale in well 31/4-3 is of Late Berriasian age. This is well documented by fossil data.
2. The Late Berriasian interval as recognised in well 31/2-2 lies some few metres above the top of the hot shale unit as defined in this well.
3. In well 31/2-2 the greater part of the interval referred to the Berriasian-Late Portlandian (c. 35-40 m) lies within the hot shale.
4. In well 31/4-3 the Berriasian-Late Portlandian interval is either very much reduced (max. 2 - 6 m) or is absent (see notes under individual well discussions).

5. The Early Portlandian-Late Kimmeridgian interval of well 31/4-3 is below the level of the hot shale.
6. The greater part (20-25 m) of the Early Portlandian-Late Kimmeridgian of well 31/2-1 is within the hot shale unit.
7. The nature of the sample material in wells 31/4-2 and 31/2-1 precludes detailed correlations of the units recognisable in wells 31/4-3 and 31/2-2 though there is evidence to suggest that

   a) The greater part of the hot shale unit in 31/4-2 is of Early Portlandian to late or Middle Kimmeridgian age.
   b) At least the Berriasian-Late Portlandian and Early Portlandian-Late Kimmeridgian intervals seem to be represented in part by the hot shale unit.

These observations enable the following general conclusions to be made concerning the hot shale units identified in the four wells involved in this study:

I The hot shale unit in the wells under consideration ranges in age from Late Berriasian to Early Portlandian/Late Kimmeridgian and its presence enables general correlation of the deposits around the Cretaceous/Jurassic boundary.

II Deposition of the hot shale seems to have commenced and ended at slightly different times over the area: note for example that the Late Berriasian of 31/4-3 lies within the hot shale unit and that the Late Berriasian of 31/2-2 is above it.

III The unit seems to be of more restricted value for detailed chronostratigraphic correlations. Given that non-sequences could occur at various levels presence of thin hot shale units in different wells could give widely differing ages(Kimmeridgian-Late Berriasian at least).

Some clarification of points II and III is required. The intervals are based on fossil evidence and are therefore dependent on the recording of particular species and also on the resolution (i.e. how precisely the range and extension of the fossil in time, are known). We have very little control on structural limitations: we do not know how thick the various intervals may have been, only their thicknesses as recorded today. If we consider these points both singly and together a number of reservations to our general conclusions can be pointed out. As examples we note the following:

- The Late Berriasian is defined by the overlapping ranges of at least two species, one having a base, the other a top in the Late Berriasian. It is for example, possible that Late Berriasian fossils are present, but not recorded (in fact none were recorded) in the upper part of the hot shale sequence of 31/2-2. This would require a downward revision of the Late Berriasion and thus the top of the hot shale would synchronous in both 31/2-2 and 31/4-3. Similarly, a non-sequence excluding part of the Berriasian/Late Portlandian and Late Berriasian intervals in 31/2-2 could explain the lack of hot shale in the Late Berriasian of 31/2-2, though would also imply removal of a non-radioactive part of the Late Berriasian of 31/4-3.

- In like manner a non-sequence between the base of the hot shale in 31/4-3 and the lower part of the Early Portlandian/Late Kimmeridgian interval of this well could explain the absence of hot-shale from the Early Portlandian-Late Kimmeridgian of 31/4-3. In this case our Early Portlandian-Late Kimmeridgian interval in 31/4-3 would have to represent the lower part, i.e. pre-hotshale facies of the Early Portlandian-Late Kimmeridgian of 31/4-3.

These reservations are rather hypothetical and require postulation of a series of minor non-sequences for which we have very little evidence. On balance, we favour an environmental model, in which the facies resulting in hot shale deposits began and ended at slightly differing times over the area.

APPENDIX THREE

DISTRIBUTION CHARTS

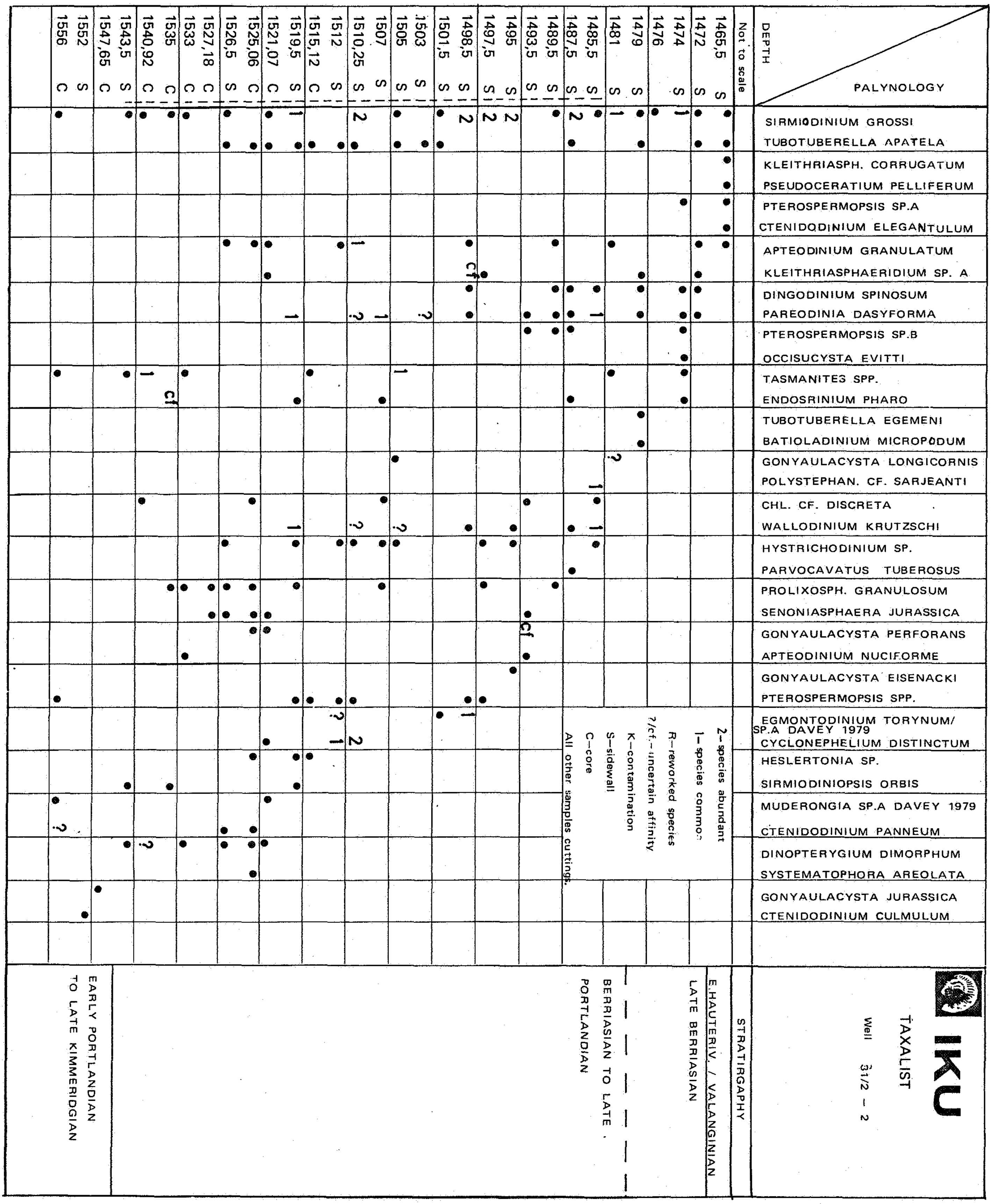


Fig. 2. Well 31/2-2, Palynology of the 'hot shale' interval.
---- hot shale as defined.

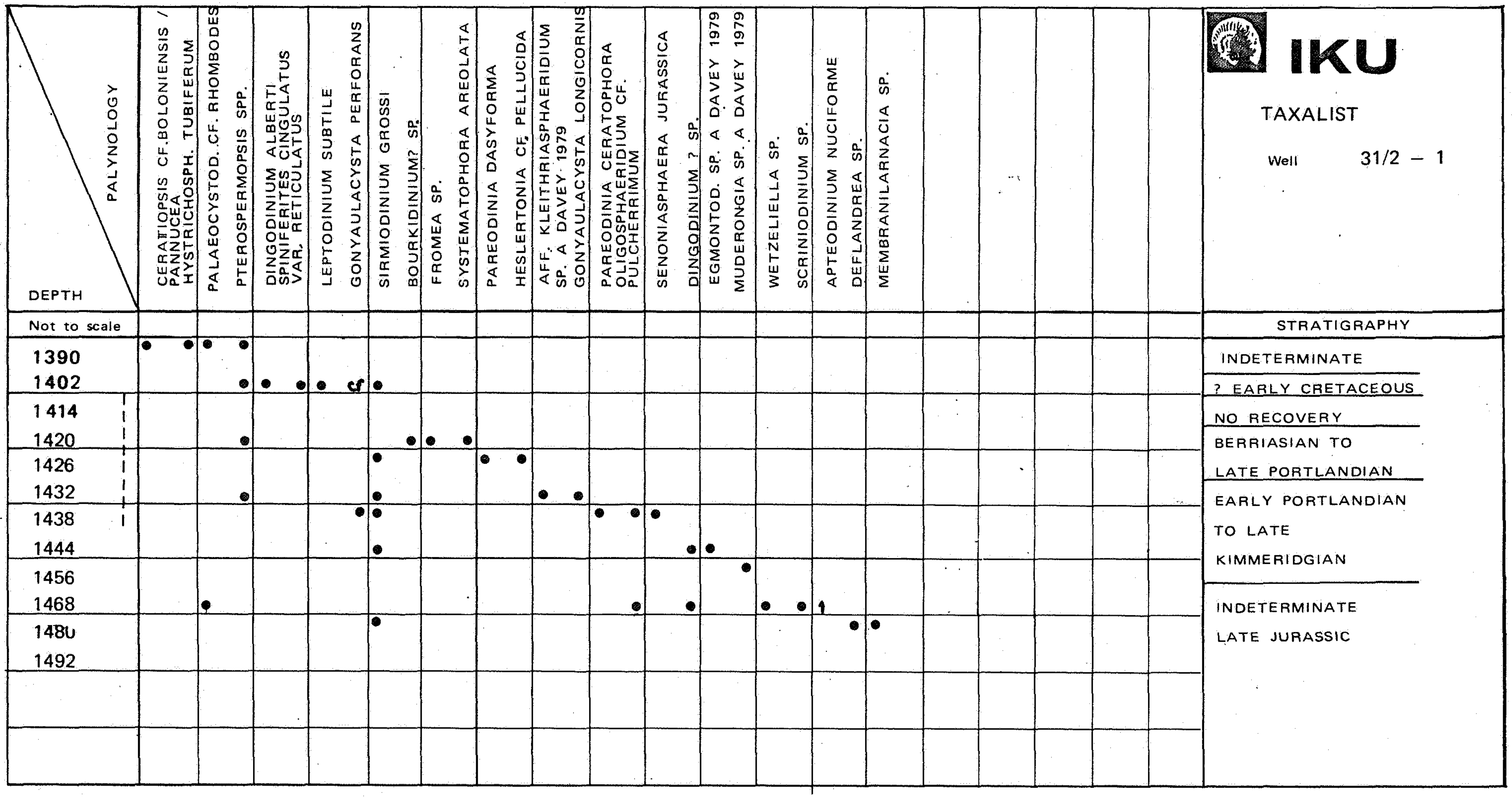


Fig. 3. Well 31/2-2, Palynology of the 'hot shale' interval.
---- hot shale as defined. All samples are cuttings.
↑ species common.

IKU

TAXALIST

Well 31/4 – 3

DEPTH (Not to scale)		DINGODINIUM SPINOSUM	SIRMIODINIUM GROSSI	BATIOLADINIUM MICROPODUM	PTEROSPERMOPSIS SP.	PAREODINIA DASYFORMA	PSEUDOCERATIUM PELLIFERUM	TUBOTUBERELLA APATELA	EGMONTOD. POLYPLACOPHORUM	SYSTEMATOPHORA AREOLATA	AMPHORULA / LANTERNA SP.	SENONIASPHAERA JURASSICA	CHL. CF. DISCRETA IOANNIDES ET. AL. 1976	SYSTEMATOPHORA AREOLATA	PAREODINIA CERATOPHORA	CRYPTARCHAEODINIUM CF. CALCARATUM	MENDICOD. GROENLANDICUM	LARGE GONYAULACEANS	DINOPTERYGIUM DIMORPHUM
2011,5	S		●	●	●	●	●	●											
2012	S	●	●	●	●	●	●												
2015	S	●	1	●	●		?	●											
2012 / 2016							?												
2016,5	S	●	●		●	●		●	●										
2021	S									●	●								
2020 / 2024		●	●		●	●						●	●						
2023	S												●	●	●	●	●	●	
2030 / 2034			1		●	●													
2034	S											●			●				●

STRATIGRAPHY

LATE BERRIASIAN

BERRIASIAN TO LATE PORTLANDIAN

EARLY PORTLANDIAN TO LATE KIMMERIDGIAN

Fig. 4. Well 31/4-3, Palynology of the 'hot shale' interval.

---- hot shale interval as defined.

S - Sidewall sample, other samples are cuttings. 1 - species common.

IKU

TAXALIST

Well 31/4 – 2

DEPTH (Not to scale)	DIVERSE LT. CRET./ FERT.	PALAEOHYSTRICHOPHORA INFUS.	GONYAULACYSTA CF. GLOBATA	CERATIOPSIS DIEBELI	ACHOMOSPAERA RAMULIFERA	ACHOMOSPAERA SAGENA	PTEROSPERMOPSIS SP.	GONYAULACYSTA LONGICORNIS	SIRMIODINIUM GROSSI	DINOPTERYGIUM DIMORPHUM	PSEUDOCERATIUM PELLIFERIUM	BATIOLADINIUM MICROPODUM	HESLERTONIA ? PELLUCIDA	EGMONTOD. POLYPLACOPHORUM	CARPEDINIUM OBLIGUICOSTATUM
2124	●				●										
2130	●			●											
2134	●	?		●											
2140	●					●									
2146	●		●	●	●		●	●							
2148															
2150															
2155				●	●										
2160				●			●		●		?				●
2164											?				
2169				●	●										
2170				●					●	?	?	?			
2158 / 78									●				●	●	

DINOFLAGELLATE SPECIES

STRATIGRAPHY

- ? TURONIAN/ CENOMANIAN
- NEOCOMIAN
- BERRASIAN/ LT. PORTLANDIAN

– – ? – – – – ? – – – – ? – – –

? EARLY PORTLANDIAN TO LATE / MIDDLE KIMMERIDGIAN

Note : P. dasyforma recorded (as caved)

Fig. 5. Well 31/4-2, Palynology of the 'hot shale' interval.
---- hot shale interval as defined. All samples are cuttings.