

A PRELIMINARY REPORT ON  
RESINITE - A POTENTIAL PETROLEUM SOURCE IN THE UPPER CRETACEOUS/  
TERTIARY OF THE BEAUFORT-MACKENZIE BASIN

Dr. L.R. Snowdon

OPEN FILE  
DOSSIER PUBLIC  
576  
Geological Survey  
Commission Géologique  
Ottawa

Institute of Sedimentary and Petroleum Geology  
3303-33rd Street, N.W.  
Calgary T2L 2A7, Alberta, Canada

This document was produced  
by scanning the original publication.

Ce document est le produit d'une  
numérisation par balayage  
de la publication originale.

## ABSTRACT

Fine-grained sedimentary rocks containing significant quantities of hydrocarbon (>50 mg/g Org C) occur in the Upper Cretaceous/Tertiary sediments of the Mackenzie Delta. These good to excellent potential petroleum source rocks are anomalous because they contain predominantly herbaceous and coaly organic matter (atomic H/C  $\approx$ 0.8) and also because they occur at low levels of thermal alteration (vitrinite reflectance  $R_o$  max  $\leq$ 0.7). The large amounts of saturated hydrocarbon which were apparently derived from diterpenoid compounds and the presence of autofluorescent resins in the kerogen suggests that the high resinite content of the sediments may be the reason for the petroleum source potential in this geological setting. The geological parameters (physical, chemical, and/or biological) which controlled the spatial and temporal distribution of these resins is not well understood. Thus prediction of the location of optimum source rock zones has not yet been attempted. It is reasonable to assume, however, that there are other occurrences of this phenomenon and that several excellent potential petroleum source rocks do exist in this sedimentary basin.

## ACKNOWLEDGEMENTS

The author wishes to acknowledge the technical assistance of M. Northcott, R.M. Evis, R.G. Fanjoy, R.A. Davidson and G.P. Michael. The resinite samples were provided by A.R. Cameron, D. Long and F.G. Young. Both the research and the manuscript benefited greatly from the suggestions of T.G. Powell. The cooperation of the companies operating wells in the Beaufort-Mackenzie area is also appreciated.

## INTRODUCTION

Oil, gas and condensate have been recovered from the Upper Cretaceous/Tertiary as well as older rocks in a number of wells in the Beaufort-Mackenzie Basin (Fig. 1). In order to assist in the quantitative evaluation of the petroleum potential and to assist in developing an overall geological model of this basin, a geochemical study was undertaken to identify the occurrence and distribution of specific, potential petroleum source rocks within the Post-Boundary Creek/Smoking Hills Upper Cretaceous/Tertiary fluviodeltaic sediments (Young *et al.*, 1976). The geological model used was essentially that of Young (1975) and Young *et al.*, 1976). These two papers as well as one by Lerand (1973) summarize the essential elements of the stratigraphy (Fig. 2) and general geological setting which will not be discussed further here.

### SOURCE ROCK DEFINITION

Potential petroleum source rocks are herein defined as sedimentary rocks containing a significant quantity of syngenetic, petroleum-like hydrocarbons, but which have not been proven as actual source rocks through correlation with a reservoirized petroleum deposit. Immature, potential source rocks are defined as those which contain a significant quantity of organic matter of the right type (hydrogen-rich) but which have not experienced sufficient thermal alteration to have produced more than trace amounts of liquid hydrocarbons. Immature source rocks are thus considered to have *no* potential. Geographical extrapolation of immature, organic-rich rocks to potential source rocks requires either knowledge or assumption of regional trends in the following:

- (1) the geothermal gradient and/or geothermal history of the basin,
- (2) the age of the sediments, and
- (3) the nature and quantity of the organic matter contained in the sediments.

Because petroleum is composed predominantly of hydrocarbons, with only small amounts of heteroatomic species (i.e. nitrogen, sulphur and oxygen containing molecules) present, potential petroleum source rocks have been defined on the basis of the quantity of extractable hydrocarbons in a rock. It has been empirically observed, however, that a high total extract or hydrocarbon extract is an insufficient criterion for source potential (Foscolos *et al.*, 1976; Powell *et al.*, in press; Powell, 1978). Thus, organic-rich samples, such as coal, may yield very large amounts of extract in the laboratory but are not good source rocks in a geological system. This limitation may be related to the fact that the migration of liquid hydrocarbons may not occur until after a threshold saturation of the organic matter by hydrocarbons is achieved. In order to overcome this problem, the total and hydrocarbon extract weights are first normalized to account for the total organic carbon content of the rock in order to obtain a measure of relative hydrocarbon saturation level. Once the relative richness has been determined, the total quantity of the organic matter which is present is considered. Thus, samples of rock which have low hydrocarbon yields would be classed as poor source rocks regardless of the absolute concentration of hydrocarbons (ppm) or the organic carbon content. These samples tend to contain relatively large amounts of inert, hydrogen-poor organic matter. On the other hand, high-yield or hydrocarbon-prone samples would be classed as excellent *potential* source rocks without

regard to the absolute quantities of petroleum one might expect. Once the above criterion has been satisfied, then the absolute amount of organic carbon and hydrocarbon present in a potential source rock can be used to calculate absolute quantities of migratable oil.

Hydrocarbon yields are expressed as milligrams of extractable hydrocarbon per gram of organic carbon in the sediment. The yields are expressed as milligrams/gram rather than as per cent because the latter implies a ratio of extractable carbon to total carbon whereas in fact extractable hydrocarbon is what is determined. Cut-off values for the descriptive source rock classes have been arbitrarily assigned on the basis of observed yields from a number of samples ranging from coals to sapropel-rich source rocks (Powell, 1978). Thus, yields of below 30 mg/g which are frequently observed in coal are considered to have no source potential, whereas rocks with hydrocarbon yields of greater than 50 mg/g and greater than 80 mg/g are respectively described as "good" and "excellent" potential source rocks (Powell, 1978).

The above criteria must be considered in the light of oil generation only, because it seems that hydrocarbon gas generation occurs throughout a sedimentary section. Estimates of the quantities of gas generated are speculative at best because it is difficult to collect and analyze interstitial gases quantitatively and migration can result in undetectable enrichment in or loss of gas from a section. At present, the only geochemical criterion by which a methane or dry gas source can be precluded is the total absence of organic matter. No examples of this have been observed in the Beaufort-Mackenzie Basin. Wet gases (ethane, propane, butanes) are not generated in significant quantities via biological

mechanisms and thus cannot be expected to occur until a reflectance level of about  $0.4 R_o$  max. Only the most hydrogen poor kerogen will not yield some wet gas eventually.

It is important to distinguish between syngenetic and epigenetic hydrocarbons. Contamination of a rock sample by refined hydrocarbon products such as diesel fuel, pipe grease (a thread lubricant) or engine oil may result in specious optimism concerning the source potential of the sample. These contaminating hydrocarbons have characteristic saturate fraction gas chromatograms and thus can usually be detected. Staining, or contamination by migrated crude petroleum on the other hand, does not necessarily result in a characteristic gas chromatogram. In fact, most or all of the physical and chemical properties of the migrated material are indistinguishable from those of syngenetic hydrocarbons. Polar compounds (i.e. heteroatomics and asphaltenes), which do not migrate as readily as hydrocarbons, are usually present in reservoirs in low concentrations relative to hydrocarbons. Therefore, reservoir or stained rock samples should and frequently do contain an abnormally high percentage of hydrocarbons and relatively lesser amounts of heteroatomics (or NSO's) and asphaltenes. At low levels of thermal alteration, the hydrocarbon enrichment of a stained sample is marked, but when a potential source rock is fully mature, the syngenetic extractable fraction may be more than 70% hydrocarbons and subsequent staining would only result in a slight increase in this value. Thus, in some cases, the differentiation between a rich potential source rock and a stained sediment may be problematical. However, ubiquitous staining in a stratigraphic section must be considered as evidence that an effective source rock exists although its precise location may not be discernable.

## RESULTS AND DISCUSSIONS

*Solvent extraction*

A number of drill cuttings samples from the Upper Cretaceous/Tertiary of the Beaufort-Mackenzie Basin have been solvent extracted (Snowdon, 1978) and the extractable hydrocarbon yield and per cent of hydrocarbons in the total extract were calculated and the results plotted on a polar coordinate diagram (Fig. 3). Most of the samples have low yields (< mg/g of organic carbon) and a low proportion of hydrocarbons in the total extract (<40%). These results are consistent with the coaly/herbaceous nature of the kerogen in these samples (Snowdon, 1978) and the low levels of thermal diagenesis found in the Mackenzie Delta (Gunther, 1976a, b; Snowdon, 1978). A number of points, however, fall above the 50 mg/g cut-off (Powell, 1978) and must be classed as good to excellent potential source rocks. The open circles on Figure 3 represent data points which are probably artifactitious due to contamination by refined products such as diesel fuel or pipe grease, or due to staining by migrated hydrocarbons.

The good to excellent potential source rocks observed in this data set are anomalous because the sapropel (or amorphous) content of the kerogen is low (Snowdon, 1978) and because the vitrinite reflectance values for these samples range between 0.45 and 0.70  $R_o$  max., that is, below the zone of optimum thermal hydrocarbon generation for coaly/herbaceous organic matter (Powell *et al.*, in press). A substantial amount of other chemical data on the organic component of these sediments suggests the possibility of a heretofore unrecognized petroleum source.

*Saturate fraction gas chromatograms*

The distribution of the n-alkanes and acyclic isoprenoids as well as the shape of the branched-cyclic "hump" in the saturate fraction of the extract from Netserk B-44 at 9690 ft (2953.5 m) (Fig. 4) is normal for an immature sample containing organic matter which was predominantly derived

from higher terrestrial plants. The pristane/phytane ratio of about 3.2/1 suggests that the organic matter underwent some oxidation before or at the time of deposition (Powell and McKirdy, 1973). The high pristane/nC<sub>18</sub> ratio and high odd to even n-alkane predominance are both consistent with the observed thermal immaturity ( $R_o$  max. =0.56). The triterpane hump centered at about C<sub>26</sub> and the maximum in the n-alkane distribution at about C<sub>29</sub> also indicate a higher land plant source and relatively little thermal alteration.

Many extract samples, however, have a distinctly different character (Figs. 5, 6), in that they contain small amounts of the waxy n-alkanes (C<sub>22</sub> to C<sub>35</sub>) relative to n-alkanes with 20 or fewer carbon atoms even though the reflectance levels of these samples are low ( $R_o$  max. =.60 and =.65 respectively). Also, the triterpane hump is small relative to the lower molecular weight hump. The apparent maximum of the unresolved hump of naphthenes in Figures 3 and 4 is at least partially a function of the extent of evaporitic loss of the material with 15 or fewer carbon atoms. The sample from Toapolok 0-54 at 8160 ft (2487.2 m) (Fig. 6) was isolated using lower boiling solvents than the sample from Kumak C-58 at 8660 ft (2639.6 m) (Fig. 5) and thus most or all of the nC<sub>14</sub> was retained in the former but lost from the latter sample. The loss of volatile hydrocarbons during extraction and fractionation processes not only influences the character of the saturate fraction gas chromatogram but also both the total extract yield and the percentage of hydrocarbons within the total extract. Both of these would be reduced relative to an extract handled with higher boiling solvents. In fact, up to 20% weight loss has been observed in the recovery of column chromatographic fractions alone. Thus many of the "marginal" source rocks, that is with 30-50 mg/g hydrocarbon yields (Figs. 3, 5, 6) may in fact be good potential source rocks

capable of generating the observed reservoir condensates. That is, the conventional  $C_{15+}$  yields may not be particularly applicable to a potential source rock which generates large amounts of more volatile hydrocarbons which ultimately result in gas and condensate filled reservoirs.

Another significant difference between these volatile samples and normal woody/herbaceous extracts is the occasional occurrence of large "extra" peaks (Figs. 5, 6, 7) which have been tentatively identified as tricyclic diterpanes (Snowdon, 1978). These compounds are related to diterpenoids or resin acids which are the main constituent of tree resins and may suggest something of the nature of source of the high yield of low molecular weight hydrocarbons in these sediments. The structure of tricyclic diterpanes is that of sandaracopimarane (Snowdon, 1978).

Because species of the order *Pinales* contain both abietic- and pimaric-type acids (Gouch, 1964), it is not possible to determine specifically what types of trees may have generated the resins found in the sediments.

It is important to note that the pristane/phytane ratio and the odd to even n-alkane predominance in the  $C_{20}$  to  $C_{30}$  range are essentially the same in the anomalous samples (Figs. 5, 6) as they are in the so-called normal sample (Fig. 4). This indicates that all of the samples have experienced similar diagenetic and mild thermal metamorphic histories ( $R_o$  max. = .55 to .65). Also, at least some of the organic matter in these two types of samples had a common, higher terrestrial plant source.

The saturate fraction gas chromatograms of the recovered drill stem fluids and especially in the case of condensates (Fig. 8) are often very similar to the extract chromatograms (Figs. 5, 6). The highest concentration n-alkane is in the  $C_{14}$  to  $C_{18}$  range depending on evaporative losses, and the pristane/phytane ratios range from about 2/1 to 5/1 (Powell and

Snowdon, 1975). No high concentration of individual diterpenoid-derived alkanes have been observed in oils or condensates recovered on drill stem test. The gas chromatograms (Figs. 5, 6, 7) suggest, however, that the concentration of these individual compounds in extracts may decrease rapidly due to cracking and or isomerization as the level of thermal alteration increases. The result is the observed, unresolved hump in diterpane or lighter range.

#### *Elemental and visual analysis of kerogen*

Kerogens isolated from sediments representing various deltaic depositional facies have been isolated using acid digestion and have been analyzed both chemically and microscopically (Snowdon, 1978). The results indicate that there is little or no algal or plankton-derived sapropel or amorphous kerogen even in the prodelta/marine shale samples. The atomic hydrogen/carbon ratios (less than 0.9) and the low vitrinite reflectance values ( $R_o$  max.  $\leq$  0.7) are consistent with the immature herbaceous/coaly nature of the organic debris preserved in these samples (McIver, 1967; Tissot *et al.*, 1974).

Microscopic examination of the autofluorescence of the kerogen samples using UV illumination confirmed the presence of resinite. This material was observed to fluoresce with a dull orange to reddish colour and frequently occurred as veins or pods within coaly fragments. Another of the types of organic material observed in transmitted light microscopy was mottled, semi-structured material. Although this material may be physically amorphous and thus described as sapropelic, the herbaceous origin is fairly certain because recognizable fragments such as spores were observed to be intact on one edge and progressively more altered towards

the other edge. It is probable that this physical degradation is due to biological activity. The overall chemical effect of the alteration on the herbaceous macerals is still largely unknown but the atomic H/C ratio is not affected and the resultant semi-structured material fluoresces only slightly under UV excitation. On the other hand some of the unaltered spores and pollen fluoresced with a fairly bright yellow colour. This suggests that the mottling process did not significantly enhance the concentration of petroleum-like hydrocarbons or bitumen which tends to fluoresce yellow.

A number of observations including 1) the high concentrations of particular C<sub>19</sub> and C<sub>20</sub> tricyclic diterpenoids of the sanaracopimarane structural type, 2) the large proportion of branched/cyclic material with less than 20 carbon atoms, 3) the low concentration of lipid-rich, sapropelic or amorphous organic matter, and 4) the occurrence of resinite in the kerogen smear slides, suggested that resins possibly derived from trees may have been the anomalous hydrocarbon-productive maceral in these sediments.

Although the atomic H/C ratio of pure resin was observed to be about 1.58, adding 20 weight per cent of this resin to herbaceous kerogen with a hydrogen to carbon ratio of 0.70 would result in an overall H/C value of 0.88 ( $0.2 \times 1.58 + 0.8 \times 0.7$ ). This falls within the observed range of H/C ratios. Thus a large resinite concentration (10-20%) in these samples would increase the H/C ratio a relatively small amount, but could have a profound effect on the total amount of hydrocarbons ultimately generated from the sample because 100% of the resin is solvent extractable and 100% of the resin is volatilized on mild thermal treatment.

*Thermogravimetric analysis and pyrolysis of kerogen and resinite*

In order to assess the possible role of resinite as a hydrocarbon source, thermogravimetric and pyrolysis studies were undertaken to compare the properties of resinite with those of other macerals and whole kerogen isolated from Beaufort-Mackenzie sediments. Essentially pure resinites were hand picked from two outcrop samples collected in the Bonnet Plume Basin (north-central Yukon Territory) and the Hat Creek coalfield (central British Columbia) and a drill cuttings sample from the Imperial Nuktuk C-22 well (6600-7000 ft, 2012-2134 m).

The thermogravimetric analysis (TGA) graphs (at 20°C per minute heating rate) for 1) an immature algal coal from British Columbia (Fig. 9, curve B), 2) a sapropel-rich kerogen from an Arctic Islands borehole (Fig. 9, curve C), and 3) a vitrinite-rich lignite from Saskatchewan (Fig. 9, curve D) all show weight losses predicted by the model discussed by Tissot *et al.* (1974) and reflecting the atomic hydrogen/carbon ratio of the organic matter in question. Respective atomic H/C values for the three samples above were about 1.28, 1.16, and 0.85. The pure resin samples (Fig. 9, curve A) which had an atomic H/C ratio of about 1.58 were completely volatilized (125% of the carbon weight) below 450°C. Weight losses at about 100°C and between 125°C and 300°C have been attributed to adsorbed water and volatile hydrocarbons (bitumen) respectively and were not considered in the relative weight losses. Similarly, weight losses above 550°C were not considered because of the decomposition of pyrite (a frequent residue in kerogen concentrates) and associated weight loss which occurs between 550°C and 630°C under a nitrogen atmosphere when the rate of temperature increase is 20°C/minute.

The TGA graphs of kerogens isolated from Beaufort-Mackenzie boreholes (Fig. 10, curves A and B) do not show the large, low-temperature weight loss associated with the pure resin samples noted above. However, many of

the kerogens isolated from delta boreholes do show a weight loss in the temperature range expected for resins ( $\approx 400^{\circ}\text{C}$  under the operating conditions used). This weight loss was somewhat higher than that observed over the same temperature range for two Saskatchewan lignites which were analyzed to provide a basis for comparison.

Thus the results of the thermogravimetric analysis serve to demonstrate that some of the kerogens isolated from the Upper Cretaceous/Tertiary of the Beaufort-Mackenzie Basin do undergo weight losses which are comparable in magnitude to those of algal coal and sapropel-rich kerogen. The temperatures at which the weight losses occur have not as yet been attributed to a particular maceral or organic matter type although at least part of the kerogen is volatilized at temperatures which correspond to the main weight loss event of resinite and sapropel.

Pyrolysis gas chromatography of pure resin at  $400^{\circ}\text{C}$  for 30 seconds in an inert atmosphere results in the generation of volatile ( $<C_{20}$ ) hydrocarbons (Fig. 11). The molecular weight distribution of these pyrolysis products is consistent with that of the condensates recovered from the Mackenzie Delta (Fig. 8). Also, the pyrolysis products fall into two main categories- the first containing fewer than 13 carbon atoms and second in  $C_{16}$  to  $C_{20}$  range containing several large, discrete peaks.

#### *Stable carbon isotope data*

Stable carbon isotope ratios of kerogen samples range from about  $-24.5$  to  $-27$  per mil PDB and average about  $-25.7$  ‰ (Fig. 12). Aromatic and saturate fractions of fluids recovered from drill stem tests range from  $-25.5$  to  $-27$  ‰ and from  $-27$  to  $-29$  ‰ respectively. These values, which suggest that the whole crude isotope ratio would be about  $-27$  ‰

are consistent with both 1) a local source (i.e. showing the expected 1 ‰ to 2 ‰ shift from the -25.7 ‰ kerogen) and 2) a higher land plant source rather than a marine source (Gearing *et al.*, 1977). Data from older (Lower Cretaceous) kerogens and crudes in the Mackenzie Delta, however, suggest that the isotope results from the Upper Cretaceous/Tertiary are not sufficiently distinctive to be diagnostic. Thus these data must be considered only as supportive of the local source hypothesis in that the results do not preclude an Upper Cretaceous/Tertiary source.

### CONCLUSIONS

Potential petroleum source rocks occur in the Upper Cretaceous/Tertiary section of the Beaufort-Mackenzie Basin. They contain predominantly coaly and herbaceous organic debris and have undergone relatively little thermal alteration. A working hypothesis which explains the occurrence of gas, condensate and light oil reservoirs within this section is that this petroleum has been derived locally from resinite or tree resin material. The supporting evidence for the above hypothesis includes the following:

- 1) the observed presence of resinous material in the kerogen;
- 2) the diterpane "hump" of unresolved branched/cyclic compounds in the saturate fraction gas chromatograms of both extracts and oils;
- 3) the high concentration in some extracts of some specific diterpenoid derivatives which are structurally similar to resin acids;
- 4) the low temperature breakdown of pure resinite during thermogravimetric analysis and the occurrence of some low temperature pyrolyzate in many of the kerogen samples;
- 5) the molecular weight distribution of volatile products which are generated during pyrolysis-gas chromatography of pure resinite;
- and 6) the stable carbon isotope data of the kerogens and recovered oils

and condensates. The oils and condensates recovered from the Mackenzie Delta are low in wax content and thus do not fit the conventional, terrestrially-sourced oil character of the Gippsland, Cooper and Uinta basins (Hedberg, 1968). At the same time, however, the pristane/phytane ratio of the oils and extracts and the type of organic matter present suggests that the Beaufort-Mackenzie oils and condensates were in fact derived from terrestrial organic matter. Furthermore, the occurrence of good to excellent potential petroleum source rocks at very low levels of thermal metamorphism is inconsistent with any previously published oil/condensate generation model.

A second possible hypothesis for the source of the anomalous hydrocarbons in this area is that the biological or chemical alteration which results in the change in the optical character of the herbaceous debris has simultaneously altered some of the chemical properties of the kerogen. That is, the hydrocarbon yield potential has been considerably enhanced but the atomic hydrocarbon ratio has not been significantly affected. This second hypothesis is not directly supported by data and also does not predict or explain the occurrence of diterpenoid compounds.

Regardless of the veracity of any hypothesis, it must be concluded that the low maturity sediments of this basin do have source potential for both oil and condensate as well as gas. The expected areal distribution of potential petroleum source rocks is still unclear but cannot as yet be restricted either temporally or geographically on the basis of the available data. Further, it must be concluded that the oil source model must be modified to accommodate the possibility of generating condensates at low levels of thermal metamorphism.

REFERENCES

- Brooks, J.D.  
1970: The use of coals as indicators of the occurrence of oil and gas; A.P.E.A. Journal, v. 10, pt. II, pp. 35-40.
- Foscolos, A.E., Powell, T.G. and Gunther, P.R.  
1976: The use of clay minerals and inorganic and organic geochemical indicators for evaluating the degree of diagenesis and oil-generating potential of shales; Geochim. et Cosmochim. Acta, v. 40, pp. 953-966.
- Gearing, P., Plucker, F.E. and Parker, P.L.  
1977: Organic carbon stable isotope ratios of continental margin sediments; Marine Chemistry, v. 5, pp. 251-266.
- Gough, L.J.  
1964: Conifer resin constituents; Chemistry and Industry, Dec. 12, pp. 2059-2060.
- Gunther, P.R.  
1976a: A study employing optical methods to evaluate organic metamorphism and oil-generating potential of sediments in the Mackenzie Delta area, District of Mackenzie; G.S.C. Paper 76-1C, pp. 143-151.
- Gunther, P.R.  
1976b: Palynomorph colour and dispersed coal particle reflectance from three Mackenzie Delta boreholes; Geoscience and Man, v. XV, p. 35-39.
- Hedberg, H.O.  
1968: Significance of high-wax oils with respect to genesis of petroleum; A.A.P.G. Bull., v. 52/5, pp. 736-750.
- Lerand, M.  
1973: Beaufort Sea; in R.G. McCrossan (ed.); The Future Petroleum Provinces of Canada, CSPG Memoir #4.
- McIver, R.D.  
1967: Composition of kerogen - due to its role in the origin of petroleum; Proc. 7th World Petrol. Cong., v. 2, p. 25-36.
- Powell, T.G.  
1978: An assessment of the hydrocarbon source rock potential of the Canadian Arctic Islands; G.S.C. Paper 78-12.
- Powell, T.G., Foscolos, A.E., Gunther, P.R. and Snowdon, L.R.  
in press: Diagenesis of organic matter and fine clay minerals - A comparative study; Geochim. et Cosmochim. Acta.

Powell, T.G. and McKirdy, D.M.

1973: Relationship between ratio of pristane to phytane, crude oil composition and geological environment in Australia; Nature (Phys. Sci.), v. 243, p. 37-39.

Powell, T.G. and Snowdon, L.R.

1975: Geochemistry of oils and condensates from the Mackenzie Delta Basin, N.W.T.; G.S.C. Paper 75-1C, pp. 41-43.

Snowdon, L.R.

1978: Organic geochemistry of the Upper Cretaceous/Tertiary delta complexes of the Beaufort Mackenzie sedimentary basin, northern Canada; Ph.D. Thesis, Rice University, Houston, Texas; 130 p.

Tissot, B., Durand, B., Espitalié, J. and Combaz, A.

1974: Influence of nature and diagenesis of organic matter in formation of petroleum; Bull. Am. Assoc. Petrol. Geologists, v. 58/3, p. 499-506.

Young, F.C.

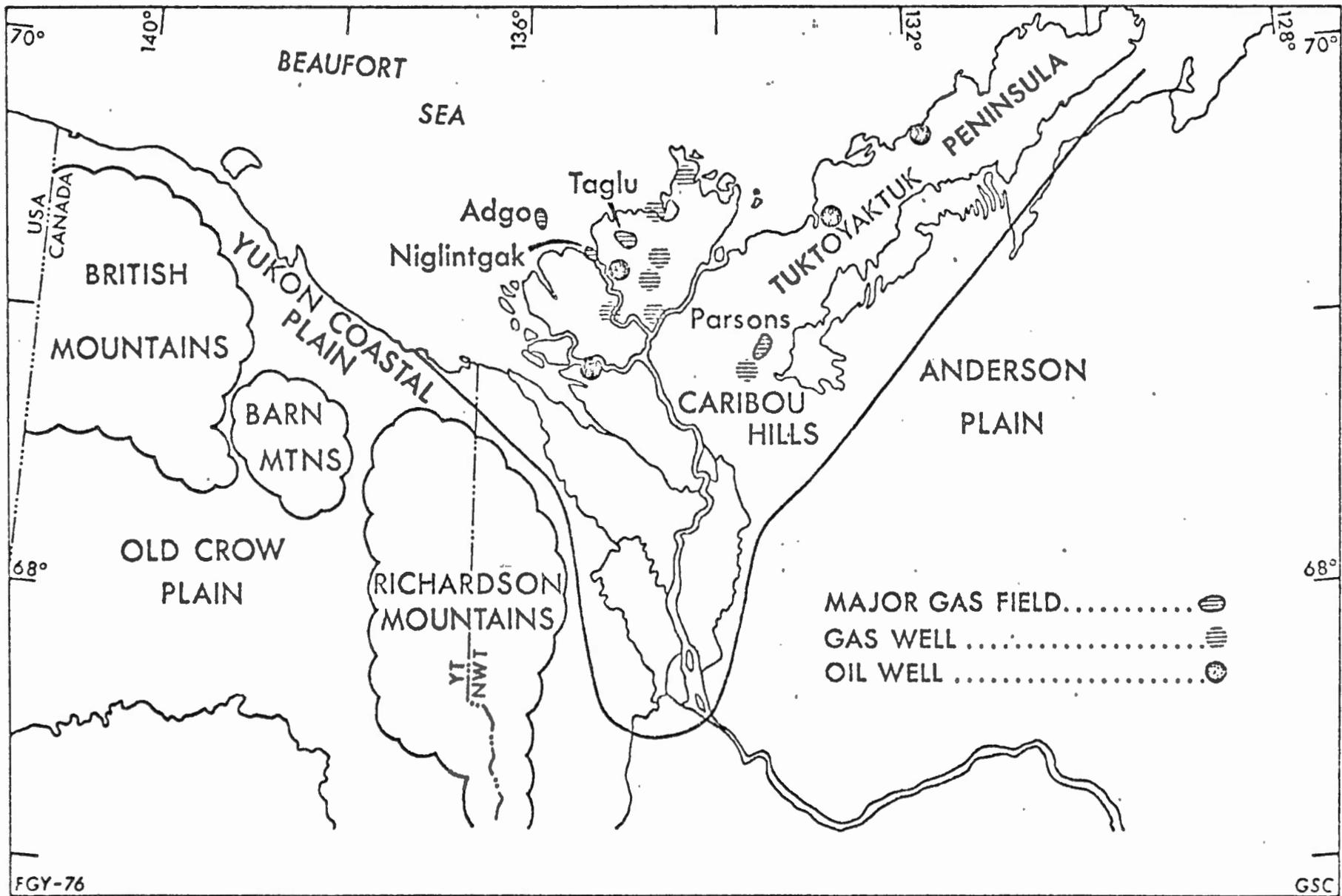
1975: Upper Cretaceous Stratigraphy, Yukon Coastal Plain and Northwestern Mackenzie Delta; G.S.C. Bull. 249.

Young, F.G., Myhr, D.W. and Yorath, C.J.

1976: Geology of the Beaufort-Mackenzie Basin; G.S.C. Paper 76-11.

Figure captions

- Figure 1. Map of the Beaufort-Mackenzie Basin area showing locations of oil and gas discoveries (after F.G. Young, unpublished).
- Figure 2. Generalized stratigraphic correlation chart simplified from Young *et al.* (1976, Table 1).
- Figure 3. Polar coordinate plot of extractable hydrocarbon yield (r) versus per cent hydrocarbons in the total extract ( $\theta$ ).
- Figure 4. Saturate fraction gas chromatogram from Newserk B-44 at 9690 feet (2953.5 m) showing high pristane/phytane ratio, high off/even n-alkane predominance, and triterpane hump.
- Figure 5. Saturate fraction gas chromatogram from Kumak C-58 at 8660 feet (2639.6 m) showing high pristane/phytane ratio, low wax content, high diterpane hump, and individual diterpane peak.
- Figure 6. Saturate fraction gas chromatogram from Toapolok 0-54 at 8160 feet (2487.2 m) showing the shift toward a lower molecular weight n-alkane maxima when low boiling solvents are used and special care is taken to retain as much volatile material as possible.
- Figure 7. Saturate fraction gas chromatogram from Toapolok 0-54 at 6510 feet (1984.2 m) showing large concentrations of two tricyclic diterpenoid-derived alkanes.
- Figure 8. Saturate fraction gas chromatogram of the high boiling ( $>210^{\circ}\text{C}$ ) portion of condensate recovered from 8145-8180 feet (2482.6-2493.3 m) (drill stem test number 4) of Kumak J-06.
- Figure 9. Thermogravimetric analysis curves (weight loss versus temperature) for A) pine resin hand picked from Hat Creek coal samples; B) an immature Cretaceous algal coal from British Columbia; C) a sapropel-rich kerogen isolated from 2290 feet (698.0 m) in the Wilkins E-60 borehole in the Arctic Islands; and D) a vitrinite-rich lignite from Saskatchewan. The temperature was programmed to rise at  $20^{\circ}\text{C}$  per minute.
- Figure 10. Thermogravimetric analysis curves for kerogens from A) Taglu D-43 at 8890 feet (2709.7 m), and B) Netserk B-44 at 1080 feet (329.2 m). Conditions as for Fig. 9.
- Figure 11. Pyrolysis - gas chromatogram of a pure resin from the Hat Creek coalfield. The sample was pyrolyzed in a helium atmosphere for 30 seconds at a temperature of  $400^{\circ}\text{C}$ .
- Figure 12. Range and average of stable carbon isotope values for kerogens, and for saturate and aromatic fractions of topped ( $>210^{\circ}\text{C}$ ) oils and condensates from Mackenzie Delta.



12cm  
 1/2 page

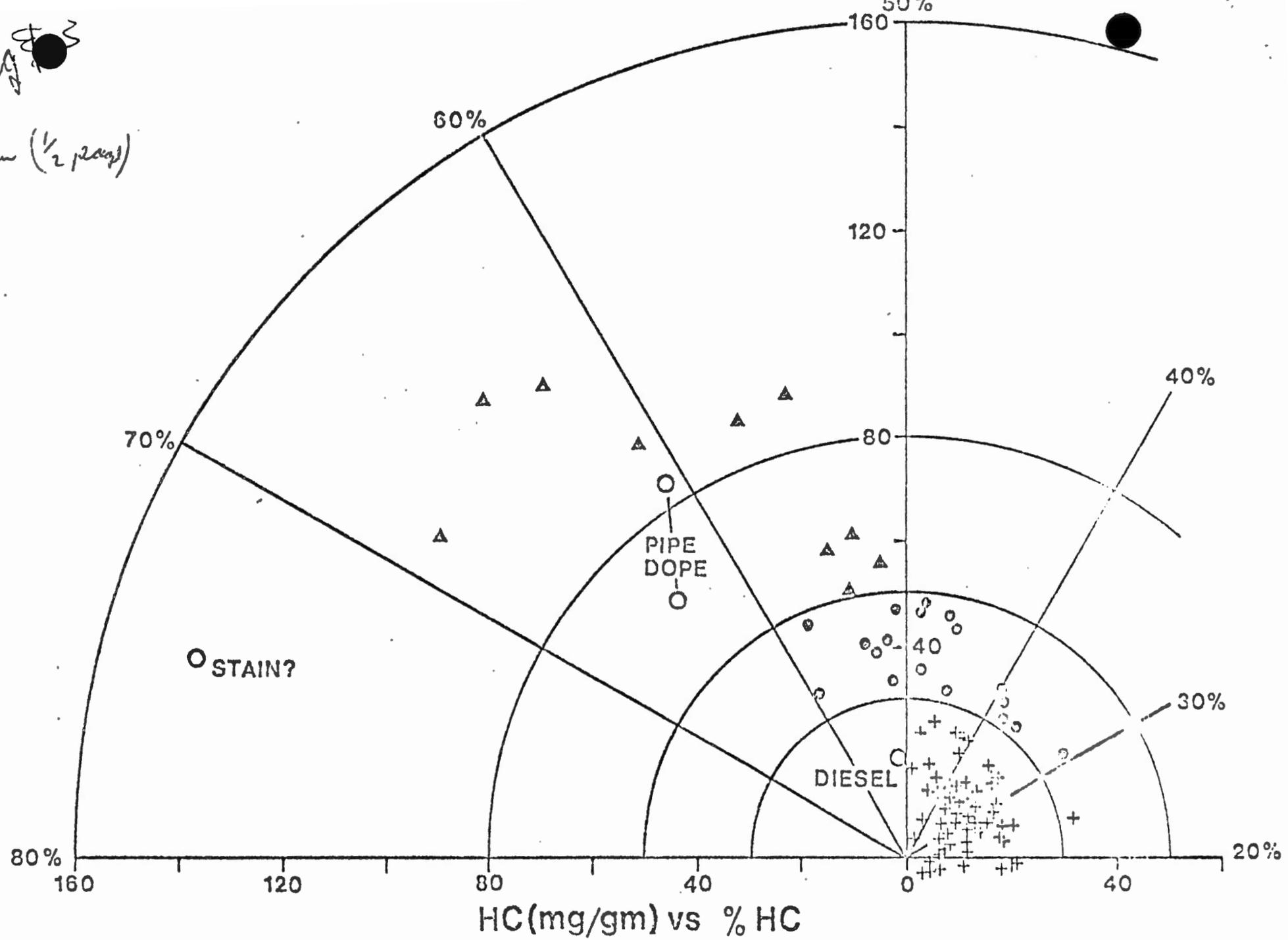
AGE		N. ALASKA	N. YUKON	MACKENZIE DELTA	ANDERSON PLAIN
Q	PLEIST-REC				
TERTIARY	PLIOC			UNNAMED A	
	MIOC			BEAUFORT	BEAUFORT
	OLIGOC			UNNAMED B	
	EOCENE			UNNAMED C	
	PALEOC	SAGAVANIRTOK	REINDEER	REINDEER	
U. CRETACEOUS	MAAST		MOOSE CHANNEL	FISH RIVER GP	MASON RIVER
	SENONIAN	PRINCE CREEK SCHRADER BLUFF IGNEK	TENT ISLAND		SMOKING HILLS
		SEABEE	BOUNDARY CREEK	BOUNDARY CREEK	
	CENOM-TUR	NANUSHUK			

GSC

12 cm  
1/2 page

Fig 3

↑ 7 cm (1/2, 2002)



LRS 78

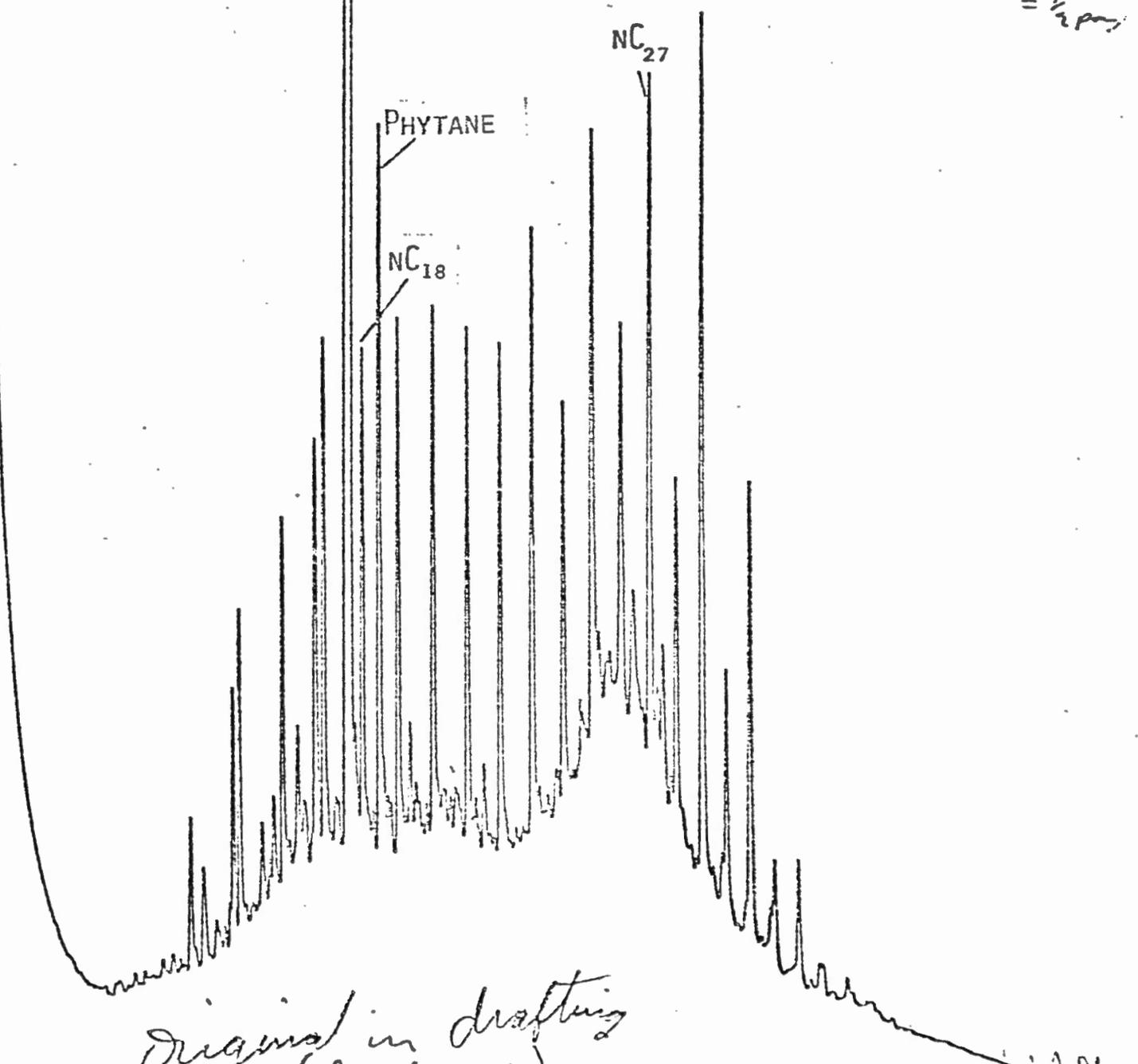
GSC

PRISTANE

119 & 7  
~~with~~

HC YIELD = 20 mg/g  
R<sub>max</sub> = .56

↑ 9 cm  
↓  
1/4 page  
with fi  
= 1/2 page



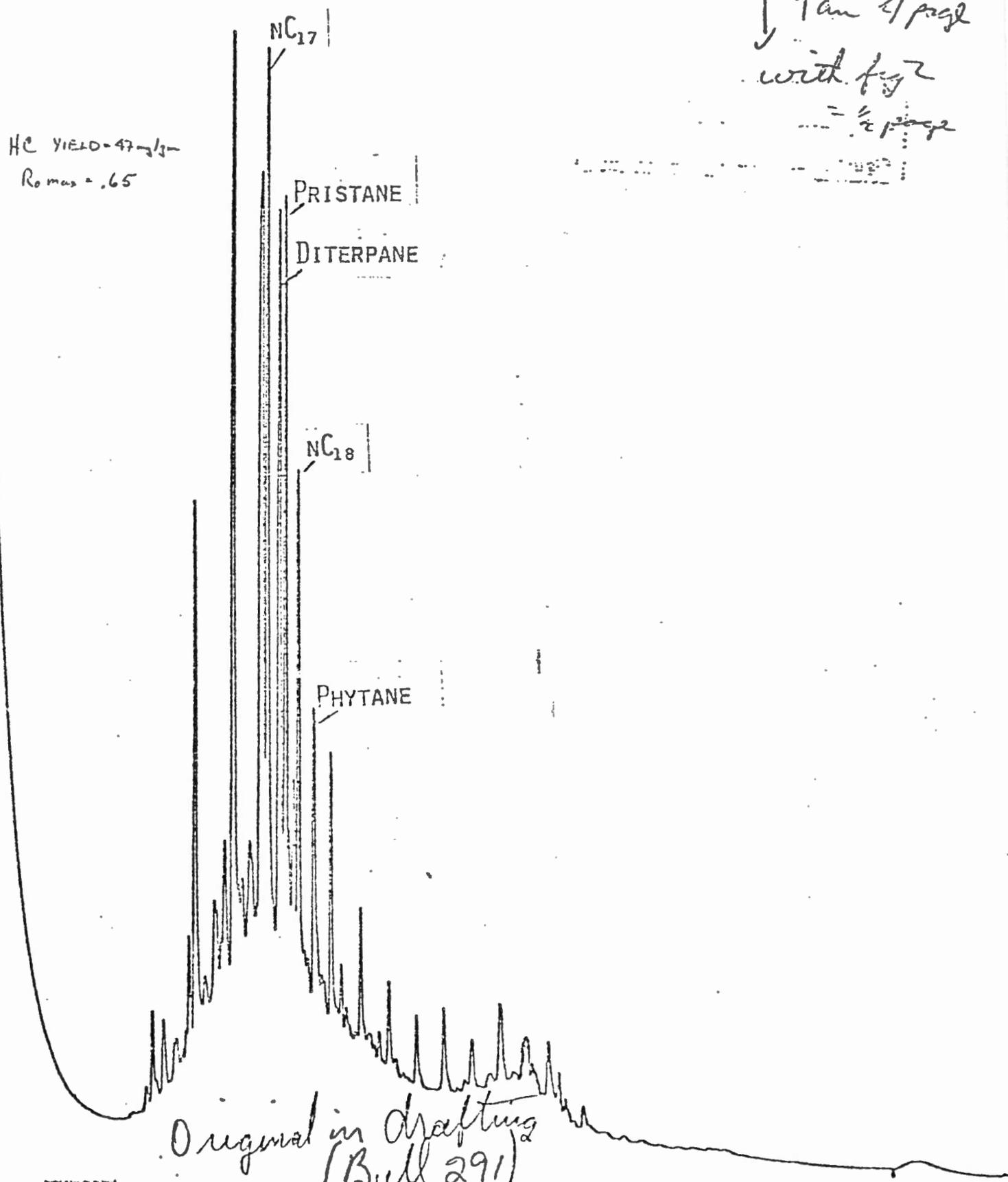
Original in drafting  
(Bull 291)

9190  
9190  
9190  
9190

Fig 35

↑ 9 am 1/4 page  
with fig 2  
= 1/2 page

HC YIELD - 47-1/2-  
Romas = .65



Original in drafting  
(Bull 291)

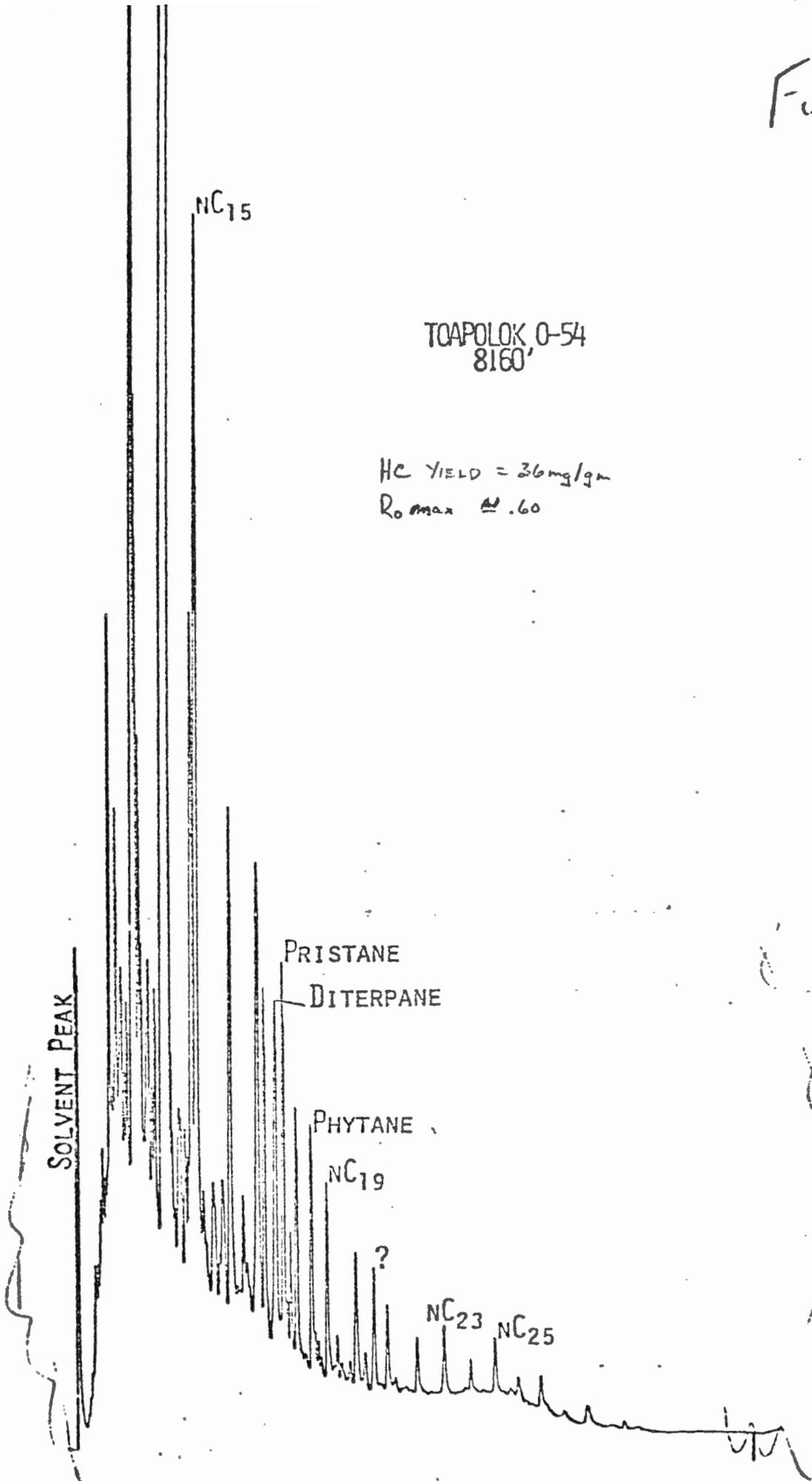


Fig 46

↑  
9 cm  
↓  
1/4 page  
with fig 5  
= 1/2 page

TOAPOLOK 0-54  
8160'

HC YIELD = 36 mg/gm  
R<sub>o max</sub> ≈ .60



↑  
↓ 9 cm  
1/2 page

HC FIELD = 20 mg/gm  
Romas ≈ .50

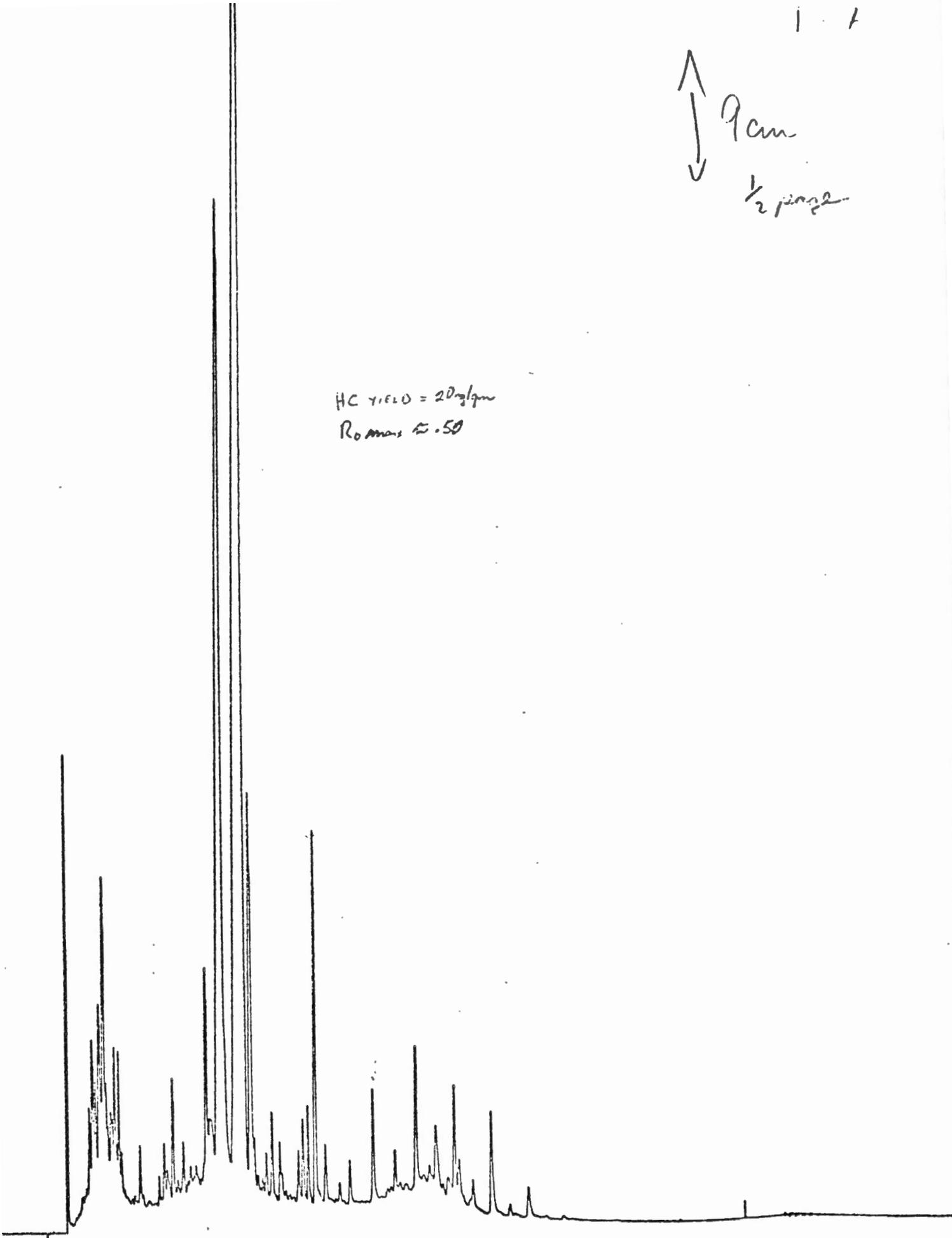


Fig 8  
9 cm  
= 1/4 page

with fig 4  
= 1/2 page

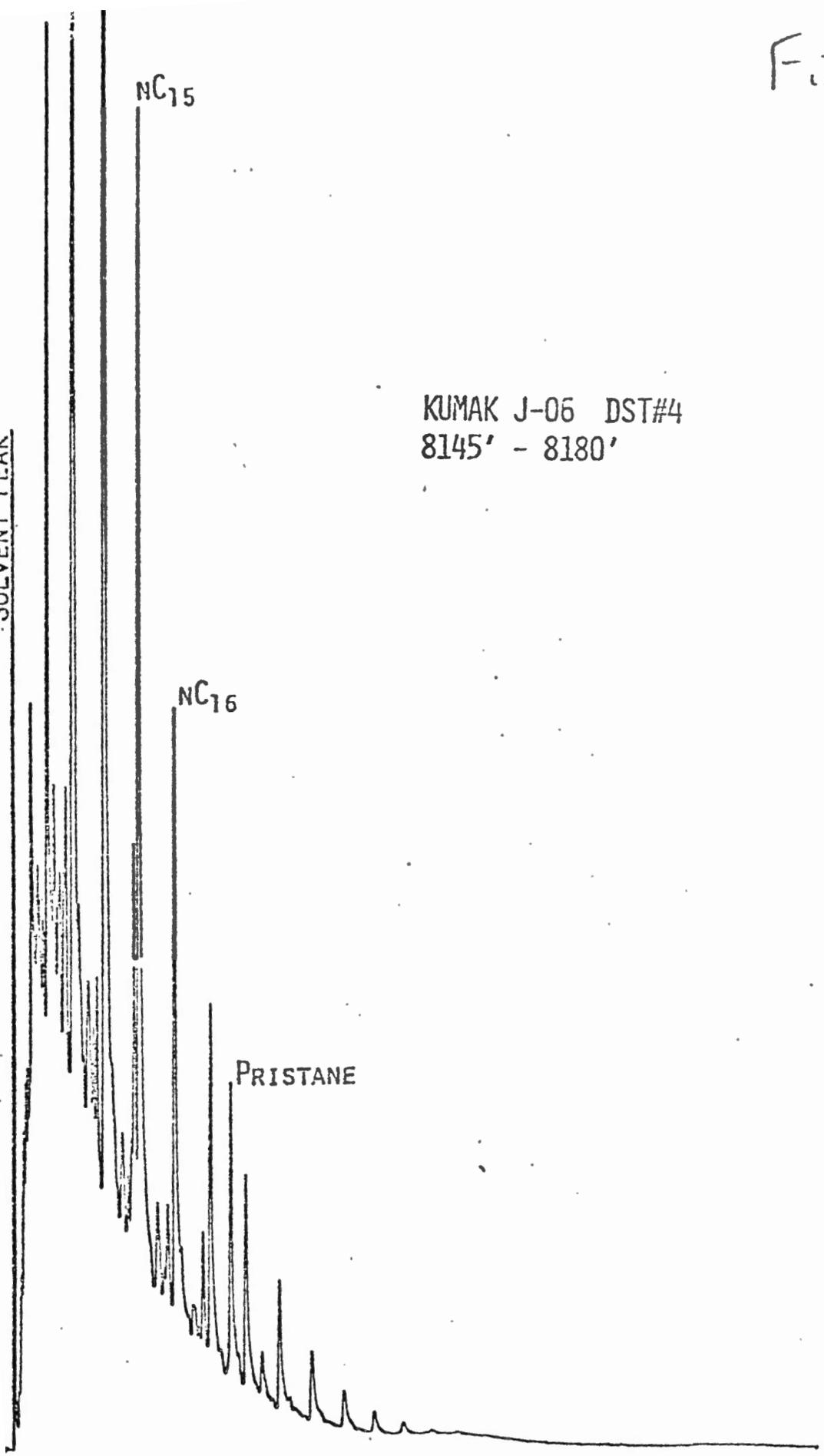
KUMAK J-06 DST#4  
8145' - 8180'

SOLVENT PEAK

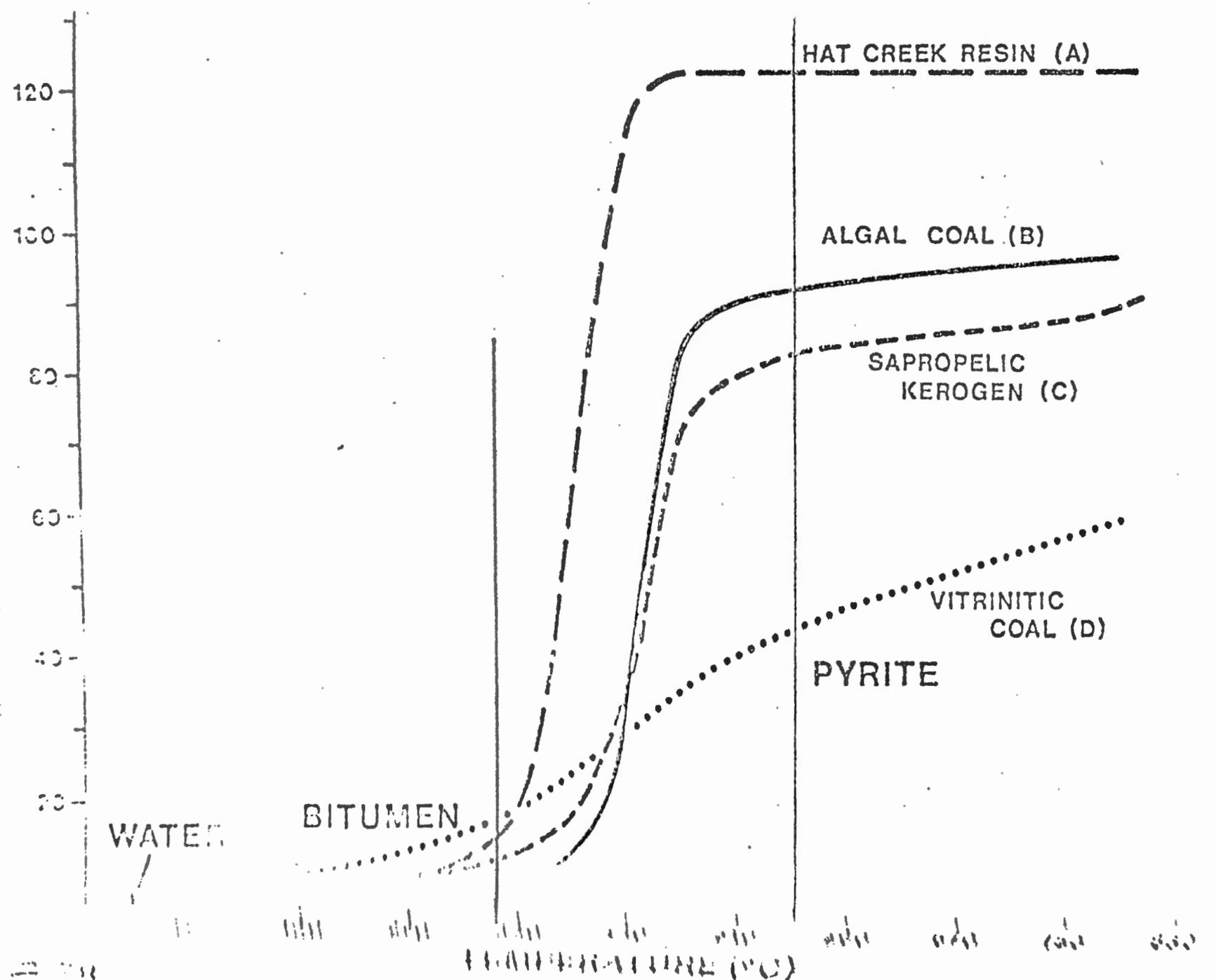
NC<sub>15</sub>

NC<sub>16</sub>

PRISTANE



WAX LIGHT LOSS AS CARBON



9  
1/2 pro

Fig 46

↑  
9cm  
↓  
1/4 page  
with fig 5  
= 1/2 page

NC<sub>15</sub>

TOAPOLOK 0-54  
8160'

HC YIELD = 36mg/gm  
R<sub>o max</sub> ≈ .60

SOLVENT PEAK

PRISTANE

DITERPANE

PHYTANE

NC<sub>19</sub>

?

NC<sub>23</sub>

NC<sub>25</sub>

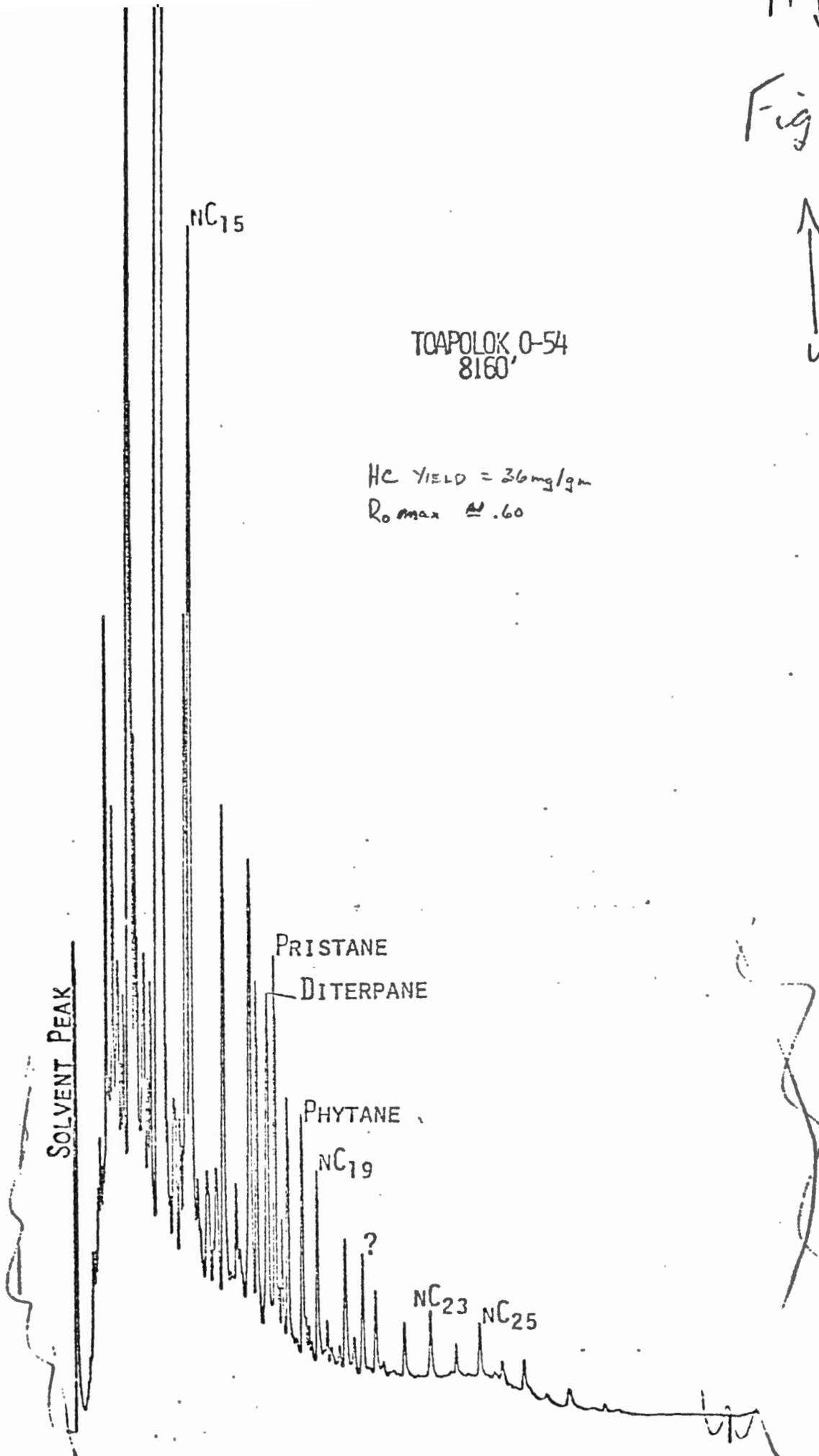


Fig 8  
9 cm  
= 1/4 page  
with fig 4  
= 1/2 page

SOLVENT PEAK

NC<sub>15</sub>

KUMAK J-06 DST#4  
8145' - 8180'

NC<sub>16</sub>

PRISTANE

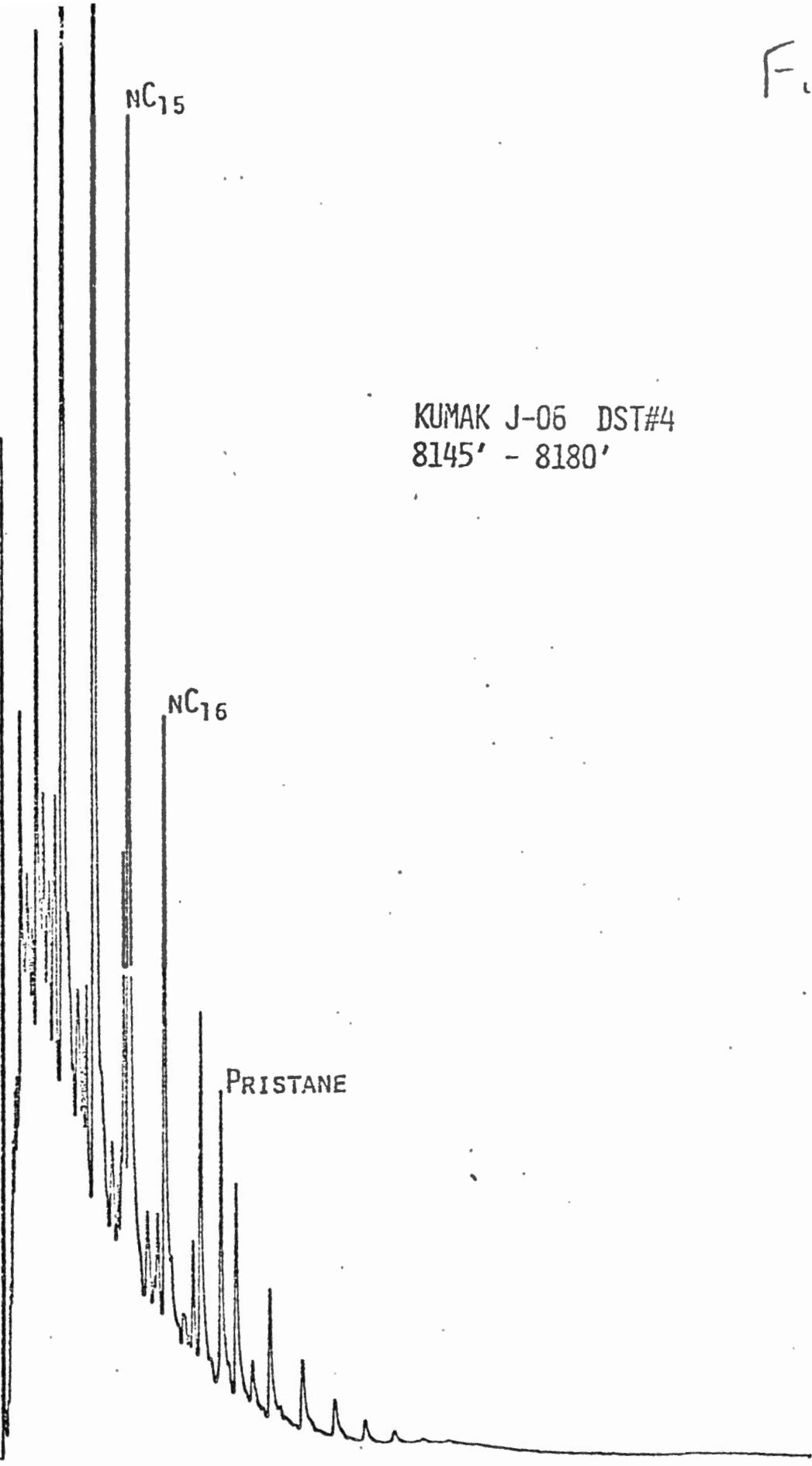


Fig 7  
↑ 9  
1/2 12

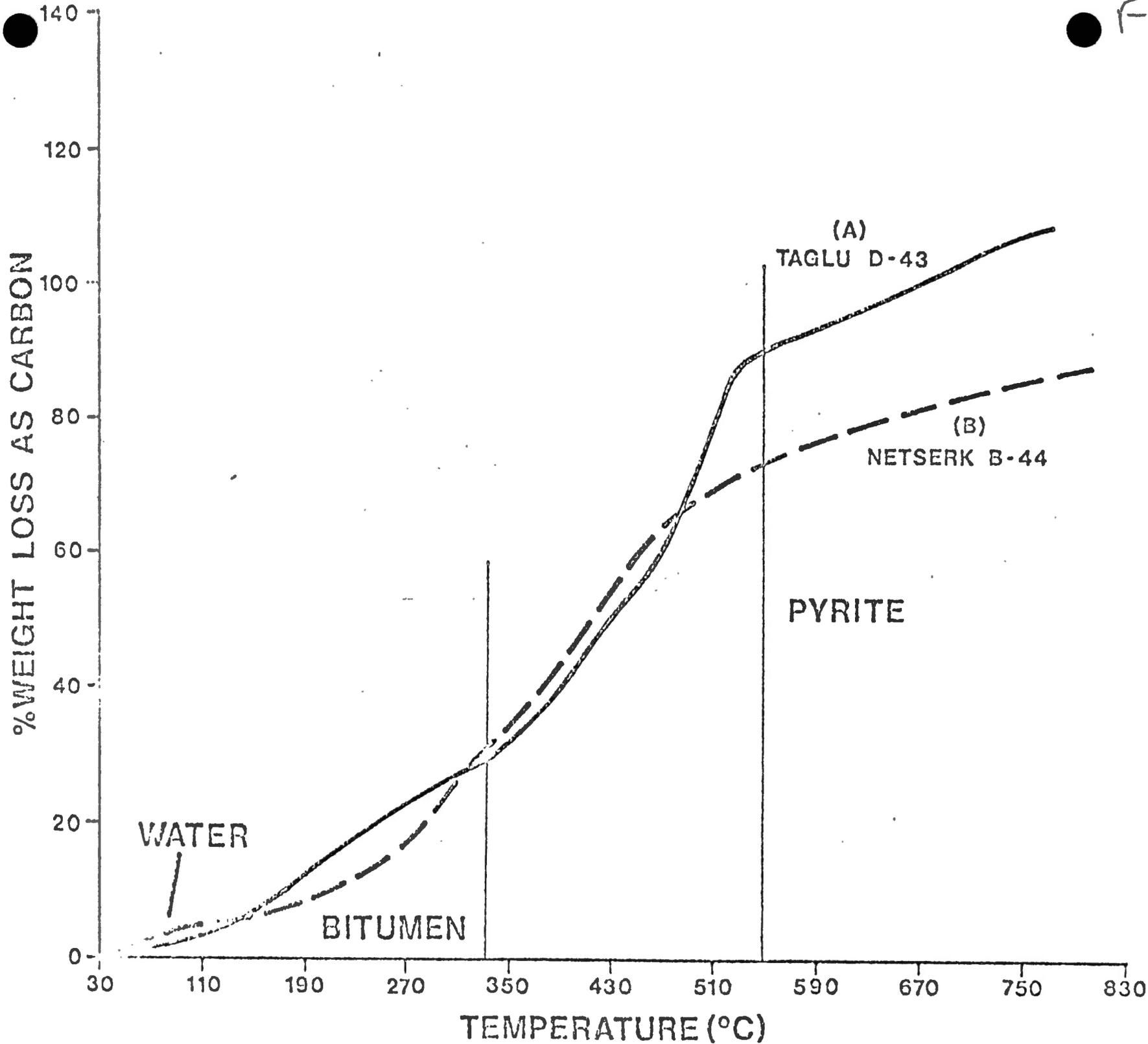
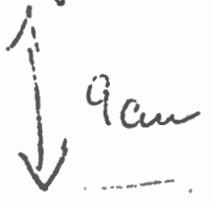


Fig 11



1/2 page

PYROLYSIS GAS CHROMATOGRAM:  
HAT CREEK RESIN  
(400° FOR 30 SECONDS)

RECORDER RESPONSE

12 14 16 18 20

APPROXIMATE N-ALKANE RETENTION

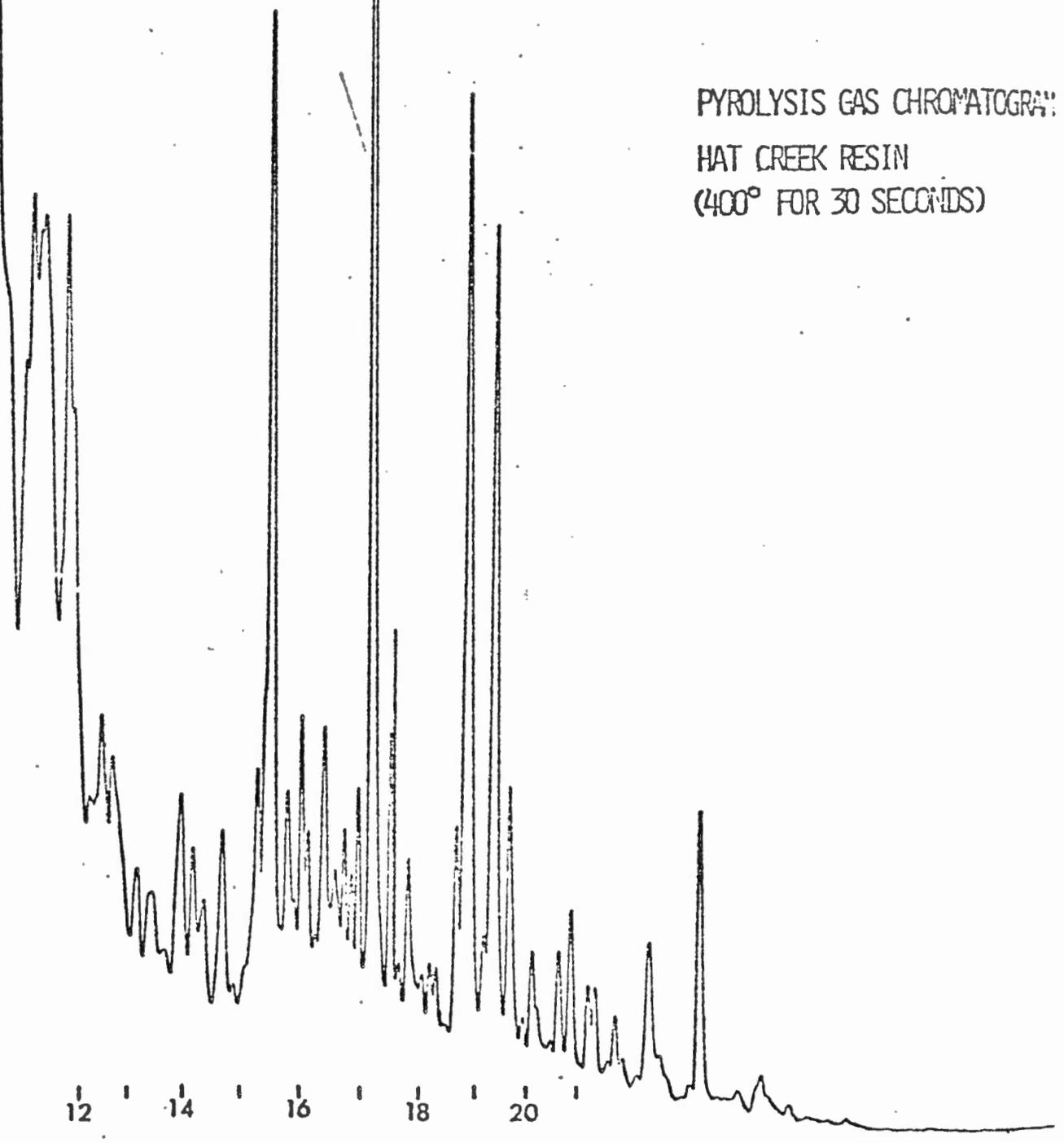


Fig. 1  
120ms  
~1/3 ps

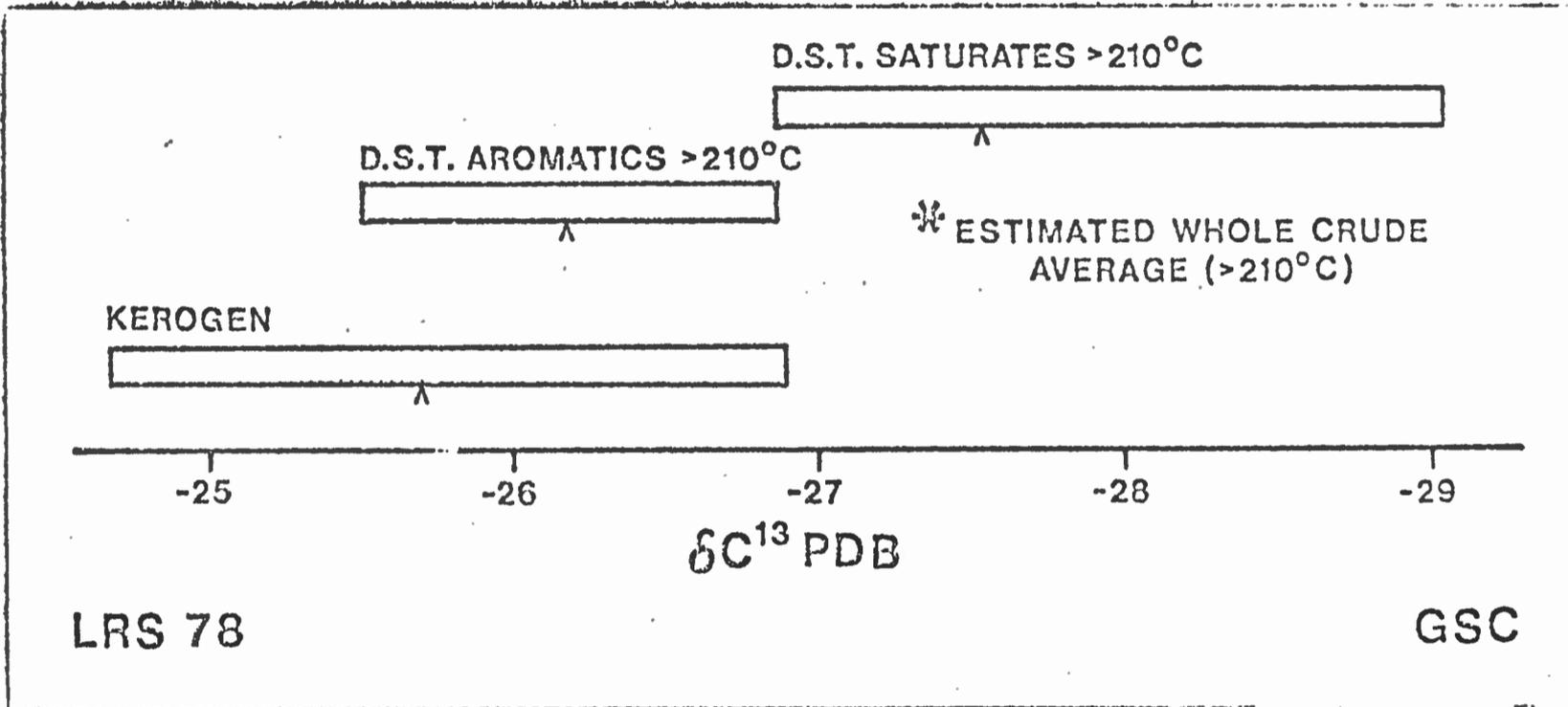


Fig 7:  
↑ 9  
1/2 12

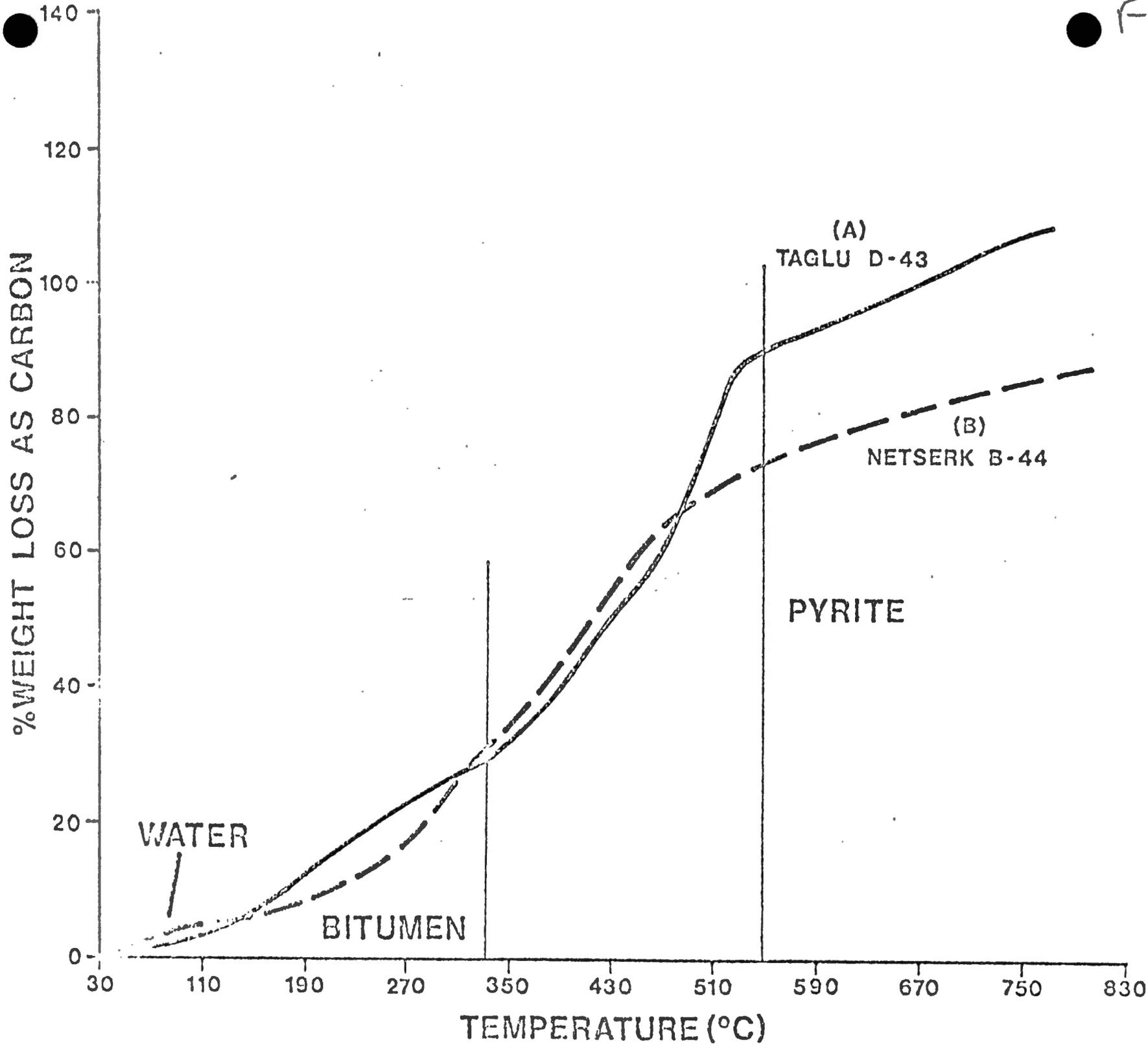
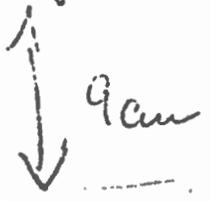


Fig 11



1/2 page

PYROLYSIS GAS CHROMATOGRAM:  
HAT CREEK RESIN  
(400° FOR 30 SECONDS)

RECORDER RESPONSE

12 14 16 18 20

APPROXIMATE N-ALKANE RETENTION

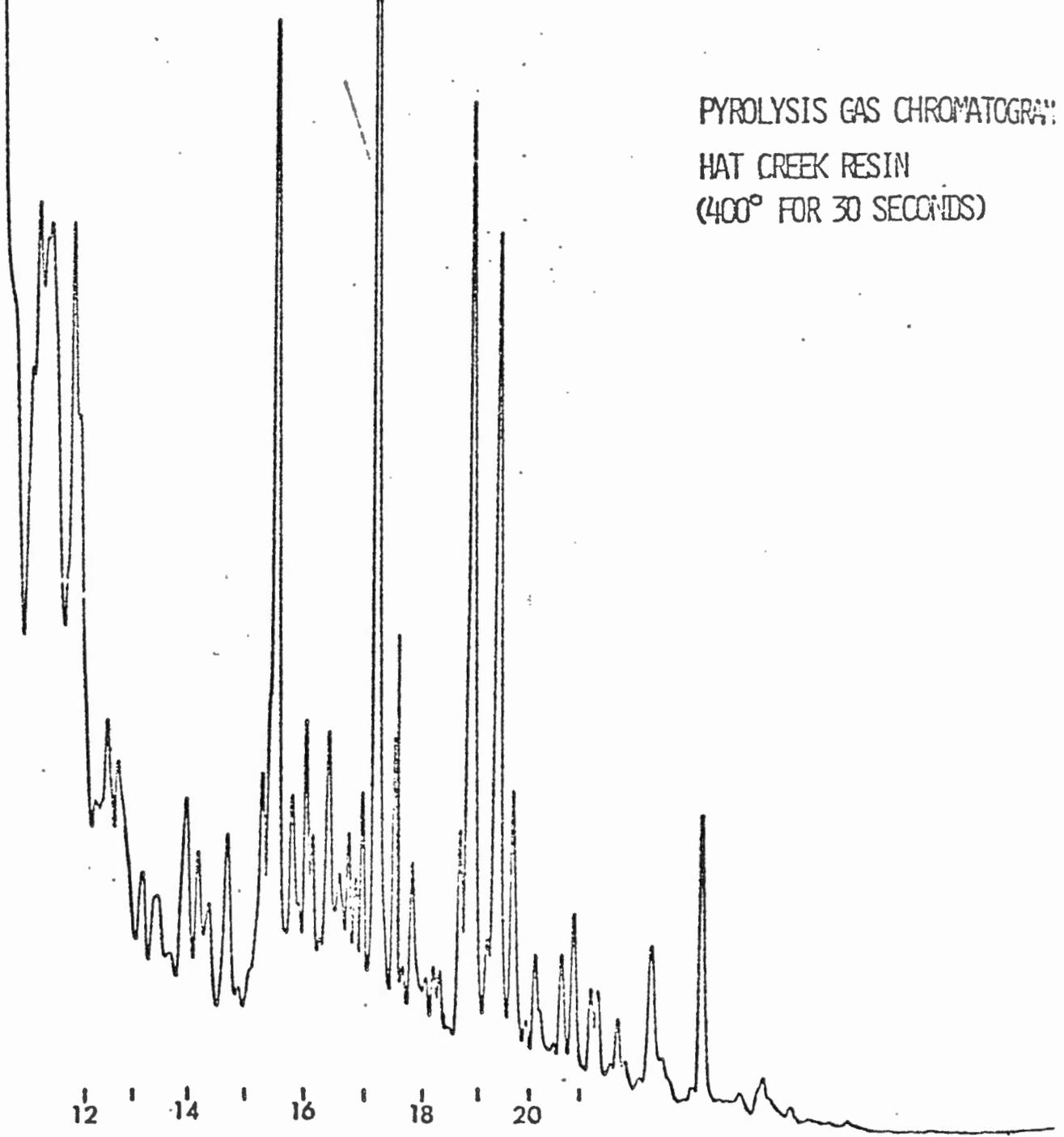


Fig. 1  
120ms  
~1/3 ps

