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Ekofisk - Norway
Lr-239-69

Nor/Exp/Geol- Geochemical
Ekofisk

December 24, 1969

Mr. T. J. Jobin, Manager
Phillips Petroleum Company Norway
Oslo, Norway

Attention: H. H. Heikkila, Chief Geologist

In accord with Mr. H. H. Heikkila's request to Mr. D. W. Williams dated November 3, we now have obtained most of the geochemical data for the samples submitted from Wells 2/4-1X and 2/4-1AX in the Norwegian Sector of the North Sea. Data still outstanding will be provided later. We do not expect, however, that these data will alter our present observations and conclusions. The inventory of samples received and used in the study are contained in Attachment 1.

Our observations and conclusions are summarized as follows:

1. Core 1 from the depth interval 5461 to 5513 feet in Well 2/4-1AX consists of organic-rich fossiliferous marine shale. The carbon isotopic composition, boron concentration, size and fragmented character of the fossils, and dearth of coarse-grained clastics indicate deposition well offshore in hypersaline waters with moderately high energy level, such as the flanks of an emergent or nearly emergent salt structure, the crest of which was stripped of previously deposited shale and became the site of carbonate deposition. The organic fraction of the shale comprising this core indicates oscillations in rates of deposition and ecology, suggesting deposition over a considerable interval of time. Core 1 represents a formation in which petroleum is in an early stage of genesis. These shales in the area of Well 2/4-1AX could have produced small amounts of gas and a liquid oil with a relatively small alkane (normal-and branched-paraffin hydrocarbons) fraction, a high proportion of naphthenic and aromatic hydrocarbons, and an intermediate amount of asphaltic residue. The oil generating potential of this rock is great, and in other locations in the basin where burial has been greater or where uplift occurred sufficiently late that earth temperatures were relatively high for a large proportion of the post-depositional history, the portion of the Middle Miocene represented by these samples could be expected to be a prolific source of petroleum.

2. Core 2 from the depth interval 10010 to 10017 feet in Well 2/4-1AX consists of fine-grained granular marine limestone. The size and degree of preservation of the fossils, presence of fine clastic in low concentrations, and the presence of authigenic pyrite and glauconite indicate deposition occurred in quiet water sufficiently below wave base as to (a) be unaffected by tractive currents, (b) prevent comminution of fossils or destruction of worm burrows, and (c) preserve reducing conditions in the bottom waters. The site of deposition, however, was close enough to shore to have a

significant component of silt-sized clastics and fossil debris transported to the site by uniform suspension currents in the overlying surface waters.

3. Petroleum constitutes the entire organic content of Core 2. The oil is not indigenous, hence the formation in this depth interval must be considered a reservoir rather than a source rock.

4. The oil contained in Core 2 is geochemically identical to the oil produced from the depth interval 10363 to 10464'.

5. The gas fraction of the oil from the 10363 to 10464 foot interval correlates chemically and isotopically with the gases obtained from Well 7/11-1X (9440 to 10197 feet) and 7/11-2X (9932 to 10190 feet) on the Cod Structure.

6. The oil from T.D. in Well 2/4-1X was generated in a source rock comparable or identical to that encountered in Core 1 from the 5461 to 5513' depth interval in Well 2/4-1AX. This oil is geochemically younger than the oil contained in Core 2 and obtained by production test of the 10363 to 10464 foot depth interval in the -1AX well.

7. The compositions of the gas and liquid phases and the computed formation fluid of the production test at the depth interval 10363 to 10464 feet in Well 2/4-1AX are contained in Table VI. The composition of the liquid phase equilibrated to atmospheric pressure, i. e. corresponding approximately to stock tank liquid, is contained in Column 2 of Table V . The distribution of hydrocarbon constituents in the gas phase is normal. The non-hydrocarbon constituents of the gas, namely carbon dioxide, nitrogen, and hydrogen sulfide, are low. The oil is highly saturated, i. e., high in paraffins and naphthenes, and contains very little asphalt. Concentrations of combined nitrogen, sulfur, nickel, and vanadium are low. The crude, therefore, constitutes a high quality refinery feed stock.

8. The oil obtained at T.D. in Well 2/4-1X, and to be expected in reservoirs deriving their oil from the formation corresponding to Core 1 in Well -1AX, are of lower gravity than the oil found at the 10363 to 10464 foot depth interval in Well -1AX. This oil is highly aromatic and contains a considerable amount of asphalt. Combined nitrogen and sulfur concentrations are intermediate; the nickel concentration is quite high. This crude, therefore, is of lower quality than that produced from the deeper interval.

9. Identification of the source rock for the oil contained in Core 2 and produced from the 10363 to 10464 foot depth interval in Well -1AX was not possible from the samples provided. It is recommended that consideration be given to an effort to identify its source rock, and determine its volume, areal distribution and productivity in terms of oil generated and migrated, as an indicator of the petroleum-producing potential of this part of the basin.

The data upon which the above conclusions are based are contained in Attachments 2 and 3, Tables I - VII, and Figures 1 - 4. Basic concepts and interpretations used to arrive at conclusions stated above are discussed in the remainder of this letter.

Detailed mineralogical data for Core 1 in Well 2/4-1AX are given in Tables I and II and the lithologic descriptions of the samples are given in Attachment 2. This core consists of soft gray clay shale with moderately varying fossiliferous and calcareous content. A number of factors dictate a marine environment of deposition, namely (1) fauna, (2) high concentration of the trace element boron as shown in the last column of Table I, (3) carbon isotopic composition and abundance of calcium carbonate (calcite) shown in the upper half of Table II, and (4) the carbon isotopic composition of the organic fraction shown in Table III. Briefly, carbon isotope values less than -30.0 are taken as indicating a fresh water origin for the organic matter; -30.0 to -29.0, brackish; and more than -29.0, marine. Except where there is major transport or organic matter, such as by turbidity currents, the environment as derived for the organic fraction is synonymous with the environment of deposition. As a quantitative indicator of salinity, both the concentration of boron and of the clay mineral illite must be taken into consideration. A boron concentration corresponding to three times the normalized per cent illite in the clay fraction is considered the boundary between brackish and marine environments. In Core 1, the boron concentrations correspond to eight to twenty times the normalized illite concentrations. These high values are believed to indicate that the water body in which the shales accumulated was hypersaline. The occurrence of echinoid spines in random orientation with some perpendicular to the bedding plane in at least one sample indicates that deposition occurred rapidly. The dearth of coarse-grained clastics would seem to indicate that these shales were deposited in quiet water. However, the presence of broken shell fragments and of spines 8 mm in length which were transported to the site of deposition after dismemberment of the skeleton of the organism would indicate that the energy level in the environment was moderately high and that the fine-grain size of the inorganic detritus might mean that no coarse-grained material was available. The most probably environment consistent with hypersalinity, fine grain size, and marine fossils would be in the lee of an areally extensive, but not necessarily emergent, offshore bar considerably removed from a source of continentally derived clastics. Such an environment would be consistent with the clay mineralogy listed in Table I and with the carbon isotopic composition which indicates that practically no terrestrial organic matter is present. This environment also would be consistent with the occurrence of a dolomite facies at this horizon in the 2/4-1X Well only a kilometer away, and with the uniformity suggested by seismic data from this horizon.

A probable model that would satisfy all these data and interpretations is a large salt structure well offshore the crest of which had been uplifted to near sea level by Middle Miocene. The shale previously deposited in this originally quiet water environment would have been removed from the crest and redeposited on the flank. At the surf zone broken shells and echinoid spines would have been mixed into the shale. Carbonates deposited on the crest of the structure would have been dolomitized in the shallow hypersaline water and tongues of undolomitizied carbonate would interfinger with the shales in deeper water as is shown by the logs of carbonate content and fossil content in Figure 1. As shown by the good correlation between these logs the calcareous fossils are partially responsible for the peak carbonate concentrations despite the fact that calcite crystals also are present. The crestal carbonates would have had adequate porosity to have held the quantity of oil produced during the early stages of petroleum genesis in the shales on the flanks of the salt structure.

Mineralogic data for Core 2 are given in Tables I and II and the lithologic descriptions in Attachment 3. In general this core consists of fine grained granular marine limestone. The high concentration of quartz and calcite and the absence of illite in the clay size fraction as shown in Table I prevent an estimation of salinity based on boron concentration. Because the oil contained in the core is not indigenous the carbon isotopic values shown in Table IV apply not to the core but to the rock which was the source of the oil.

The well preserved character of the fossils contained in the core indicate deposition in fairly quiet water; however, the relative abundance of silt-size quartz and the size of some of the spines up to 2 mm in length suggest that the surface waters over-lying this site of deposition were affected by currents of moderate competence. The log of the carbonate concentration in the core shown in Figure 2 indicate that the non-carbonate constituents vary as would be expected if supplied by currents of small and varying competence. These data suggest an environment of moderate depth and no great distance from shore. The presence of authigenic pyrite and glauconite in the core indicates that the bottom waters were reducing and hence sufficiently deep to be relatively unaffected by the surface turbulence which introduced the transported material. The well site thus was considerably seaward of wave base so that no tractive current deposition occurred and sufficiently far from this turbulent zone that carbonate deposition far exceeded deposition from uniform suspensions in the surface waters. Absolute distance from shore or depth of water cannot be assigned without information on the seaward dip of the sediment-water interface, whether or not there is a sharp break in this slope, or whether the energy level in the water between the well site and the shoreline.

Data pertinent to source rock evaluation of Core 1 in 2/4-1AX is contained in Table III. The procedure used for recognition of source rocks has been discussed previously(1). The organic content for all 18 samples from this core fall within the range 0.5 to 6.0 considered optimum for a source rock. The ratio of soluble organic matter to total organic matter is very low, indicating that residual oil is indigenous to the rock. The high recovery from the silica gel absorbant indicates that normal petroleum genesis is underway. The odd-even predominance or OEP values are higher than would be expected for a mature source rock, i. e., a rock in which maximum petroleum genesis has occurred and from which the petroleum has subsequently migrated. Those sections of the core with OEP values less than 2 may have generated and yielded small amounts of gas and crude oil. From the relative concentrations of saturated hydrocarbons, aromatics and asphaltics contained in the extract any crude accumulated from the rock would be expected to be of relatively low gravity, highly aromatic and with a reasonably high asphalt content.

Data concerning the organic fraction of Core 2 in Well 2/4-1AX is given in Table IV. Only a few per cent of the organic matter deposited in a source rock and which survives geologic time is converted to petroleum. The remainder is converted to a dark brown to black amorphous insoluble substance known as kerobitumen. The fact that the ratio of soluble organic matter to total organic matter for all twelve samples from Core 2 are close to unity indicates that the organic matter contained in this core is present almost entirely as petroleum which could not have been generated in the rock but must have migrated in from another source. Core 2 therefore must be considered a reservoir rather than a source rock. The odd-even predominance, i. e. OEP, values close of unity indicate a mature oil probably derived from a source rock in which

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(1) Letter Er-132-69 to D. W. Williams, dated August 12, 1969

petroleum genesis is well advanced. The uniformity in the compositional and isotopic values for the saturated hydrocarbon, aromatic and asphaltic fractions are consistent with the concept that the oil has migrated into the rock. The properties of the combined extract are given in the last column of Table V. The values correspond closely to those for the oil derived by production test from the 10363 to 10464 foot interval. Evaporation losses during extraction can easily account for the somewhat lower API gravity, higher specific gravity and higher viscosity. A comparison of the odd-even predominance, O P, as a function of carbon number for the rock extract and for the crude oil is shown in Figure 4. The correlation coefficient for these two curves is 0.743 with 19 degrees of freedom. Significance on "t" Test is better than 99.9 per cent, i. e., there is less than one chance in a thousand that the correlation observed between these two curves is by accident, therefore it is concluded that the oil in the rock and produced on test is as would be expected, identical.

The component composition of the low molecular weight fraction of the gas from the production test and the carbon isotopic values for the first several members of the hydrocarbon series are provided in Table VI. In Table VII are provided the ratios of the major constituent, methane, to the next four members of the hydrocarbon series and these values compared with the values for the gas samples from Well 7/11-1X, 2X and 3X on the Cod Structure. The ratios for the gas from Well 2/4-1AX correlate with those for the gases from Wells 7/11-1X and 2X, but differ considerably from the ratios for the gas phase obtained from Well 7/11-3X. The isotopic data plotted in Figure 3 provide additional support for this conclusion.

Identification of the source rock for the deep production in Well 2/4-1AX was not possible from the samples provided. Identification of the source rock, determination of its productivity in terms of oil generated and migrated, its volume and areal distribution, would provide an indicator of the petroleum-producing potential of this part of the basin. Samples of likely source rocks from the present and/or future wells would be required. Pieces of core such as those provided from Cores 1 and 2 in the 1AX well are ideal. Good sidewall cores also can be used.

Original Signed By
J. GORDON ERDMAN

J. Gordon Erdman

JGE:M

Attachments 3, Tables 7,
Figures 4

Attachment 1

Inventory of Samples Received and Used In The Study

1. From Well 2/4-1X. Oil sample from TD collected at atmospheric pressure. Transmitted by A. T. Crump (SB-010-69). Received November 7, 1969. Assigned Geochemistry Branch Code FLK.

2. From Well 2/4-1AX

   (a) Eighteen rock samples from Core 1 at depth intervals from 5461 to 5513'. Transmitted by H. H. Heikkila (NOB-164-69). Received November 11, 1969. Assigned Geochemistry Branch Code letters FLM through FMD.

   (b) Twelve rock samples from Core 2 at depth intervals from 10010 to 10017'. Transmitted by H. H. Heikkila (NOB-164-69). Received November 11, 1969. Assigned Geochemistry Branch Code letters FME through FMP.

   (c) Companion gas-liquid samples collected using Geochemistry Type A kit and Method 67-1B. Transmitted by A. T. Crump (GWB/GJ-094/69). Received December 8, 1969. Assigned Geochemistry Branch Code letters FQV (gas) and FQW (liq.).

3. From Wells 7/11-1X, 2X and 3X. See my letters Er-83-69 dated May 19, 1969 and Er-132-69 dated August 12, 1969 both to D. W. Williams.

Attachment 2

Lithological Description of Core No. 1
Well 2/4-1AX, Norwegian Sector, North Sea

Geochem. Branch Code

FLM - Depth 5461 feet. Olive gray (5Y 4/1), soft, calcareous, micaceous, fossiliferous, well-bedded clay shale with greasy luster and soapy feel; contains a few minute carbonaceous and biotite flakes; microfossils are fairly well-preserved and consist of minute broken valves, foraminifera tests, and spines; the spines have both hollow and solid cores and the hollow ones are somewhat flattened, and the longer spines, up to 8 mm in length, are generally striated along their length.

FLN - Depth 5466 feet. Dark greenish gray (5GY 4/1), soft, non-calcareous, micaceous, sparsely fossiliferous, well-bedded clay shale with greasy luster and soapy feel; contains minute black flecks and reddish brown blebs of organic matter; the microfossils are not as common as in Sample FLM and consist predominately of minute, tapered, chitinous spines.

FLO - Depth 5468 feet. Olive gray (5Y 4/1) shale, identical to Sample FLN except that no microfossils were observed and the mica flakes are larger, ranging up to 0.3 mm in diameter.

FLP - Depth 5472 feet. Light olive gray (5Y 6/1) shale, identical to Sample FLO except that mica flakes are not as common and are considerably smaller.

FLQ - Depth 5475 feet. Greenish gray (5GY 6/1), soft, slightly calcareous and micaceous, somewhat carbonaceous, fossiliferous, well-bedded clay shale with a greasy luster and soapy feel; the carbonate occurs as minute, uniformly-distributed calcite crystals; minute spherules of psilomelane and pyrolusite occur with the carbonaceous matter and apparently has replaced some of the organic matter.

FLR - Depth 5478 feet. Olive gray (5Y 4/1), soft, slightly calcareous and micaceous, fossiliferous, well-bedded clay shale with greasy luster and soapy feel; a few of the mica flakes are biotite; the microfossils consist of foraminifera tests and minute spines of unknown affinity, both of which commonly have hollow interiors partially filled with minute spherules of pyrite, psilomelane, and pyrolusite; the minute fragments of carbonaceous matter commonly are covered with framboidal psilomelane.

FLS - Depth 5481 feet. Olive gray (5Y 4/1), soft, calcareous, micaceous, fossiliferous, well-bedded clay shale with greasy luster and soapy feel and many indistinct slickensided surfaces; the foraminifera, and particularly the globigerina, are exceptionally well-preserved, with transparent punctate test walls; most of the tests are partially filled with minute spherules of pyrite and psilomelane; minute spherules of psilomelane are also associated with the few small flakes of carbonaceous matter present.

FLT - Depth 5484 feet. Light olive gray (5Y 6/1) shale, identical to Sample FLS except that it is more calcareous and foraminifera tests are more abundant.

FLU - Depth 5487 feet. Dark greenish gray (5GY 4/1) shale, identical to Sample FLS except that it is more fossiliferous and contains numerous spines in addition to foraminifera; the spines are probably from echinoids and most are poorly preserved, however a few of the longer ones, up to 2 mm in length, are pyritized and exceptionally well preserved; the longer spines have hollow cores containing small quantities of framboidal psilomelane; these spines are of uniform diameter throughout their length with cellular wall construction and a fine linear striae; in addition to the numerous spines and foraminifera tests, a few wafer-shaped microfossils and fragments of minute bivalve shells also are present; the wafer-shaped fossils are reddish-brown with irregular, undulating surfaces and apparently have been partially altered to organic matter; the shall fragments are poorly preserved and replaced by limonite but have retained concentric growth lines in the umbo area.

FLV - Depth 5490 Feet. Greenish black (5G 2/1), soft, slightly calcareous and carbonaceous, micaceous, fossiliferous, well-bedded clay shale with greasy luster and soapy feel and poorly-defined slickensides; the microfossils commonly have hollow interiors partially filled with framboidal psilomelane and pyrite; pyrite also occurs as minute crystals on bedding planes.

FLW - Depth 5493 feet. Dark greenish gray (5GY 4/1) shale, identical to Sample FLV except that slickensides are less common and minute blebs of reddish-brown viscous organic matter are present; the viscous matterial occurs in rounded blebs approximately 0.3 mm in diameter and fluoresces yellow under ultraviolet light; this substance appears to have formed <u>in situ</u> from the alteration of the wafer-shaped microfossils described in Sample FLU.

FLX - Depth 5496 feet. Olive gray (5Y 4/1) shale, identical to Sample FLV except that it is more calcareous and lacks blebs of reddish-brown liquid, although blebs of reddish-brown solid organic matter up to 0.3 mm in diameter are distributed throughout the sample; spines are commonly pyritized and minute spherules of psilomelane pyrite and pyrolusite are present in the cavities of microfossils and in intimate association with carbonaceous fragments.

FLY - Depth 5499 feet. Olive gray (5Y 4/1) shale, identical to Sample FLX except that it lacks the small reddish-brown blebs of organic matter.

FLZ - Depth 5502 feet. Yellowish gray (5Y 8/1), medium hard, slightly calcareous, slightly micaceous, silty, fossiliferous, well-bedded clay shale with poorly developed slickensides; the microfossils are poorly preserved and consist predominantly of fragmented spines altered to psilomelane; pyrite occurs as minute crystals in trace amounts throughout the shale; minute carbonaceous fragments and blebs of reddish-brown organic matter also are present; silt-size quartz grains are rounded to subrounded and fairly well-sorted.

FMA - Depth 5505 feet. Olive black (5Y 2/1), soft, somewhat plastic, non-calcareous, slightly micaceous and silty, slightly fossiliferous, well-bedded clay shale with greasy luster, soapy feel, and well-developed slickensides; the slickensided surfaces indicate that the direction of movement has frequently changed 180° or more within a lateral distance of only a few mm; the microfossils are poorly preserved and consist of only a few small spine fragments; minute blebs of reddish brown solid organic matter are distributed throughout; silt-size quartz grains are rounded to subrounded and fairly well-sorted.

FMB - Depth 5508 feet. Light olive gray (5Y 6/1) shale, identical to Sample FMA except that the shale is calcareous and microfossils are more common and better preserved; some of the reddish brown blebs of solid organic matter in this sample have been deformed by movement along the slickensided surfaces.

FMC - Depth 5511 feet. Olive black (5Y 2/1) shale, identical to Sample FMA except that the shale is slightly calcareous and spines with solid and hollow centers up to 4 mm in length are present; the spines lack ornamentation and are generally replaced with limonite; some of the hollow types are partially filled with psilomelane and pyrite spherules; minute valves with undulose surfaces and concentric growth lines in the umbo area also are present; wafer-shaped microfossils like those described in Sample FLU have been altered to reddish brown solid organic matter distributed throughout the sample.

FMD - Depth 5513 feet. Olive gray (5Y 4/1) shale, identical to Sample FLZ except that microfossils are more abundant and better preserved and the shale is more calcareous; orientation of some of the small delicate spines up to 1.5 mm in length perpendicular to the bedding planes suggests that deposition must have been consistently rapid during deposition of the interval sampled.

Attachment 3

Lithological Description of Core No. 2
Well 2/4-1AX, Norwegian Sector, North Sea

Geochem.
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Code

FME - Depth 10010 feet. Yellowish gray (5Y 8/1), medium hard, massive, very fine-grained, granular, slightly fossiliferous, limestone; microfossils consist of sparse, fairly well-preserved, calcareous, translucent foraminifera tests partially filled with minute psilomelane and pyrite crystals, apparently replacing the soft parts of the organism; pyrite also occurs as minute cubes uniformly distributed throughout, and fine- to medium-grained sparry calcite crystals are similarly disseminated; the few silt-size quartz grains present are rounded to subrounded and fairly well-sorted.

FMF - Depth 10011 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FME except that a 0.7 mm-thick lamina of closely-spaced, small pyrite cubes and fine quartz grains is present; very fine-grained pyrite also occurs in association with a trace of psilomelane in anastomosing filaments probably representing fillings in small organism trails and burrows; additional occurrences of pyrite are as crystals lining the interior of foraminifera and as a replacement of a few minute spines.

FMG - Depth 10012 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FMF except that considerably more spines are present with many ranging up to 2 mm in length; a few of the spines are pyritized but most have been dissolved leaving only external molds which contributes significantly to the porosity; pyrite occurs in trace amounts as disseminated crystals and as fillings in minute organism trails and burrows; traces of glauconite and silt-size, subrounded quartz grains also are present.

FMH - Depth 10012.25 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FMG except that it is softer and somewhat coarser grained, glauconite is more common, spines are considerably more numerous, a trace of muscovite is present, and minute, soft, black flakes of carbonaceous matter are distributed throughout; spines have contributed significantly to the vuggy, high porosity, both as a result of most of them having been dissolved leaving external molds and as a result of most of those preserved having hollow cores.

FMI - Depth 10012.75 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FMH except that glauconite is slightly more abundant and minute cubes of pyrite are distributed throughout.

FMJ - Depth 10013 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FMI except that glauconite occurs only in trace amounts, pyrite is less common, and the grain size is somewhat finer; spines are the predominant fossil type but only a few have been dissolved hence the porosity appears to be lower than in Samples FMI and FMH.

FMK - Depth 10013.25 feet. Yellowish gray (5Y 8/1), medium hard, very fine-grained, granular, slightly fossiliferous limestone with several planar medium gray (N 5) laminae 2 mm thick, containing scattered blebs < 0.1 mm in diameter of very fine-grained pyrite crystals, psilomelane and pyrolusite spherules and medium grained sparry calcite; the blebs generally have rounded outlines but a few are rectangular and probably represent organic matter that has been altered and replaced; these laminae were probably deposited during intervals when reducing conditions prevailed at the sediment-water interface; the major yellowish gray, portion of the sample is similar to Sample FMJ except that glauconite is absent, microfossils are less common, spines are fewer and poorly-preserved, and a few minute, irregular blebs of chert are present.

FML - Depth 10014 feet. Yellowish gray (5Y 8/1), medium hard, massive, very fine-grained, granular, fossiliferous limestone; well-preserved, calcareous, translucent foraminifera tests provide good vuggy porosity even though minute spherules of pyrite and psilomelane partially fill their interiors; a few spines also are present; muscovite and glauconite occur in trace amounts throughout.

FMM - Depth 10015 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FML except that it is somewhat coarser grained and contains small euhedral crystals of polysynthetically twinned sparry calcite distributed throughout; foraminifera are generally poorly preserved, some having been completely replaced by sparry calcite and some having been dissolved and their external molds lined with drusy calcite crystals; several very small fractures also are lined with minute crystals of euhedral calcite; all spines have solid cores; minute pyrite crystals are distributed throughout and drusy pyrite with psilomelane occur as replacement of carbonaceous matter and as fillings in minute organism trails and burrows; muscovite flakes and glauconite grains occur in trace amounts.

FMN - Depth 10015.75 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FML except that several faint medium gray (N 5), very thin planer laminae occur from 0.5 to 5.0 mm apart; these laminae are more carbonaceous than the remainder of the rock; minute pyrite crystals closely associated with psilomelane spherules and medium-grained euhedral marcasite occur in fine anastomasing filaments on bedding planes and probably represent worm trails.

FMO - Depth 10016 feet. Yellowish gray (5Y 8/1) limestone, identical to Sample FML except that it is somewhat softer.

FMP - Depth 10017 feet. Yellowish gray (5Y 8/1), soft, massive, very fine-grained, granular, slightly fossiliferous pyritic limestone; pyrite occurs with traces of psilomelane spherules in rounded blebs up to ½ mm in diameter and as minute cubes distributed throughout; the blebs are probably replacements of organic matter; the microfossils are poorly preserved and commonly replaced by sparry calcite.

TABLE I

Mineralogy by X-Ray Diffraction of Core Samples From
Well 2/4-1AX, Norwegian Sector, North Sea

Geochem. Branch Code	Depth, feet	Whole Rock							Clay Size Fraction								Bo Con tra (pp
												Normalized Clay Mineral Content (%)					
		Quartz	Calcite	Feldspar	Illite	Kaolinite	Unidentified Clay	Other	Quartz	Calcite	Feldspar	Illite	Kaolinite	Montmorillonite	Other	
							Core 1										
FLM	5461	M	P	P	P	P	P	N	P	P	P	20	25	55	N	> 2
FLN	5466	M	P	P	P	P	P	N	P	N	P	25	20	55	(1)	2
FLO	5468	M	P	P	P	P	P	N	P	N	P	20	20	60	N	2
FLP	5472	M	N	P	P	P	P	N	P	P	P	15	25	60	N	> 2
FLQ	5475	M	P	P	P	P	P	N	P	P	P	15	15	70	N	2
FLR	5478	M	P	P	P	P	P	N	P	P	P	15	15	70	N	2
FLS	5481	M	M	P	P	P	P	Chlorite	P	P	P	10	15	75	(1)	20
FLT	5484	P	M	N	P	P	P	N	P	P	P	20	20	60	N	16
FLU	5487	M	P	P	P	P	P	N	P	P	P	20	10	70	(1)	> 2
FLV	5490	M	P	P	P	P	P	N	P	P	P	20	15	65	N	2
FLW	5493	M	M	P	P	P	P	N	P	P	P	15	15	70	N	2
FLX	5496	M	P	P	P	P	P	N	P	P	P	15	10	75	N	2
FLY	5499	M	M	P	P	P	P	N	P	P	P	20	15	65	N	2
FLZ	5502	M	P	P	P	P	P	N	P	P	P	20	15	65	N	2
FMA	5505	M	N	P	P	P	P	N	N	N	P	20	20	60	N	2
FMB	5508	M	M	P	P	P	P	N	P	P	P	10	20	70	N	16
FMC	5511	M	P	P	P	P	P	N	P	P	P	10	25	65	N	20
FMD	5513	M	M	P	P	P	P	N	P	P	P	10	20	70	N	18
							Core 2										
FME	10010	M	M	N	N	P	N	N	M	M	N	N	P	N	N	5
FMF	10011	M	M	N	N	P	N	N	M	M	N	N	P	N	N	6
FMG	10012	P	M	N	N	P	N	N	M	M	N	N	N	N	N	2
FMH	10012.25	P	M	N	N	P	N	N	M	M	N	N	N	N	N	4
FMI	10012.75	P	M	N	N	N	N	N	M	M	N	N	P	N	N	7
FMJ	10013	P	M	N	N	N	N	N	M	M	N	N	P	N	N	2
FMK	10013.25	P	M	N	N	P	N	N	M	M	N	N	P	N	N	5
FML	10014	P	M	N	N	P	N	N	M	M	N	N	P	N	N	10
FMM	10015	P	M	N	N	P	N	N	M	M	N	N	P	N	N	13
FMN	10015.75	P	M	N	N	P	N	N	M	M	N	N	P	N	N	6
FMO	10016	P	M	N	N	N	N	amphibole	M	M	N	N	P	N	N	2
FMP	10017	P	M	N	N	P	N	N	M	M	N	N	P	N	unidentified clay	13

M indicates major component; N indicates not detected; P indicates present

(1) Interlayered montmorillonite chlorite

TABLE II

COMPOSITION OF CALCIUM CARBONATE AND ITS CARBON ISOTOPIC COMPOSITION IN CORES 1 AND 2, WELL 2/4-1AX, NORWEGIAN SECTOR, NORTH SEA

Geochemistry Branch Code	Depth Interval, feet	Carbonate Carbon Wt %	Calcium Carbonate ($CaCO_3$) Wt %	Carbon Isotopic Composition δC^{13}_{PDB}
		CORE 1		
FLM	5461	0.71	5.9	
FLN	5466	0.07	0.6	
FLO	5468	0.04	0.3	
FLP	5472	0.06	0.5	
FLQ	5475	0.45	3.6	
FLR	5478	0.36	3.0	
FLS	5481	1.38	11.5	
FLT	5484	3.26	27.2	+ 2.6
FLU	5487	0.89	7.4	
FLV	5490	0.46	3.8	
FLW	5493	0.95	7.9	
FLX	5496	1.01	8.4	
FLY	5499	1.29	10.8	
FLZ	5502	1.26	10.5	
FMA	5505	0.04	0.3	
FMB	5508	1.54	12.8	
FMC	5511	0.98	8.2	
FMD	5513	1.63	13.6	
		CORE 2		
FME	10010	8.64	72.0	+ 2.0
FMF	10011	8.25	68.8	+ 2.3
FMG	10012	9.31	77.6	+ 0.8
FMH	10012.25	9.62	80.3	+ 1.6
FMI	10012.75	9.71	80.9	+ 2.9
FMJ	10013	10.74	91.2	+ 0.9
FMK	10013.25	9.55	79.6	+ 2.2
FML	10014	9.27	77.3	+ 2.7
FMM	10015	9.24	77.0	+ 0.8
FMN	10015.75	9.13	76.1	+ 2.5
FMO	10016	10.31	85.9	+ 2.3
FMP	10017	9.47	78.9	+ 1.8

TABLE III

CHARACTERIZATION OF THE ORGANIC FRACTION OF CORE NO. 1
WELL 2/4-1AX, NORWEGIAN SECTOR, NORTH SEA
(SOURCE ROCK EVALUATION-ISOTOPIC ENVIRONMENT OF DEPOSITION)

Geochemistry Branch Code	Depth, Feet	Organic Carbon Content, Wt %(1)	Ratio(2) Soluble Organic Matter / Total Organic Matter	Extractible Organic Matter: Total Soluble Wt %(1)	Total Soluble δC^{13}_{PDB}	Saturate Fraction Wt %(3)	Saturate Fraction δC^{13}_{PDB}	Aromatic Fraction Wt %(3)	Aromatic Fraction δC^{13}_{PDB}	Asphaltic Fraction Wt %(3)	Asphaltic Fraction δC^{13}_{PDB}	Recovery from Silica Gel Adsorbent, % (4)	Odd-Even Predominance, OEP	Indicated Isotopic Environment of Deposition	Source Rock Evaluation
FIM	5461	1.17	0.021	0.031	-24.1	18	-27.3	32	-25.6	50	-23.0	91	1.688	marine (all samples)	Geochemically young source rock. May have generated some gas and oil (all samples)
FLN	5466	0.96	0.019	0.023	-24.3	15	(5)	32	-24.6	53	-23.0	91	1.660		
FLO	5468	1.05	0.016	0.021	-24.4	12	(5)	29	-25.4	59	-23.2	93	2.086		
FLP	5472	1.43	0.010	0.018	-24.3	16	(5)	43	-24.5	41	-22.7	94	1.654		
FLQ	5475	1.15	0.008	0.011	-25.2	18	(5)	47	-25.2	35	-23.7	83	1.395		
FLR	5478	1.56	0.006	0.011	-23.9	16	(5)	44	-24.5	40	-22.6	95	(5)		
FLS	5481	1.11	0.013	0.018	-25.0	22	(5)	46	-26.0	32	-23.3	96	1.668		
FLT	5484	0.77	0.010	0.009	-24.8	27	(5)	37	-24.4	36	(5)	104	1.686		
FLU	5487	1.20	0.010	0.015	-23.8	18	(5)	39	-24.3	43	-22.7	94	2.308		
FLV	5490	1.18	0.009	0.014	-23.7	23	(5)	37	-25.0	40	-23.5	99	1.863		
FLW	5493	0.83	0.017	0.018	-25.3	34	-27.4	38	-25.3	28	-24.4	78	1.417		
FLX	5496	0.79	0.010	0.010	-25.2	23	(5)	33	-25.1	44	-23.4	99	2.626		
FLY	5499	0.73	0.008	0.007	-25.1	26	(5)	31	-25.9	43	-24.3	99	1.783		
FLZ	5502	0.51	0.011	0.007	-26.1	26	(5)	33	-25.9	41	-24.1	105	1.662		
FMA	5505	0.63	0.020	0.015	-26.5	47	-27.3	30	-25.5	24	-24.2	89	1.288(6)		
FMB	5508	0.69	0.010	0.008	-25.1	12	(5)	36	-25.9	52	-24.2	93	(5)		
FMC	5511	0.86	0.021	0.023	-25.3	26	(5)	33	-25.1	41	-24.0	87	2.060(6)		
FMD	5513	0.77	0.016	0.016	-24.3	16	(5)	83	-24.6	0.3	(5)	94	12.724		

(1) Of the core, dry weight basis.
(2) The total content of organic matter is derived from the total organic carbon content by applying a factor of 1.25.
(3) Of the total soluble fraction recovered from the silica gel adsorbent.
(4) A few per cent usually are lost in handling. Low recoveries indicate the presence of highly polar substances unlike petroleum.
(5) Fractions two small for determination.
(6) Values are approximate.

CHARACTERIZATION OF THE ORGANIC FRACTION OF CORE NO. 2
WELL 2/4-1A NORWEGIAN SECTOR, NORTH SEA
(PRIMARILY INDIGENOUS OIL)

Geochemistry Branch Code	Depth, Feet	Organic Carbon Content, Wt %(1)	Ratio(2) Soluble Organic Matter / Total Organic Matter	Extractible Organic Matter: Total Soluble		Saturate Fraction		Aromatic Fraction		Asphaltic Fraction		Recovery from Silica Gel Adsorbent % (4)	Odd-Even Predominance, OEP	Indicated Isotopic Environment of Deposition	Source Rock Evaluation
				Wt %(1)	δC^{13}_{PDB}	Wt %(3)	δC^{13}_{PDB}	Wt %(3)	δC^{13}_{PDB}	Wt %(3)	δC^{13}_{PDB}				
FME	10010	1.55	0.933	1.807	-27.0	65	-26.8	31	-27.6	4	-26.9	95	1.030		
FMF	10011	1.65	0.860	1.773	-26.2	70	-27.5	26	-27.3	5	-26.6	97	1.033		
FMG	10012	1.59	1.104	2.194	-27.3	66	-28.0	29	-27.3	4	-26.2	99	1.019		
FMH	10012.25	1.44	0.915	1.647	-27.2	62	-28.4	33	-27.3	4	-27.3	100	1.011		
FMI	10012.75	1.39	0.969	1.683	-26.9	66	-26.6	30	-26.8	4	-26.7	96	1.042		
FMJ	10013	1.74	1.197	2.603	-27.4	65	-27.4	31	-27.0	4	-26.6	97	0.993	marine	Oil is not indigenous. Not a source rock
FMK	10013.25	1.80	1.261	2.837	-27.4	65	-28.4	32	-26.9	3	-26.1	93	1.032		
FML	10014	1.68	0.745	1.564	-27.2	66	-27.1	31	-27.2	3	-27.1	95	1.010		
FMM	10015	0.98	0.906	1.110	-27.1	63	-27.4	32	-26.4	4	-27.3	96	1.006		
FMN	10015.75	1.04	1.044	1.358	-27.8	67	-28.1	29	-26.6	3	-27.3	96	1.011		
FMO	10016	1.20	0.970	1.456	-28.2	64	-28.5	29	-27.1	7	-26.4	95	1.002		
FMP	10017	1.36	1.033	1.757	-27.6	66	-27.3	30	-26.8	3	-26.4	93	1.044		

(1) Of the core, dry weight basis.
(2) The total content of organic matter is derived from the total organic carbon content by applying a factor of 1.25.
(3) Of the total soluble fraction recovered from the silica gel adsorbent.
(4) A few per cent usually are lost in handling. Low recoveries indicate the presence of highly polar substances unlike petroleum.

TABLE V
CHARACTERIZATION OF CRUDE OIL SAMPLES
FROM WELLS 2/4-1X AND -1AX
NORWEGIAN SECTOR, NORTH SEA

Well	2/4-1X	2/4-1AX	Oil Extracted From Core No. 2
Depth Interval	T. D.	10363-10464'	10010-10017'
Geochem Branch Code	FLK	FQW	FRP
Gravity API	21.1	36.4	31.5
Specific Gravity at 60° F	0.927	0.843	0.87
Kinomatic Viscosity Centistokes at 100° F	663	4.6	185.6
Alkanes (paraffins plus naphthenes) Per Cent, Wt/Wt (1)	38 (2)	69	75
Carbon isotopic composition, SC^{13}_{PDB}	-27.5	-27.8	-27.6
Aromatics Per Cent, Wt/Wt (1)	50	28	22
Carbon isotopic composition, SC^{13}_{PDB}	-26.4	-26.0	-27.1
Asphaltics Per Cent, Wt/Wt (1)	12	3	3
Carbon isotopic composition, SC^{13}_{PDB}	-26.0	-26.9	-26.6
Nitrogen, Total Per cent, Wt/Wt	0.31	0.12	0.16
Sulfur, Total Per cent, Wt/Wt	0.72	0.17	0.24
Nickel-In Solution ppm	13.5	0.6	2.3
Vanadrum-In Solution ppm	3.1	1.4	1.2

(1) Based on oil equilibrated to atmospheric pressure, i.e. approximately stock tank oil.
(2) Contains very little n-paraffins in the C_{13} and higher molecular weight range.

TABLE VI

COMPOSITION BY COMPONENT OF THE C_1 THROUGH C_3 FRACTION OF THE FLUID FROM THE 10363 - 10464' INTERVAL IN WELL 2/4-1AX, NORWEGIAN SECTOR, NORTH SEA

	Gas (FQV)(1)			Liquid (FQW)(1)		Formation Fluid	
Component	Mol or Vol %	Wt. %	Carbon Isotopic δC^{13}_{PDB}	Mol %	Wt %	Mol %	Wt %
helium							
carbon Dioxide	1.7	3.56	-1.68	0.35	0.09	1.56	1.90
nitrogen	0.23	0.31		-	-	0.21	0.16
hydrogen Sulfide	Trace	Trace		-	-	Trace	Trace
methane	80.55	61.53	-41.5	7.96	0.78	72.89	32.34
ethane	9.84	14.09	-29.2	4.90	0.90	9.31	7.75
propane	4.19	8.80	-28.6	5.95	1.59	4.38	5.34
i-butane	0.55	1.52		1.49	0.53	0.65	1.04
n-butane	1.31	3.63		4.75	1.68	1.67	2.69
i-pentane	0.31	1.07		2.27	0.99	0.52	1.03
n-pentane	0.38	1.31		3.42	1.50	0.70	1.40
hexanes	0.33	1.35		7.52	3.93	1.09	2.59
heptanes-plus	0.61	2.85		61.39	88.02	6.48	42.28
Total	100.	100.	-38.0	100.	100.	100.	100.

(1) Geochemistry Branch Code letters - These samples were collected in a Geochemistry Branch companion sample kit, Type A, at separator temperature and pressure according to Method 67-1B.

Er-239-69

TABLE VII

COMPARATIVE VALUES OF THE RATIOS OF METHANE TO HIGHER HOMOLOGS FOR FLUIDS FROM THE ECHOFISH AND COD STRUCTURES NORWEGIAN SECTOR, NORTH SEA

Mol Basis

Ratio	Well Designation			
	2/4 - 1AX (10363-10464')	7/11-1X (1) (9440-10197')	7/11-2X (1) (9932-10190')	7/11-3X (1) (10125-10145')
methane/ethane	8.2	12.4	11.0	2.0
methane/propane	19.2	30.6	26.1	2.3
methane/i-butane	146.4	144.1	138.3	12.2
methane/n-butane	61.6	83.5	74.4	7.2

(1) See letter Er-83-69, Cod Structure - North Sea, May 19, 1969.

Er-239-67

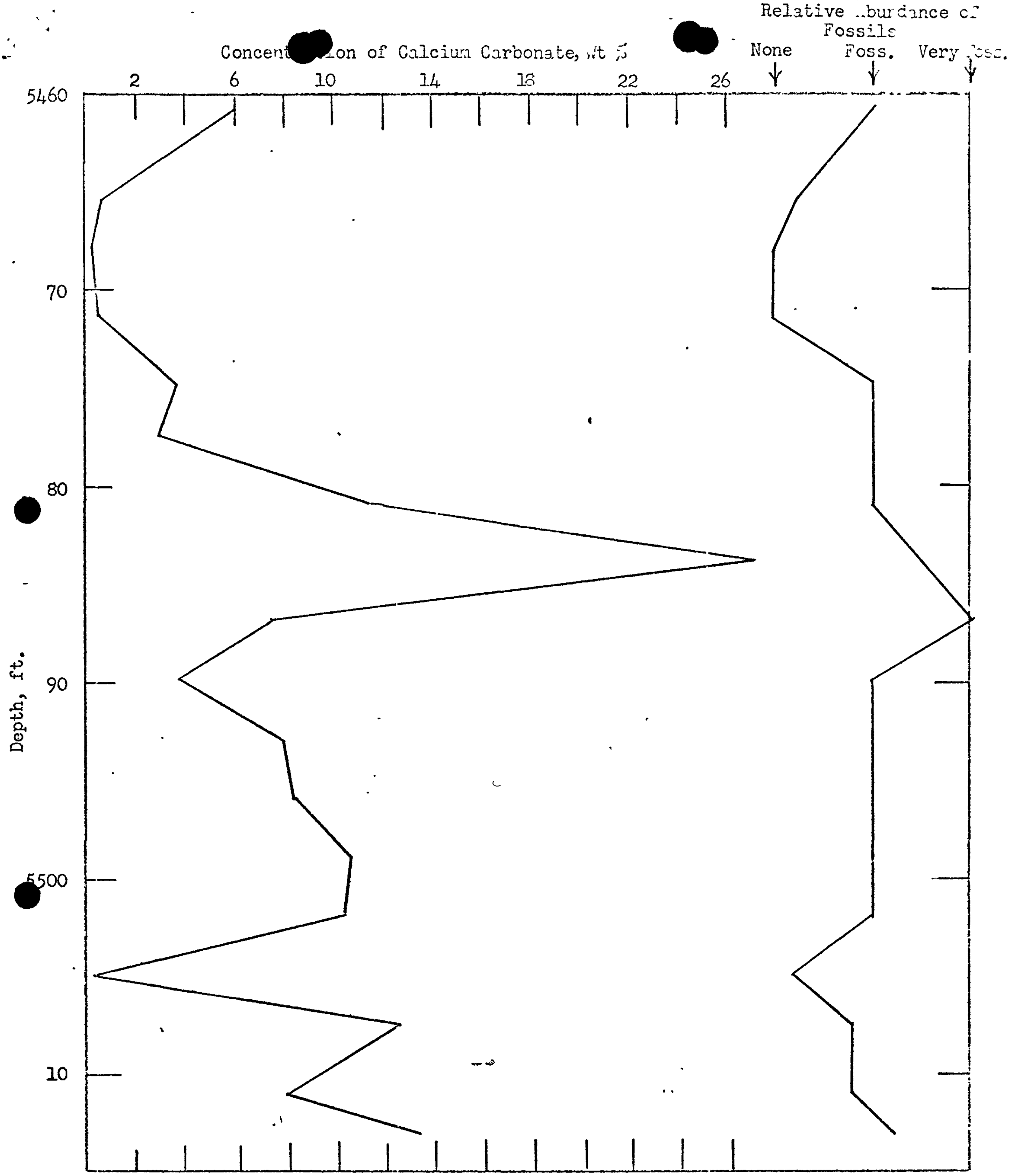

Figure 1 Concentration of Calcium Carbonate, Calculated From Measured Values For Carbonate Carbon, and Fossils, Qualitatively Determined by Inspection, Plotted Against Depth in Core 1 From Well 2/4-1AX, Norwegian Sector, North Sea.

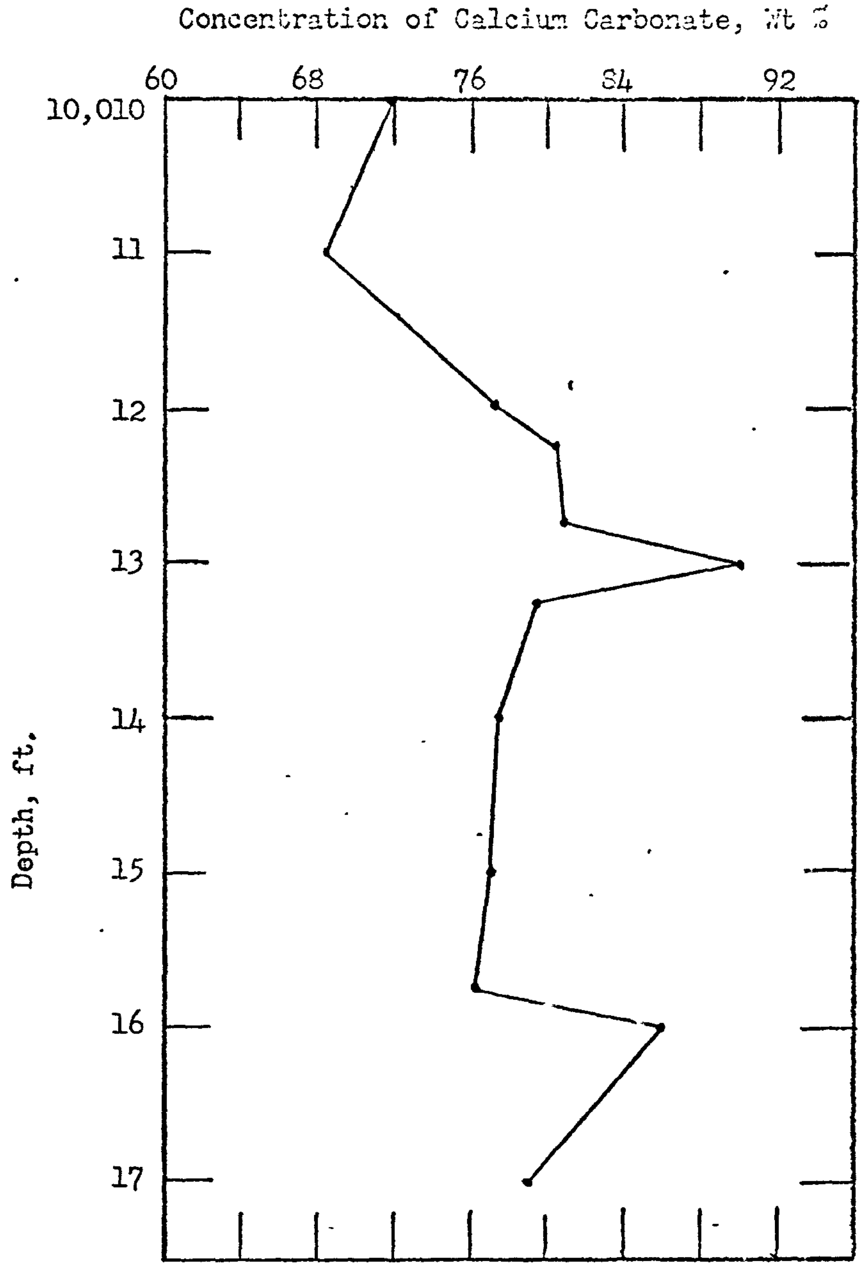

Figure 2 Concentration of Calcium Carbonate Calculated From Measured Values For Carbonate Carbon Plotted Against Depth in Core 2, From Well 2/4-1AX, Norwegian Sector, North Sea.

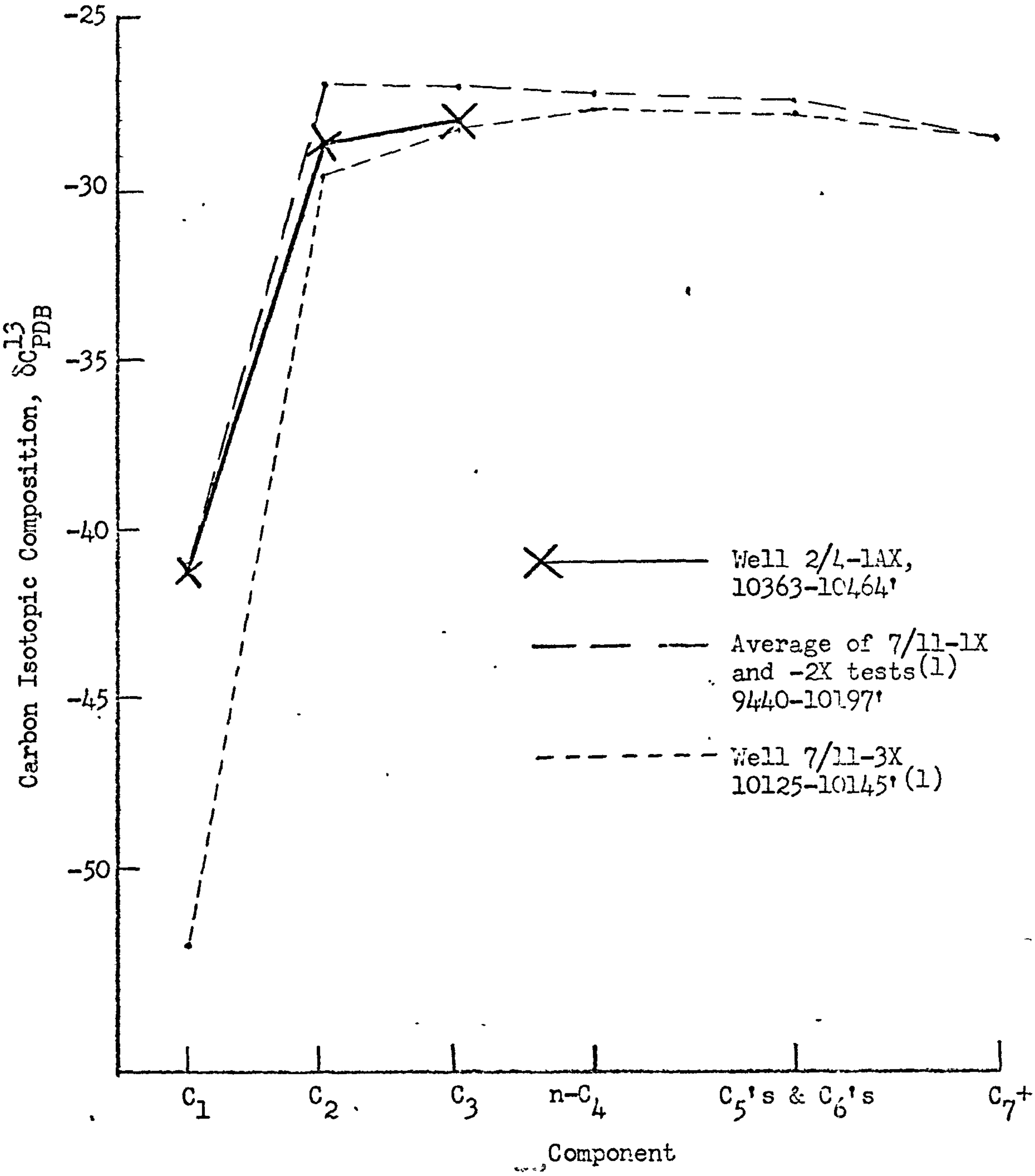

Figure 3. Comparison of Carbon Isotopic Values of the Low Molecular Weight Components of the Fluids From the Echofish and Cod Structures.

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(1) See letter Er-83-69, Cod Structure-North Sea, May 19, 1969.

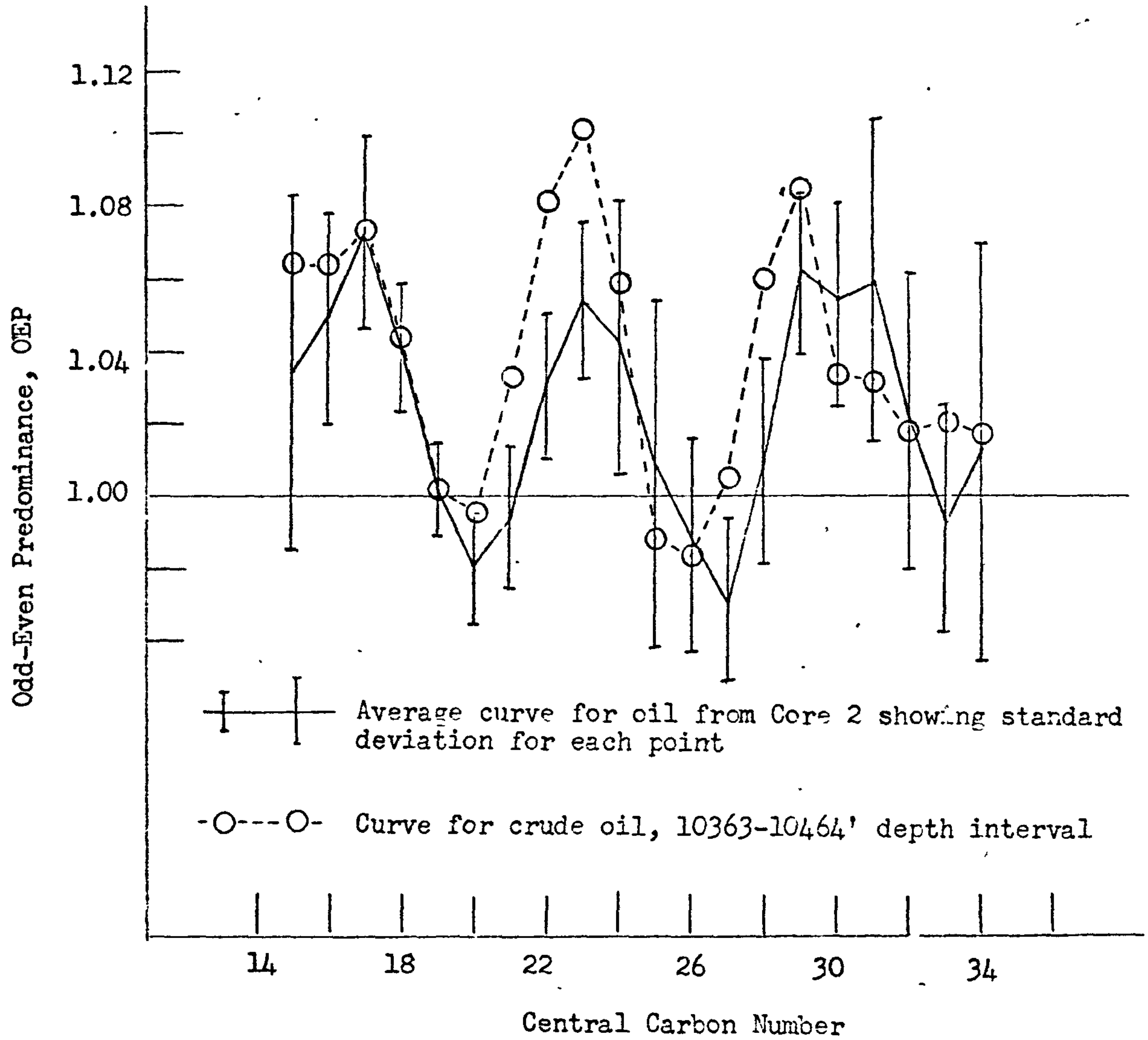

Figure 4. Relation of Odd-Even Predominance to Carbon Number, i. e., to Molecular Weight, of the n-Alkanes In Core 2 and In the Oil From the 10363-10464' Interval in Well 2/4-1AX, Norwegian Sector, North Sea