REGIONAL HYDROCARBON POTENTIAL OF THE LABRADOR SHELF

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ABSTRACT

The hydrocarbon potential of the Labrador Shelf has been evaluated using source rock analyses and maturation indices from 14 wells drilled between 1978 and 1983. This data supplements previous studies on 9 earlier wells.

Using corrected subsurface temperatures, an average geothermal gradient of 2.93°C/100m was calculated. The distribution of gradients does not display any clear relationship to sediment thickness or basement structure. Wells drilled on the flank of basement highs may have enhanced geothermal gradients. This reflects the proximity of these wells to faults penetrating to basement.

The Cenozoic-Mesozoic sediments contain above average concentrations of organic carbon, however, it is predominantly terrestrially derived and thus gas prone. The concentration of heavy hydrocarbons in the sediments are generally below required threshold values for significant oil generation. A few oil prone zones were encountered, but are thin and discontinuous. These suggest there is considerable variation in the source potential of the organic matter on the Labrador Shelf.

Tertiary sediments have reached full maturity in only one well. Full maturity is attained at a depth of approximately 3000-3300m. Wells penetrating thick Tertiary sections (>4km) are only marginally mature despite high subsurface temperatures (110-120°C). This reflects the effect of time on maturation. Consideration of recent hydrocarbon generation models indicate the reservoired gas condensate on the Labrador Shelf is derived from predominantly Cretaceous sediments dominated by terrestrial organic matter in the marginally mature to mature zone.

Introduction

The Labrador Shelf consists of a thick Mesozoic-Cenozoic clastic wedge overlying block faulted Precambrian basement or local Paleozoic outliers. Maximum sediment thickness exceeds 10km (Umpleby, 1979). Early Cretaceous to Paleocene rocks are restricted to inshore ēn ēchelon fault controlled basins trending approximately parallel to the present Labrador coast. By Eocene time, open marine conditions were established resulting in simple outbuilding and upbuilding of a fine grained clastic wedge over earlier marginal marine and rift basin sediments. Active seafloor spreading was initiated in the southern Labrador sea approximately 70 Ma and terminated just prior to 40 Ma (Gradstein, 1982).

Lower Cretaceous sediments consist of continental to paralic coarse-grained siliciclastics with minor shale and coal. The first marine influences are recorded in Albian time (Umpleby, 1979). Marginal marine light grey shale and minor local sandstone characterize Upper Cretaceous to Paleocene rocks. Eocene and younger sediments are typically turbiditic mudstones with thin, but widespread sandy facies. The detailed geological aspects of the Labrador Shelf are discussed by McMillan (1973), Umpleby (1979), McMillan (1979) and McWhae et al. (1980) (Figure 1).

Hydrocarbon discoveries and exploration prospects have been generally confined to structural and/or stratigraphic traps associated with horsts and grabens created during initial rifting. Exploration activity has resulted in six significant discoveries of gas with minor condensate and local traces of paraffinic oil. With two exceptions, the reservoirs occur within Early Cretaceous coarse clastics draping over or abutting against basement highs.

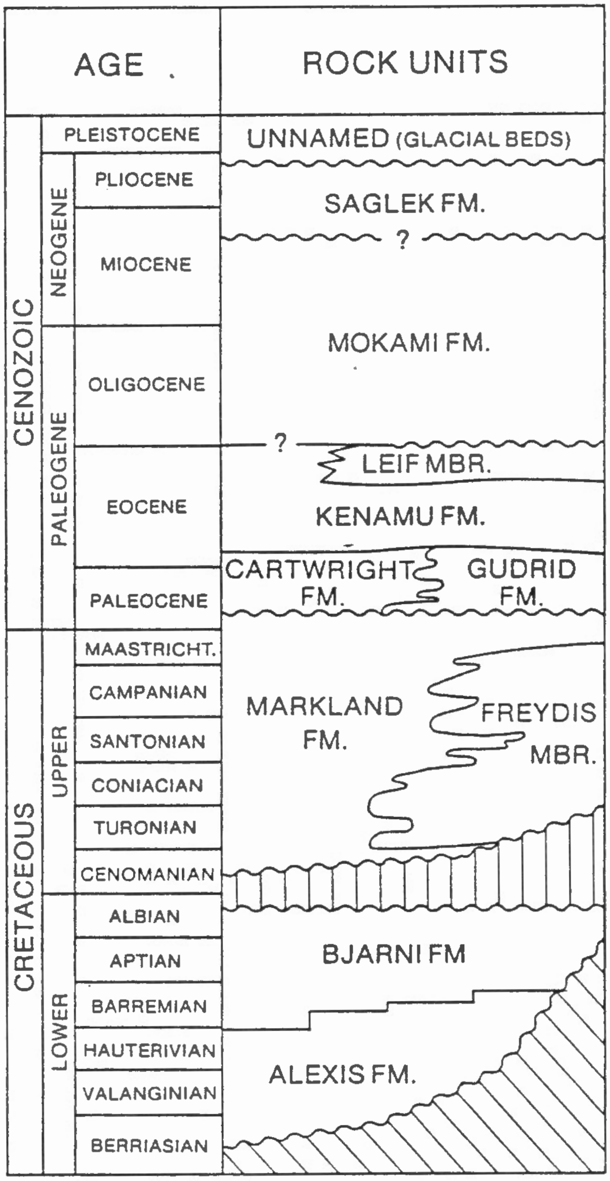


FIGURE 1: Generalized

Stratigraphic Column

Labrador Shelf

In Gudrid H-55, gas and condensate is reservoired in a Paleozoic carbonate outlier perched on a basement high. The hydrocarbons encountered in Snorri J-90 occupy a Paleocene clastic reservoir.

The geochemical characteristics of sediments and their hydrocarbon source potential on the Labrador Shelf have been investigated by Cassou _et al_. (1977), Bujak _et al_. (1977), Powell (1979), and Rashid _et al_. (1980). These studies have been primarily based on nine wells (Table 1). The purpose of this study is to compile and interpret the qualitative and quantitative aspects of potential source rocks for recently drilled wells. The geochemical parameters for 6 recently completed wells are provided. Maturation data only is illustrated for an additional 8 wells (Figure 2).

The geochemical data used in this study are from operator requested source facies analyses completed by private geochemical service companies on file with Canadian Oil and Gas Lands Administration, Dartmouth, Nova Scotia. Total organic carbon and cuttings gas analysis for 3 wells were provided by the Eastern Petroleum Geology Subdivision of the Geological Survey of Canada (Roberval K-92, Skolp E-07, Tyrk P-100).

Previous Geochemical Studies

Consideration of various geochemical and maturation parameters suggest favourable conditions exist for the generation of hydrocarbons on the Labrador Shelf. Mesozoic-Cenozoic rocks are relatively rich in organic carbon, averaging approximately 3% (Rashid _et al_., 1980; McMillan, 1979). Eocene and younger sediments are oil prone, whereas Paleocene and older sediments contain dominantly terrestrially derived organic matter (Umpleby, 1979). Local Paleozoic outliers possess little amorphogen and are lean (Bujak _et_

Table 1. Exploratory wells used for this study.

Rashid *et al.* (1980)	THIS STUDY	
	Maturation and Geochemistry	Maturation Only
Indian Harbour M-52	Skolp E-07	S. Labrador N-79
Freydis B-87	North Leif I-05	S. Hopedale L-39
Leif M-48	Rut H-11	Hopedale E-33
Cartier D-70	Tyrk P-100	Ogmund E-73
Gudrid H-55	Roberval K-92	Gilbert F-53
Bjarni H-81	Pothurst P-19	Roberval C-02
Herjolf M-92		Bjarni 0-82
Snorri J-90		N. Bjarni F-06
Karlsefni A-13		

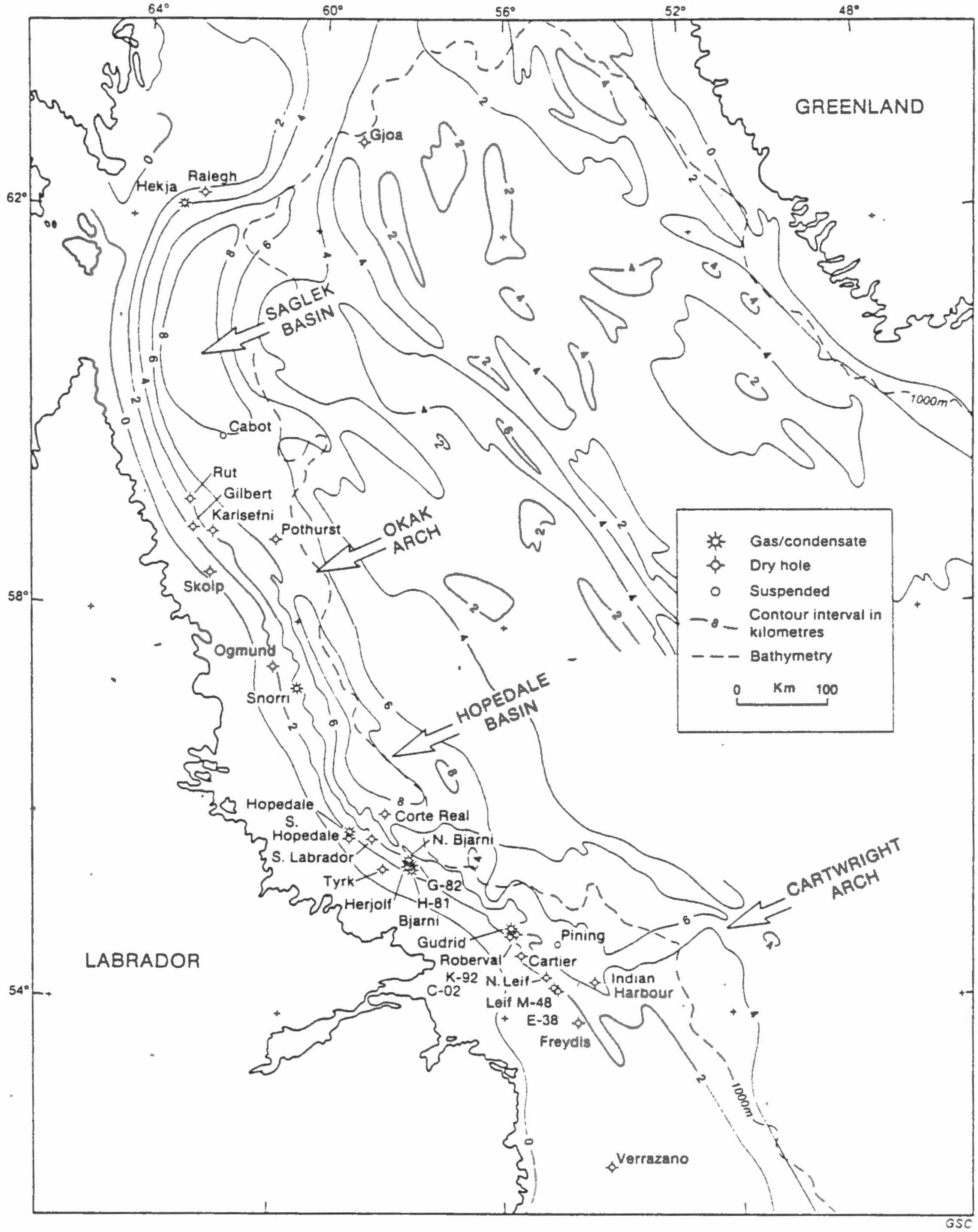


FIGURE 2: Basement structure - Labrador Shelf (contours in km) showing locations of main basins and exploratory wells (after Jackson, in press).

al., 1977).

The source rock potential for gas on the Labrador Shelf is fair to good. In the vicinity of Snorri J-90 and Karlsefni A-13, excellent gas source potential is indicated. The quantities of extractable organic matter and concentrations of heavy hydrocarbons indicate a poor source potential for oil throughout the section (Rashid et al., 1980).

Generally, post Paleozoic source rocks have proven to be immature to marginally mature (McWhae et al., 1980). Wells encountering thick post Paleozoic sediments have attained full maturity at depths of 3000-3500m (Rashid et al., 1980). The onset of maturation indicated by wet gas analysis is 500-1000m shallower than the top of the fully mature zone. The narrowing of the marginally mature zone on the Labrador Shelf relative to the Scotian Shelf has been attributed to the higher geothermal gradients encountered on the Labrador margin (Rashid et al., 1980).

Insufficient maturation and the predominance of terrestrial organic matter within the fully mature zone preclude significant generation of liquid hydrocarbons. McWhae et al. (1980) suggest Upper Cretaceous and Paleocene marine shales may generate condensate and oil if covered by 3-4km of sediment.

There is a lack of consensus on the presumed source rocks and levels of maturation required to generate the hydrocarbons encountered in known reservoirs on the Labrador Shelf. Powell (1979) and Snowdon and Powell (1979) report condensates discovered in thermally immature to marginally mature reservoirs have undergone extensive vertical migration and can be classed as conventional mature to overmature condensates. Geochemical analysis of the condensates indicate those from Gudrid H-55, Snorri J-90 and Hopedale E-33 have a common or related source which is dominantly terrestrially derived. The dissimilarity of certain geochemical criteria has been attributed to variations in maturation and possibly migration. McWhae et al. (1980) believe the gas condensate is derived from marginally mature source rocks dominated by terrestrial organic matter. The variation in hydrocarbon composition from various wells is explained by variation in the character of source beds rather than different levels of maturation. Thus it is not necessary to invoke long distance vertical migration since potential source beds lie adjacent to reservoir rocks.

Geothermal Gradients

A theoretical method for correcting downhole temperatures from well logs as discussed by Dowdle and Cobb (1975) and Fertl and Wichmann (1977) has been used to derive equilibrium subsurface temperatures and geothermal gradients. Using 24 wells, an average geothermal gradient of 2.93°C/100m was calculated (Table 2). Gradients ranged from 2.18 to 3.6°C/100m. Rashid et al. (1980) recorded an average nonequilibrium gradient of 2.7°C/100m based on 9 wells. Umpleby (1979) documented gradients from 2.74 to 3.4°C/100m.

The quality of the temperature data is generally fair. Many of the wells are relatively shallow, resulting in fewer logging runs and consequently, fewer data points. An ambient seafloor temperature of 0°C was assumed in most cases. A linear gradient was assumed for all wells due to the section being dominantly shale and the limited confidence in the temperature data.

Table 2. Equilibrium Geothermal Gradients on the Labrador shelf

WELL	GEOTHERMAL GRADIENT °C/100m	SEDIMENT THICKNESS m	BASEMENT/SEDIMENT STRUCTURE
SAGLEK BASIN			
Karlsefni A-13	2.63	3942	ridge of horst (drape)
Gilbert F-53	3.40	3355	dip closed feature against basement high
Ogmund E-73	2.35	2925 [2]	updip end of tilted graben
Pothurst P-19	2.98	3787*	rollover anticline
Rut H-11	3.00	4331*	SE-NW mounded sequence
Skolp E-07	3.25	2790	?
HOPEDALE BASIN			
Tyrk P-100	3.60	1573	basement high (drape)
Roberval K-92	2.92	3263	dip closed feature against basement high
Roberval C-02	2.18	2513	basement high (drape)
Hopedale E-33	3.31	1413	basement high (drape)
S. Hopedale L-39	2.64	1772	basement high (drape)
S. Labrador N-79	2.52	3087	?
N. Leif I-05	3.05	3357 [1]	sands onlapping a N plunging anticlinal nose
Leif M-48	3.20	1702 [1]	ridge of horst (drape)
Leif E-38	2.50	270*	ridge of horst (drape)
N. Bjarni F-06	3.60	2650 [2]	dip closed feature against basement high
Bjarni O-82	3.18	2494 [2]	basement high (drape)
Bjarni H-81	3.00	2364	ridge of horst (drape)
Snorri J-90	2.60	2996	ridge of horst (drape)
Herjolf M-92	2.98	3860	dip closed feature against basement high
Gudrid H-55	2.57	2352	ridge of horst (drape)
Cartier D-70	2.45	1658	ridge of horst (drape)
Freydis B-87	3.10	1711	updip end of tilted graben
Indian Hbr. M-52	3.10	3274	graben structure
AVERAGE	2.93		

[1] - total depth in Alexis Formation
[2] - total depth in Bjarni Formation
* - total depth in Tertiary sediments

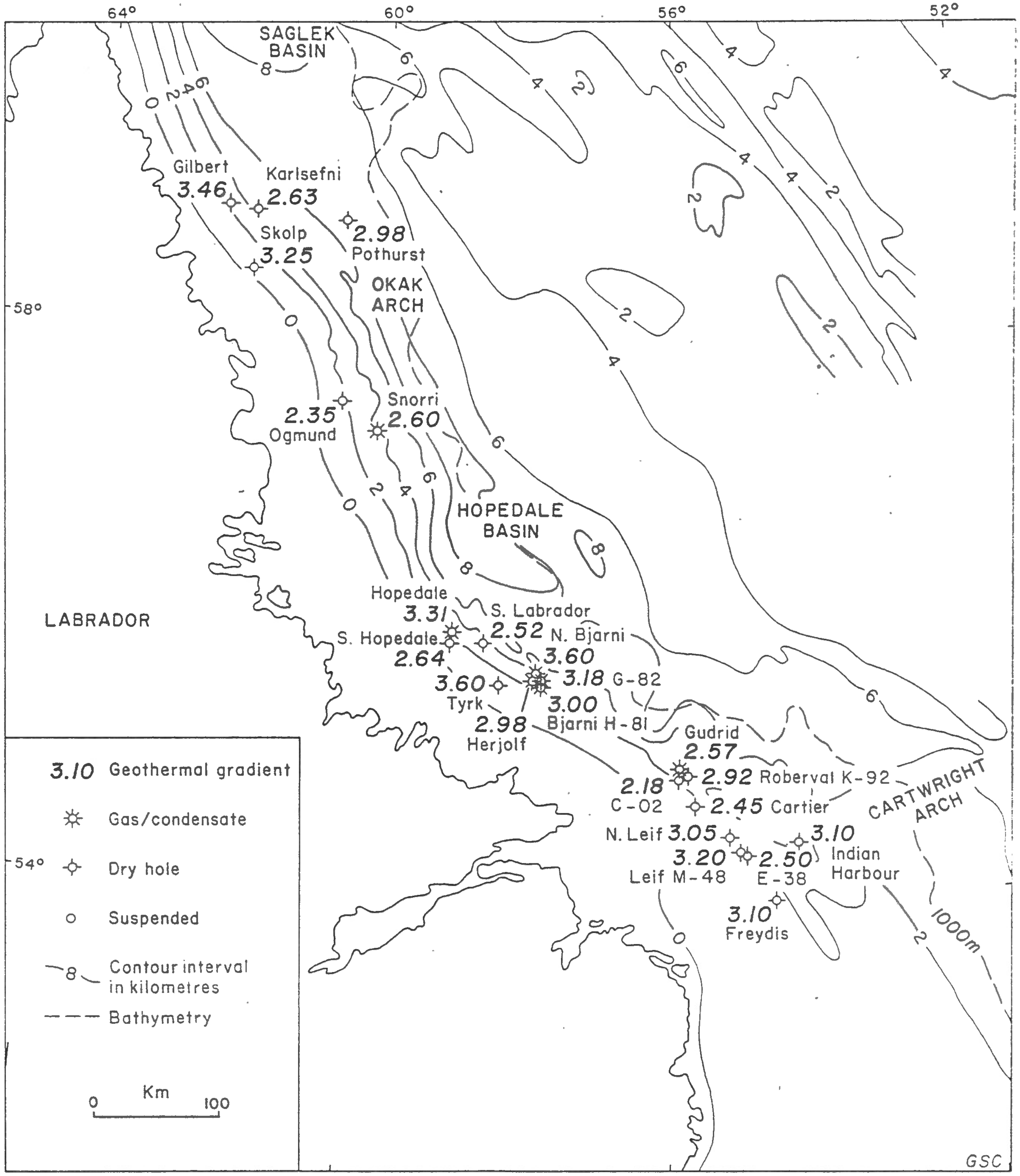


FIGURE 3. GEOTHERMAL GRADIENTS ON THE LABRADOR SHELF (°C/100m)

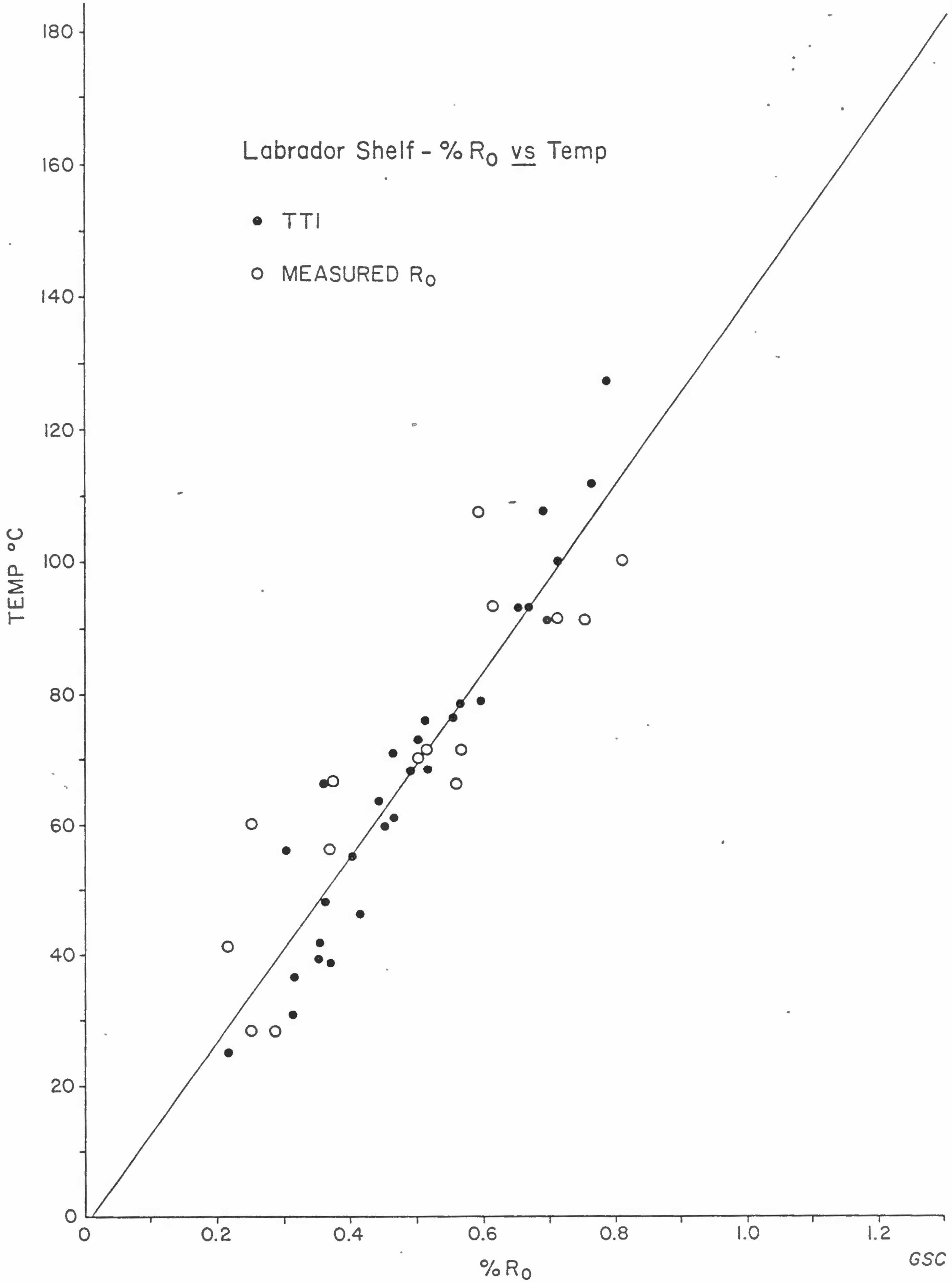


FIG. 3B EQUILIBRIUM SUBSURFACE TEMPERATURE VS VITRINITE REFLECTANCE

There is some evidence to suggest higher geothermal gradients existed during Early Cretaceous to Paleocene time as a result of post rifting cooling (Umpleby, 1979). Eocene and younger units were not subject to this high heat flux. Consequently, present day temperatures are maximum for the upper portion of the section (McMillan, 1979).

The distribution of geothermal gradients on the Labrador Shelf show no simple relationships to sediment thickness or basement structure (Figure 3). Basement heterogeneity and possibly variable sand/shale ratio probably affect measured gradients. There may be a relationship between well locations, relative to basement structure and measured temperature gradients. Wells testing dip closed features abutting against basement highs have above average gradients compared to wells drilled on the crests of adjacent horsts (Gilbert F-53, N. Bjarni F-06, Roberval K-92, Freydis B-87). Presumably, this is due to the proximity of these wells to faults penetrating to basement. McMillan (1979) advocates the best hydrocarbon prospects may occur in sediments above fracture zones which trend at right angles to the Labrador coast. The higher heat flux from these zones may result in enhanced maturation. Interestingly, the shallowest reservoired hydrocarbons generally occur in wells with the highest geothermal gradients.

Source Rock Potential

Source rock characteristics of the most recently drilled wells support the previous conclusions of Rashid *et al*. (1980). Total organic carbon increases with depth, reaching a maximum in the Eocene. Paleocene and older sediments contain less organic carbon. However, there are a few exceptions. The Albian-Cenomanian sediments in Skolp E-07 are enriched in organic carbon

(4 to 20%). This has also been observed in Snorri J-90 (average 5.31%). The Tertiary sediments in Pothurst P-19 are deficient in organic carbon and average less than 1.0%. However, Late Eocene sediments are enriched relative to the remainder of the well. There is a degree of correlation between total organic carbon and total cuttings gas.

Amorphogen constitutes a major proportion of the organic matter in Eocene and younger sediments, but is less abundant with depth in Paleocene and Late Cretaceous rocks. Lower Cretaceous sediments are dominated by terrestrially derived kerogens. Hydrogen/carbon and oxygen/carbon ratios indicate much of the amorphogen is actually degraded phyrogen and thus gas prone (Rashid _et al._, 1980).

The concentration of heavy hydrocarbons as a percent of extract are below required threshold values for generation of oil. North Leif I-05 displays one zone in Early Cretaceous sediments which has potential for liquid hydrocarbon generation. This zone contained a small volume of light waxy oil generated from indigenous terrestrial organic matter. Pothurst P-19 possesses one thin Early Tertiary oil prone interval within the marginally mature zone.

Despite moderately high organic carbon and fair to good gas potential, the potential for liquid hydrocarbons is low due to the preponderance of terrestrial organic matter and the lack of sufficient maturation.

Maturation Indices

Issler (1984) using 118 data points from 16 wells calibrated time-temperature index to vitrinite reflectance. These maturation indices have been determined to be related by the function:

$$\log TTI = 5.2824 \log \%Ro + 1.8075$$

This equation is only applicable to post Paleozoic sediments. Time- temperature index curves were constructed for a number of wells and the maturation gradients determined (Appendix 1).

A number of factors have injected uncertainty into the TTI calculation. The frequency, position and duration of unconformities or breaks in sedimentation are not well known. Consequently, the duration of known unconformities were estimated for most curves. Changes in heat flux over time can lead to incorrect estimates of maturity when present day geothermal gradients are used to approximate ancient temperature regimes, particularly if the relative temperature flux has not been uniform across the margin. The evidence for a higher heat flux in the Cretaceous has been discussed previously. Temperature grids were constructed assuming linear geothermal gradients because of the quality of the temperature data. Finally, compaction effects may have a detrimental effect on TTI since the basin is dominantly shale. The sum effect of these limitations would be to under estimate the true maturity. This is evident in some of the TTI curves.

From the wells in Appendix 1 it is apparent the Tertiary sediments have not reached full maturity in most wells. Early Tertiary sediments in N. Leif I-05, S. Labrador N-79, Gilbert F-53, Bjarni O-82, N. Bjarni F-06 and Roberval K-92 have reached marginal maturity. South Hopedale L-39, Hopedale E-33, Roberval C-02 and Tyrk P-100 are immature to basement. Full maturity occurs at approximately 3000 to 3300m for wells penetrating to these depths. There are two important exceptions, Rut H-11 and Pothurst P-19. Both wells penetrated nearly 4km of Tertiary sediments and display relatively low levels of thermal maturation (0.6-0.7%Ro) despite subsurface temperatures of 110-120°C. However, lower Paleocene sediments wihtin Rut H-11 have reached full maturity. Presumably, the low maturation values are due to insufficient residence time at high ambient temperatures. This has important implications in terms of source rock evaluation.

Rashid et al. (1980) have reported that the top of the marginally mature zone, as indicated by wet gas analysis, is coincident with the 60°C isotherm. Data presented in Table 3 promote an alternative hypothesis. Temperature at the wet gas threshold is variable and affected by the age of the sediments and to some degree by the quality of the organic matter. Vitrinite reflectance appears to be a superior indice. The top of the marginally mature zone averages 0.46%Ro. This threshold is considered to be independent of organic matter type (Monnier et al., 1983).

The depth to the marginally mature zone tends to mirror basement structure. At equivalent depths, sediments overlying basement highs are older than adjacent sediments occupying flanking grabens. Consequently, the top of the marginally mature zone in wells drilled over graben structures are deeper than average. Thick Cretaceous sections behave like basement highs and the top of the wet gas zone will be shallower (Figure 4).

The nature of generated hydrocarbons and their composition is dependent upon the type of organic matter and the degree of maturation. The proportion of various components that comprise the kerogen strongly influences the level of maturation necessary to source hydrocarbons. The variation in maturation threshold is attributed to differences in the activation energy associated with the dominant chemical structure type in the organic matter.

Table 3. Maturation and Temperature at 50% Wet Gas Threshold

WELL	DEPTH @ 50% WET GAS (m) THRESHOLD	EQUILIBRIUM TEMPERATURE °C	VITRINITE REFLECTANCE
Skolp E-07	1800	62	0.45
Roberval K-92	2875	73	0.50
N. Leif I-05	1700	59	0.51
Rut H-11	2250	61	0.39
Tyrk P-100	rarely 18%		
Pothurst P-19	3610	102	0.48
Karlsefni A-13	2425	59	0.44
Snorri J-90	2350	61	0.46
Cartier D-70	1850	37	
Herjolf M-92	2600	73	0.55
Indian Hbr. M-52	2650	76	
Leif M-48	1475	41	
Freydis B-87	rarely 50%		
Bjarni H-81	2050	56	0.44
Gudrid H-55	2325	55	0.37
AVERAGE	2300	62.5	0.46

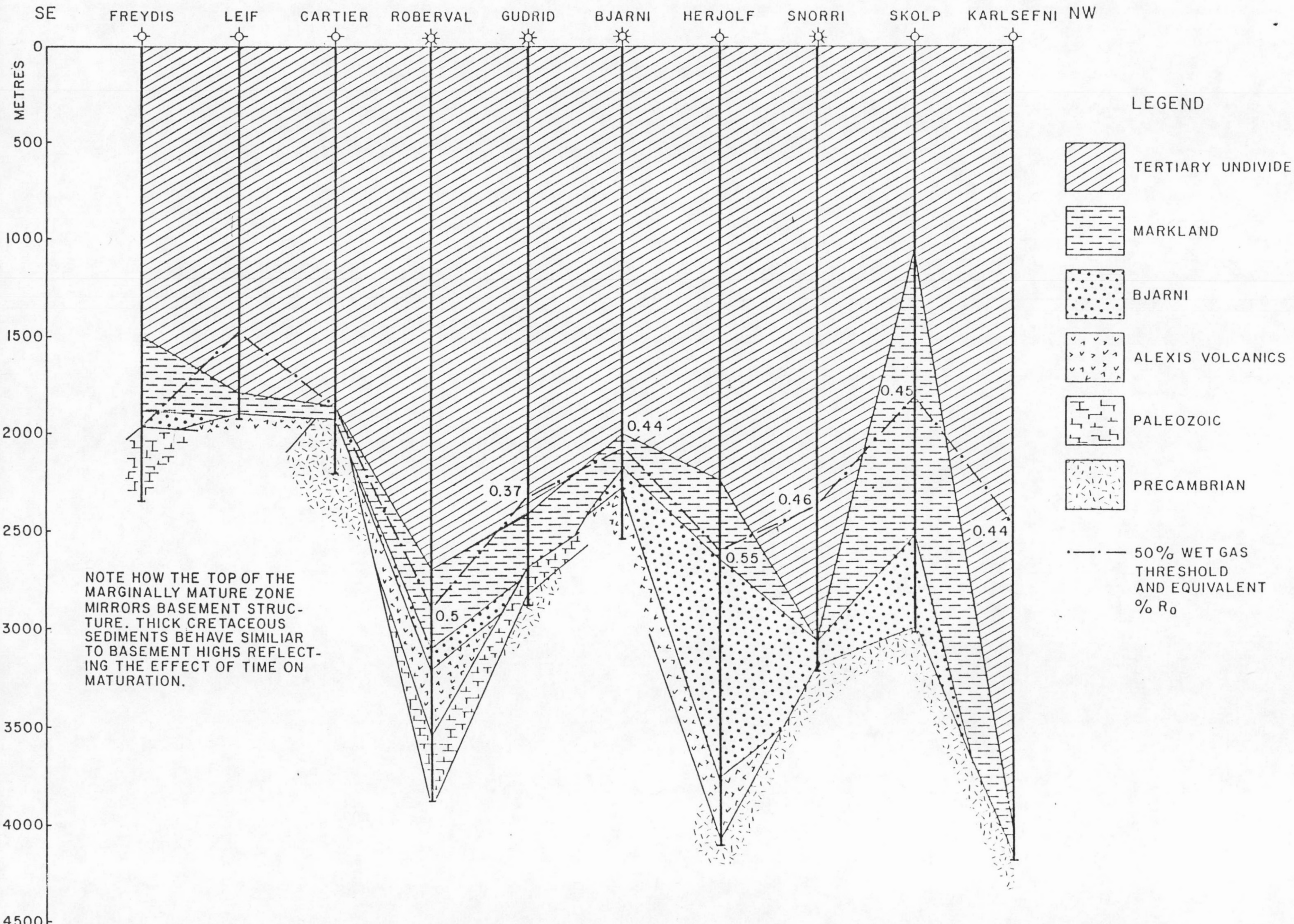


FIG. 4 ONSET OF MATURATION ON THE LABRADOR SHELF

Recently, data collected from Canadian frontier basins indicate modification to hydrocarbon generation models are required, particularly regarding terrestrial organic matter. These recent models have important implications for evaluating the source potential of the Labrador Shelf.

Monnier et al. (1983) have semi-quantitatively evaluated gas generation potential from different organic matter types utilizing data from cuttings gas analysis. This data suggests significant gas generation can occur from Type III kerogen at levels of maturation as low as 0.6%Ro. Type III organic matter begins to generate significant quantities of gas at 0.55%Ro and reaches a maximum at 0.7%Ro where liquid hydrocarbon generation begins. Type II kerogen generates only 1/3 of the gas generated from Type III organic matter at low levels of maturation. The maximum gas potential for Type II kerogen is reached in the overmature zone. Type II organic matter commences significant oil generation at 0.5%Ro, whereas for Type I kerogen the threshold value is 0.7%Ro (Powell and Snowdon, 1983). Figure 5 illustrates a revised hydrocarbon generation model for Type II and Type III organic matter. The variable source quality of oganic matter is readily understood, since it consists of a mixture of hydrogen rich and hydrogen deficient components.

Powell (1979) and Snowdon and Powell (1982) have reported the hydrocarbons discovered on the Labrador Shelf are conventional mature to overmature gas condensate. In order to satisfy this hypothesis, long distance vertical migration must be invoked, since the reservoirs occupy the marginally mature or immature zone. However, recent data suggests reservoired hydrocarbons were sourced from adjacent sediments within the marginally mature to mature

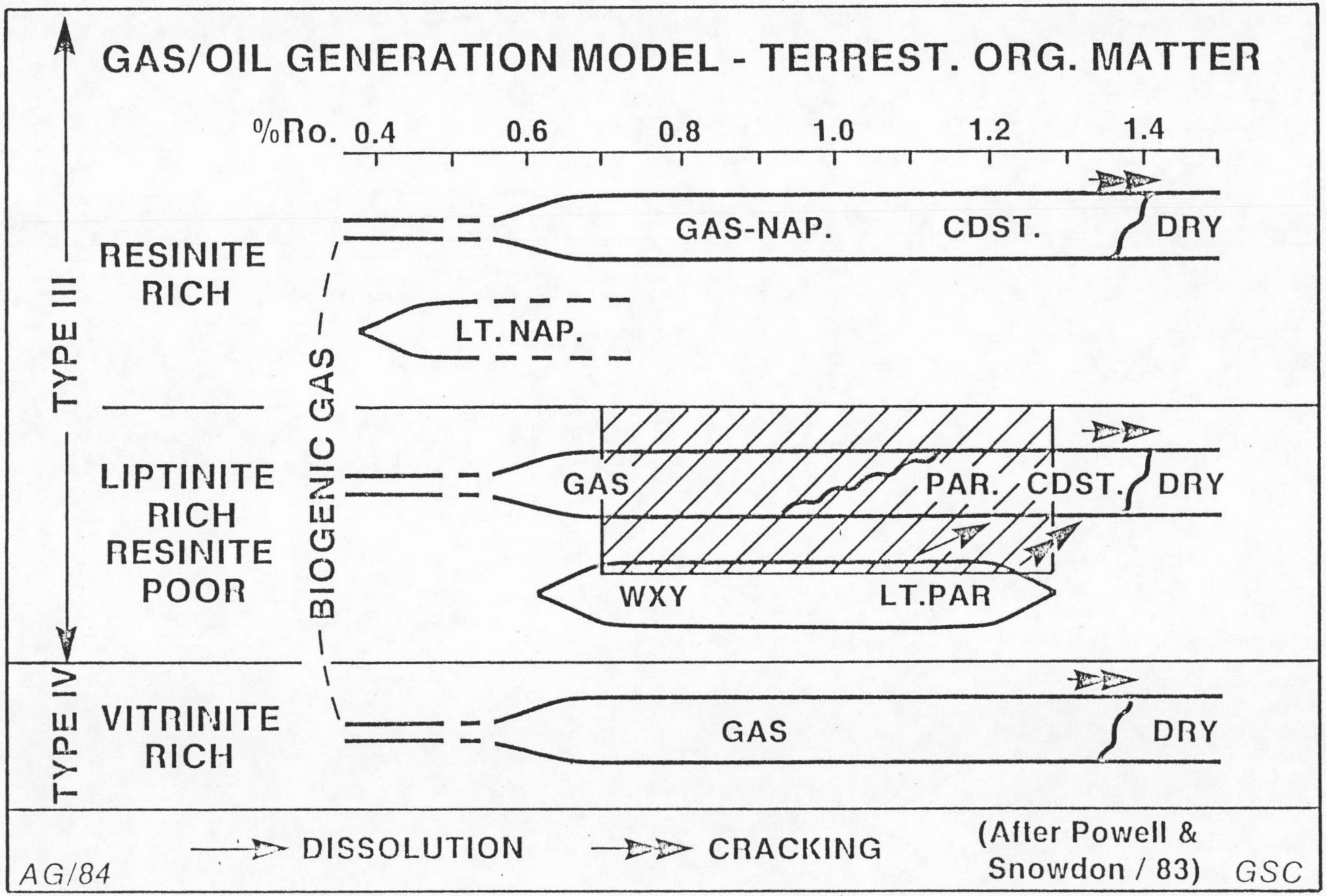


FIGURE 5: Hydrocarbon Generation Model. Shaded area depicts Labrador Shelf. (after Powell and Snowdon, 1983)

zone.

Paraffin indices and gas condensate ratios have been employed by Powell (1979) and Snowdon and Powell (1982) to ascertain if hydrocarbon generation has occurred over a range of maturation from mature to overmature. Paraffin index I for Labrador Shelf condensates are similar to condensates reservoired in Cretaceous sediments on the Scotian Shelf (Figure 6). Scotian Shelf hydrocarbons are interpreted as being generated in the principal zone of hydrocarbon generation. The variation in paraffin index II has been attributed to maturation effects (Snowdon and Powell, 1982). However, it is possible to ascribe this variation to differences in source materials. The paraffin indices of Thompson (1979) vary according to thermal maturation, biodegradation and organic matter type. Visual kerogen studies and H/C and O/C ratios indicate the organic matter from the Labrador Shelf is different than the kerogen from the Scotian Shelf. The organic matter from the Labrador Shelf contains a larger proportion of amorphous matter and hydrogen enriched components. There is likely considerable variation in the organic matter and source potential of these sediments.

Snowdon and Powell (1982) also utilized gas condensate ratios as indicators of maturity on the Labrador Shelf. They report that condensates with the lowest paraffin indices have the lowest gas condensate ratios and vice versa. However, gas condensate ratio data from Bjarni O-82 imply variations in source rock affect the relative volume of gas condensate generated (Table 4). In Bjarni O-82 three reservoirs between 2280 and 2350m have gas condensate ratios from 4500 to 17,000. The lowest ratio occurs in the shallowest reservoir which is opposite to what one would expect if the reservoirs were

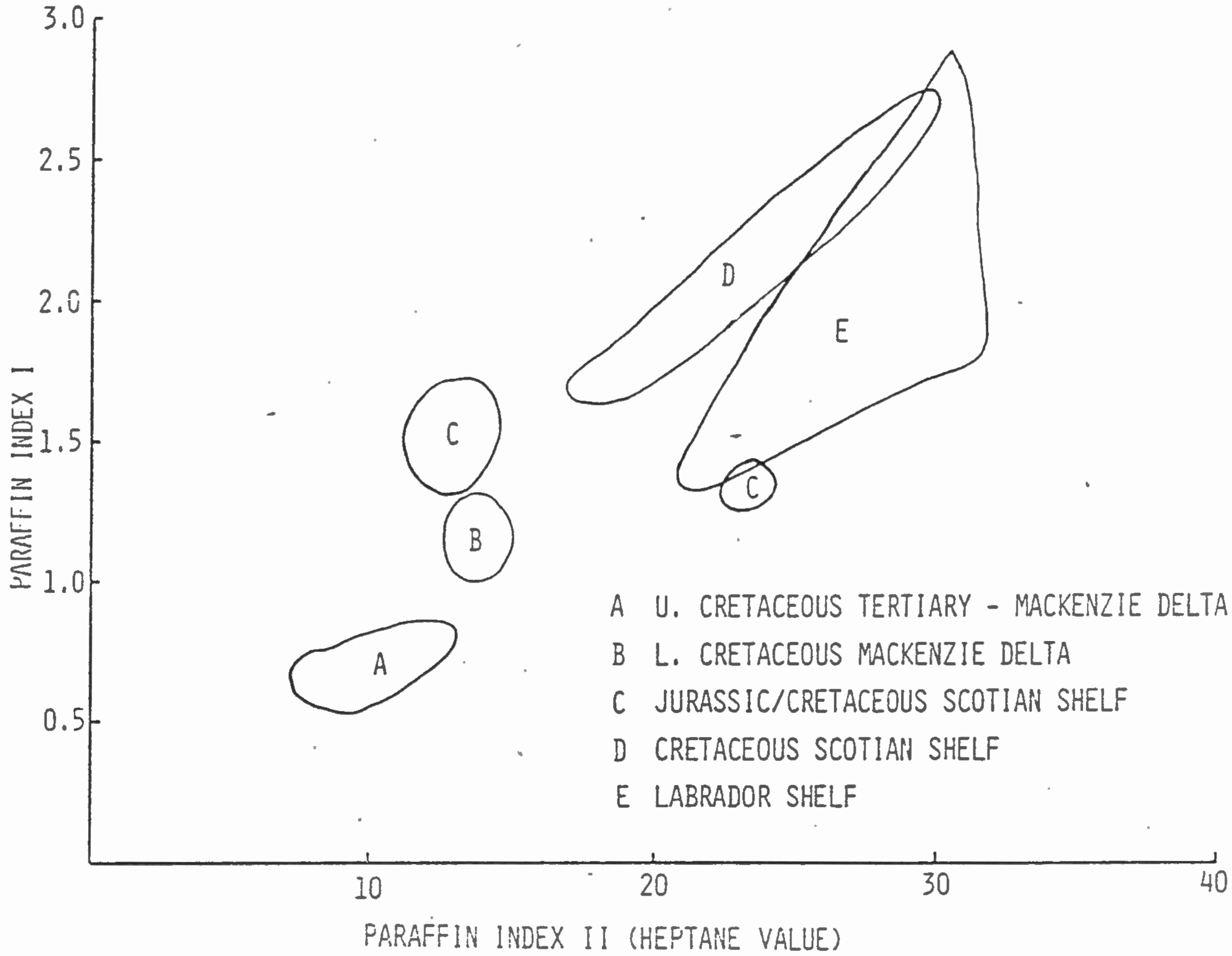


FIGURE 6: Paraffin Index I versus Paraffin Index II for oils and condensates derived from terrestrial organic matter in several Canadian frontier basins, from Snowden and Powell (1982).

Table 4. Hydrocarbon Occurrences of the Labrador shelf

WELL	HYDROCARBON & DEPTH	%Ro TTI	%Ro TRUE	TEMP. °C	FORMATION	GOR	GRADIENT °C/100m
Roberval K-92	gas/cond						
	3089m	0.56	0.53	82.0	Bjarni	?	2.92
Gudrid H-55	gas/cond						
	2744m		0.75	62.5	Paleozoic	31512	2.57
	2651m	0.45 @ 2450m		60.0	carbonate	31291	
Bjarni H-81	gas/cond						
	2138m		0.44	59.6	Bjarni	22996	3.00
Bjarni 0-82	gas/cond						
	2350m	0.49		69.8	Bjarni	16895	3.18
	2325m	0.49		69.0	Bjarni	10426	
	2279m	0.48		67.5	Bjarni	4478	
N. Bjarni F-06	gas/cond						
	2300m	0.60		82.0	Bjarni	?	3.60
Hopedale E-33	gas/cond						
	1970m	0.58	0.41	46.6	Bjarni	6961	3.31
	1935m	0.58	0.41	45.3	Bjarni	8150	
Snorri J-90	gas/cond						
	2484m		0.46	60.6	Cartwright	7420	2.60
N. Leif I-05	trace oil						
	3096m	0.71	0.80	90.0	Bjarni		3.05
Herjolf M-92	gas show						
	trace oil						
	2587m		0.55	72.2	Bjarni		2.98

in hydrodynamic equilibrium. Because of the proximity of the three reservoirs, differences in temperature, pressure and maturation cannot be cited as contributing to the observed variation in gas condensate ratio unless migration is a factor. Logically, the difference in ratios is due to variations in source rock.

The condensates from Gudrid H-55 and Snorri J-90 are extremely rich in saturated hydrocarbons (Powell, 1979). The saturates comprise dominantly n-alkanes in the range C11 to C20. High pristane/phytane values indicate the condensates are derived from terrestrial organic matter. Liquid hydrocarbons derived from terrestrial organic matter normally contain a high proportion of waxes (n-alkanes above nC22). They are conspicuously absent in Gudrid H-55 and Snorri J-90 (Figure 7). Powell (1979) has attributed this to either thermal cracking of previously generated hydrocarbons or migration effects. Alternatively, the absence of waxy n-alkanes can be ascribed to early maturation of mixed organic matter which is probably dominantly terrestrial with a dispersed marine component. The condensate is being derived from the more thermally labile components of the organic matter.

Clearly, the condensates on the Labrador Shelf are formed as a result of thermal degradation of terrestrial organic matter at moderate levels of maturation. Data from Table 4 indicates threshold values of 0.5-0.7%Ro. Variations in threshold temperature, maturation and gas condensate ratio are due to differences in source materials in Cretaceous sediments. Hydrocarbons generated from Early Cretaceous sediments likely have higher gas/condensate ratios because of the absence of hydrogen enriched components in

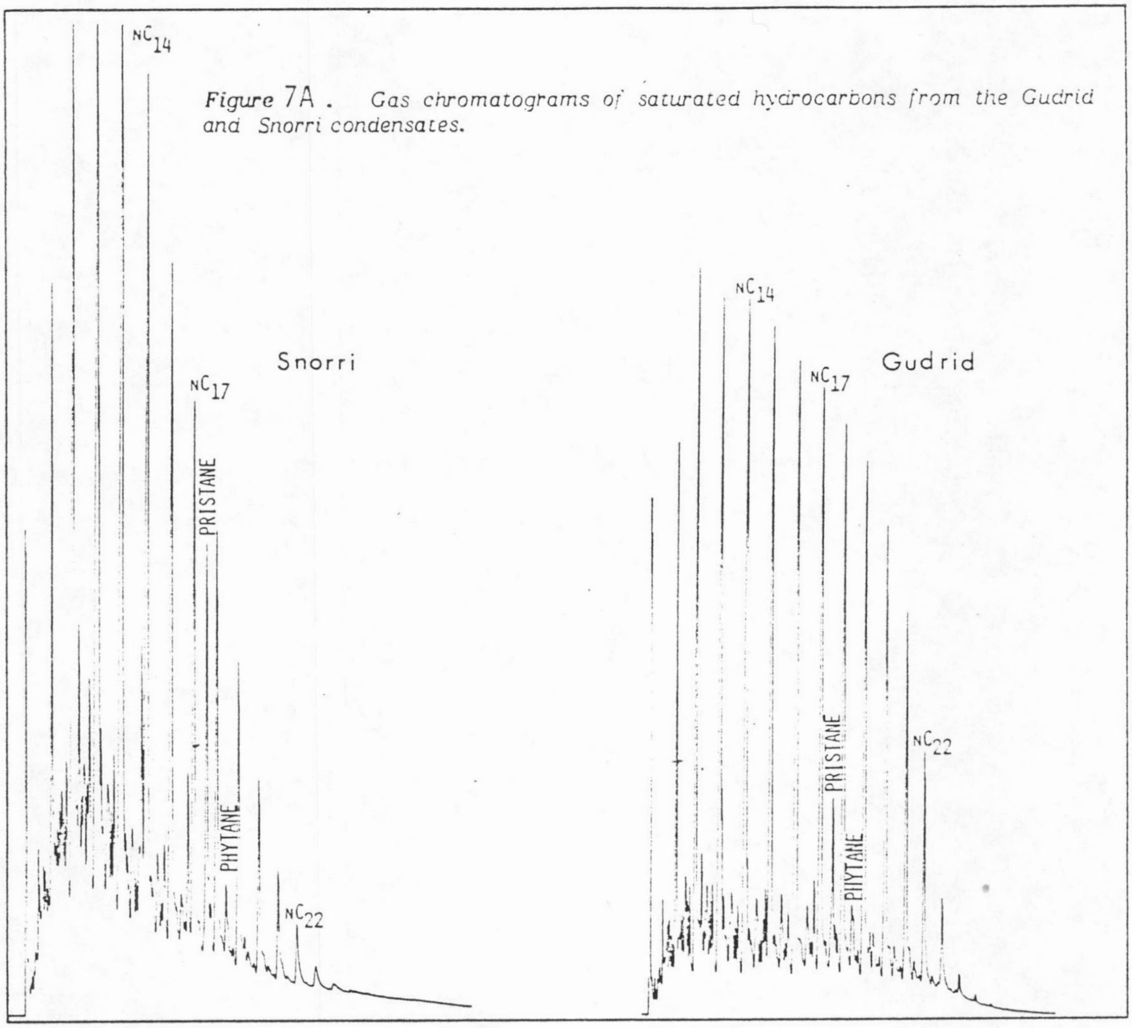


Figure 7A . *Gas chromatograms of saturated hydrocarbons from the Gudrid and Snorri condensates.*

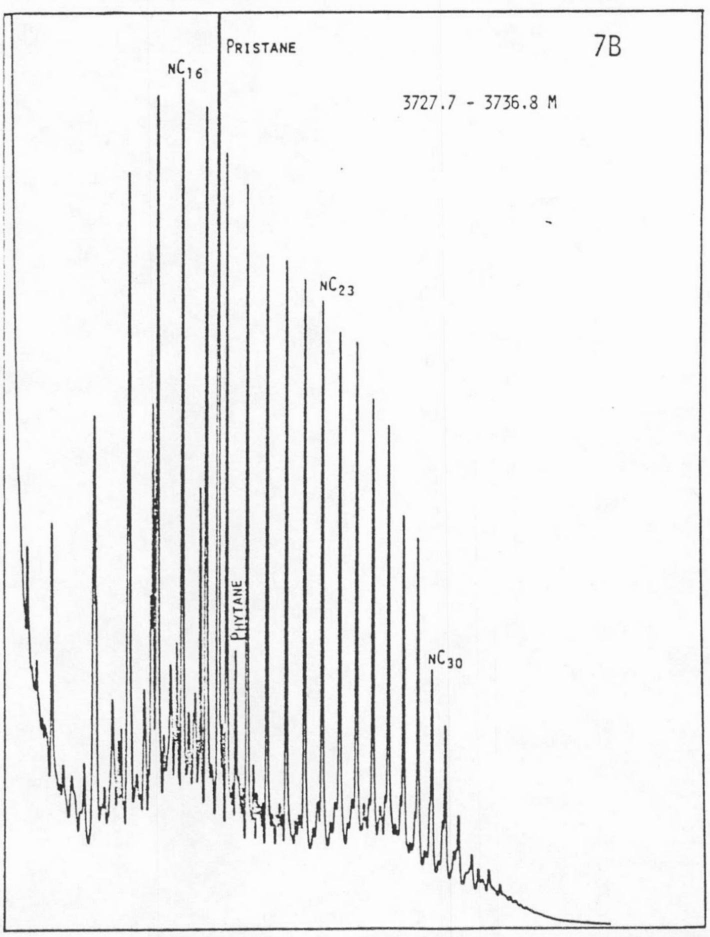


Figure 7A: Note the lack of waxy n-alkanes in the Snorri and Gudrid condensates. This suggests a mixed source, however moderate pristane/phytane ratios indicate the organic matter is dominated by terrestrial components.

Figure 7B: Gas chromatograms of saturated hydrocarbons from the Bjarni Formation in Herjolf M-92. Note the abundant waxy n-alkanes and high pristane/phytane ratio indicating a terrestrial source rock.

(Powell, 1979)

the organic matter. Most of the wells containing hydrocarbons drape basement highs. Source rocks flanking these reservoirs are at higher levels of maturation due to deeper burial, assuming the relative age of the sediments is not a factor in maturation.

Summary and Conclusions

All hydrocarbons discovered to date on the Labrador Shelf are in reservoirs at low levels of maturation. Consequently, two hypothesis can be submitted to explain this fact. Powell (1979) and Snowdon and Powell (1982) have presented evidence to support large scale vertical migration of conventional mature to overmature gas condensate. Alternatively, the generation of gas condensate at low levels of maturation has been proposed (McWhae et al., 1980). Evidence presented in this study support the latter. Recent hydrocarbon generation models for Type II and Type III organic matter quantitatively support this hypothesis (Monnier et al., 1983).

Differences in paraffin indices and gas condensate ratios have been explained by variations in the composition of source beds at low levels of maturation rather than differences in the level of maturation in similar terrestrial source material. Potential mature source beds lie adjacent to each reservoir, therefore it is not necessary to invoke long distance vertical migration. If discoveries to date are from overmature source rocks, then the potential for locating significant liquid hydrocarbons is low.

The gas condensate on the Labrador Shelf is derived from Cretaceous sediments containing dominantly gas prone terrestrial organic matter with a possible dispersed marine component. Between basement highs, considerable thicknesses of Cretaceous sediment exist and these may be important for sourcing shallower reservoirs. The coal beds and carbonaceous strata of the Lower Cretaceous section should not be overlooked as a source for high wax oils since traces of oil have been observed in these intervals.

It has been suggested that the Tertiary section could yield liquid hydrocarbons if buried to a sufficient depth. However, despite high subsurface temperatures and burial to 4km, most of the Tertiary section was still only marginally mature in two wells in the Saglek Basin. This is due to insufficient time within an adequate temperature regime. There may be some potential for Tertiary derived hydrocarbons where lower Paleocene sediments are within the fully mature zone. Rich potential source rocks have been intersected in Albian-Cenomanian sediments, and where mature may prove to be oil prone. Consequently, the overall potential for significant oil generation on the Labrador Shelf is fair to poor, although considerable quantities of gas/condensate may exist.

References

Barss, M.S., J.P. Bujak, G.L. Williams, 1979; Palynological zonation and correlation of sixty-seven wells, eastern Canada. Geol. Surv. Can. Paper 78-24, 118 p.

Bujak, J.P., M.S. Barss, G.L. Williams, 1977; Offshore eastern Canada: organic matter type and color and hydrocarbon potential. Oil and Gas Journal, v. 75/14, 15, pp. 198-202, 96-100.

Cassou, A.M., J. Connan, B. Porthault, 1977; Relationship between maturation of organic matter and geothermal effect, as exemplified in Canadian east coast offshore wells. Bull. Can. Petrol. Geol., v. 25, pp. 174-194.

Dowdle, W.L., W.M. Cobb, 1975; Static formation temperature from well logs - an empirical method. J. Petrol. Tech., pp. 1326-1330.

Fertl, W.H., P.A. Wichmann, 1977; How to determine static BHT from well log data. World Oil, Jan., pp. 37-40.

Gradstein, F.M., 1982; Stratigraphic modelling. B.I.O. Review 1982/1983, pp. 47-53.

Issler, D., 1984; Calculation of organic maturation levels for offshore eastern Canada - implications for general application of Lopatin's method. Can. J. Earth Sci., v. 21/4, pp. 477-488.

McMillan, N.J., 1979; Geology of the Labrador sea and its petroleum potential. Tenth world petroleum congress, Bucharest (preprint), 33 p.

McWhae, J.R., R. Elie, K.C. Laughton, P.R. Gunther, 1980; Stratigraphy and petroleum prospects of the Labrador shelf. Bull. Can. Petrol. Geol., v. 29/4, pp. 460-498.

Monnier, F., T.G. Powell, L.R. Snowdon, 1983; Qualitative and quantitative aspects of gas generation during maturation of sedimentary organic matter - examples from Canadian frontier basins. Advances in Organic Geochemistry 1981, J. Wiley & Sons Ltd., pp. 487-495.

Powell, T.G., 1979; Geochemistry of Snorri and Gudrid condensates, Labrador shelf: implications for future exploration. Current Research, Part C, Geol. Surv. Can. Paper 79-1C, pp. 91-95.

Powell, T.G., L.R. Snowdon, 1983; A composite hydrocarbon generation model - implications for evaluation of basins for oil and gas. Erdöl und Kohle -Erdgas-Petrochemie, v. 36/4, pp. 163-170.

Rashid, M.A., L.P. Purcell, I.A. Hardy, 1980; Source rock potential for oil and gas of the east Newfoundland and Labrador shelf areas. Can. Soc. Petrol. Geol., Memoir 6, pp. 589-608.

Snowdon, L.R., T.G. Powell, 1982; Immature oil and condensate - modification of hydrocarbon generation model for terrestrial organic matter. Am. Assoc. Petrol. Geol., v. 66/6, pp. 775-788.

Thompson, K.F.M., 1979; Light hydrocarbons in subsurface sediments. Geochemica et Cosmochemica Acta, v. 43, pp. 657-672.

Umpleby, D.C., 1979; Geology of the Labrador shelf. Geol. Surv. of Canada Paper 79-13, 34 p.

APPENDIX 1. Time-Temperature Index Curves

North Leif I-05

Pothurst P-19

South Labrador N-79

South Hopedale L-39

Hopedale E-33

Ogmund E-73

Gilbert F-53

Skolp E-07

Rut H-11

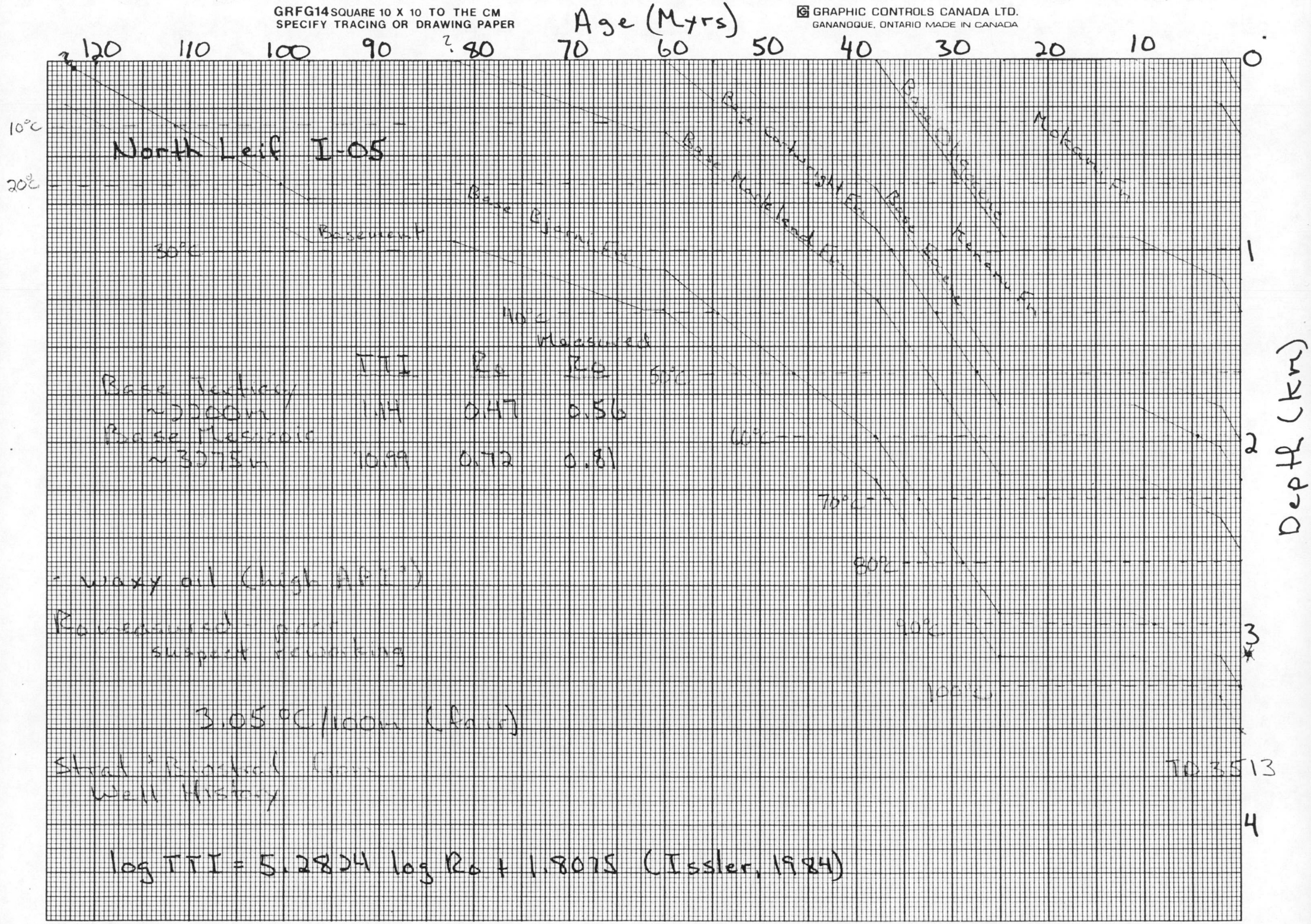
Roberval C-02

Roberval K-92

Tyrk P-100

Bjarni 0-82

North Bjarni F-06


GRFG14 SQUARE 10 X 10 TO THE CM
SPECIFY TRACING OR DRAWING PAPER
GRAPHIC CONTROLS CANADA LTD.
GANANOQUE, ONTARIO MADE IN CANADA
Age (Myrs)
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
Depth (km)
North Leif I-05
10°C
20°C
30°C
40°C
50°C
60°C
70°C
80°C
90°C
100°C
Basement
Base Bjarni Fm
Base Markland Fm
Base Cartwright Fm
Base Eocene
Base Oligocene
Kenamu Fm
Mokami Fm
Measured
TTI
Ro
Ro
Base Tertiary
~2200m
1.14
0.47
0.56
Base Mesozoic
~3275m
10.99
0.72
0.81
waxy oil (high API)
Ro measured
suspect
3.05°C/100m
Strat
Well History
TD 3513
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)

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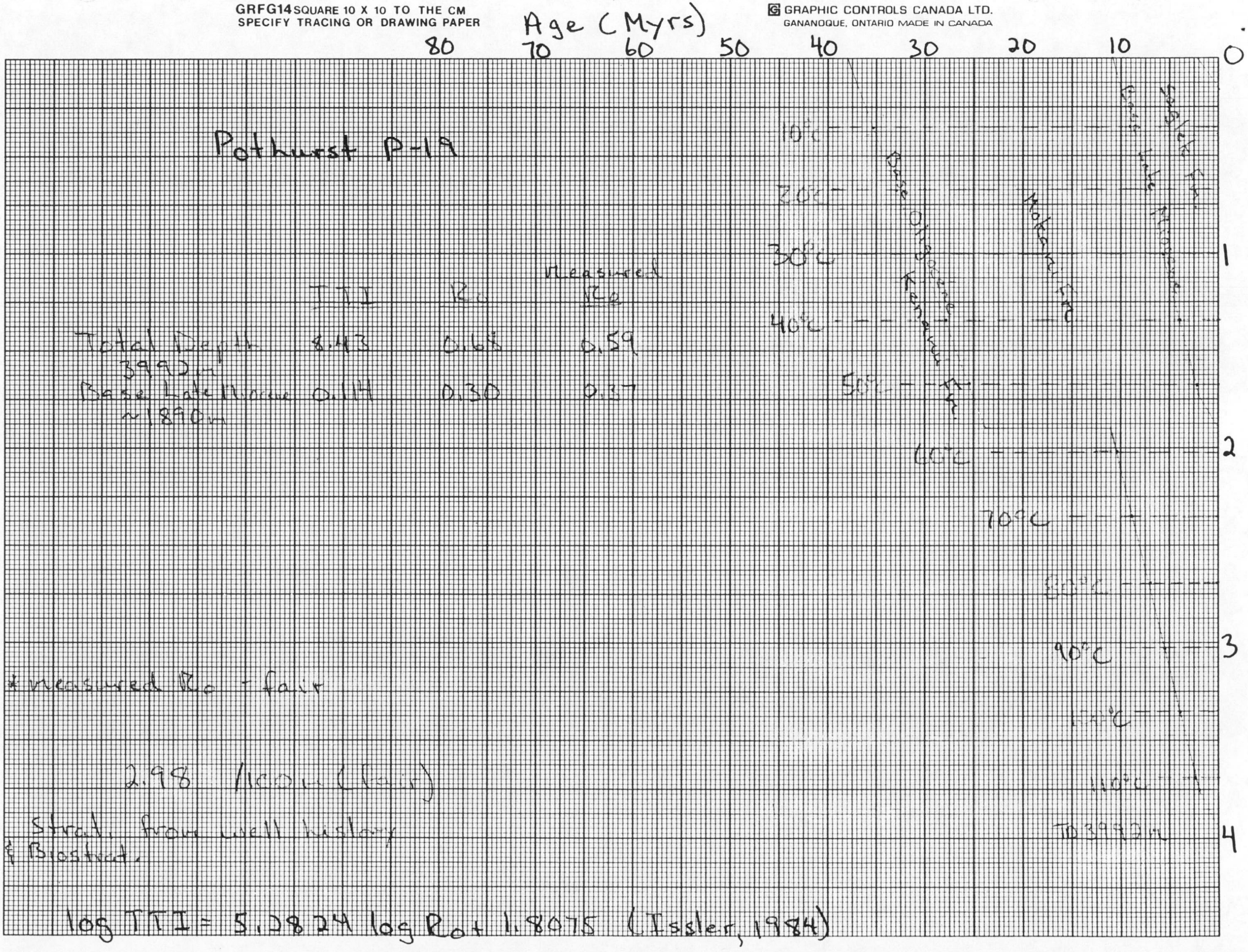

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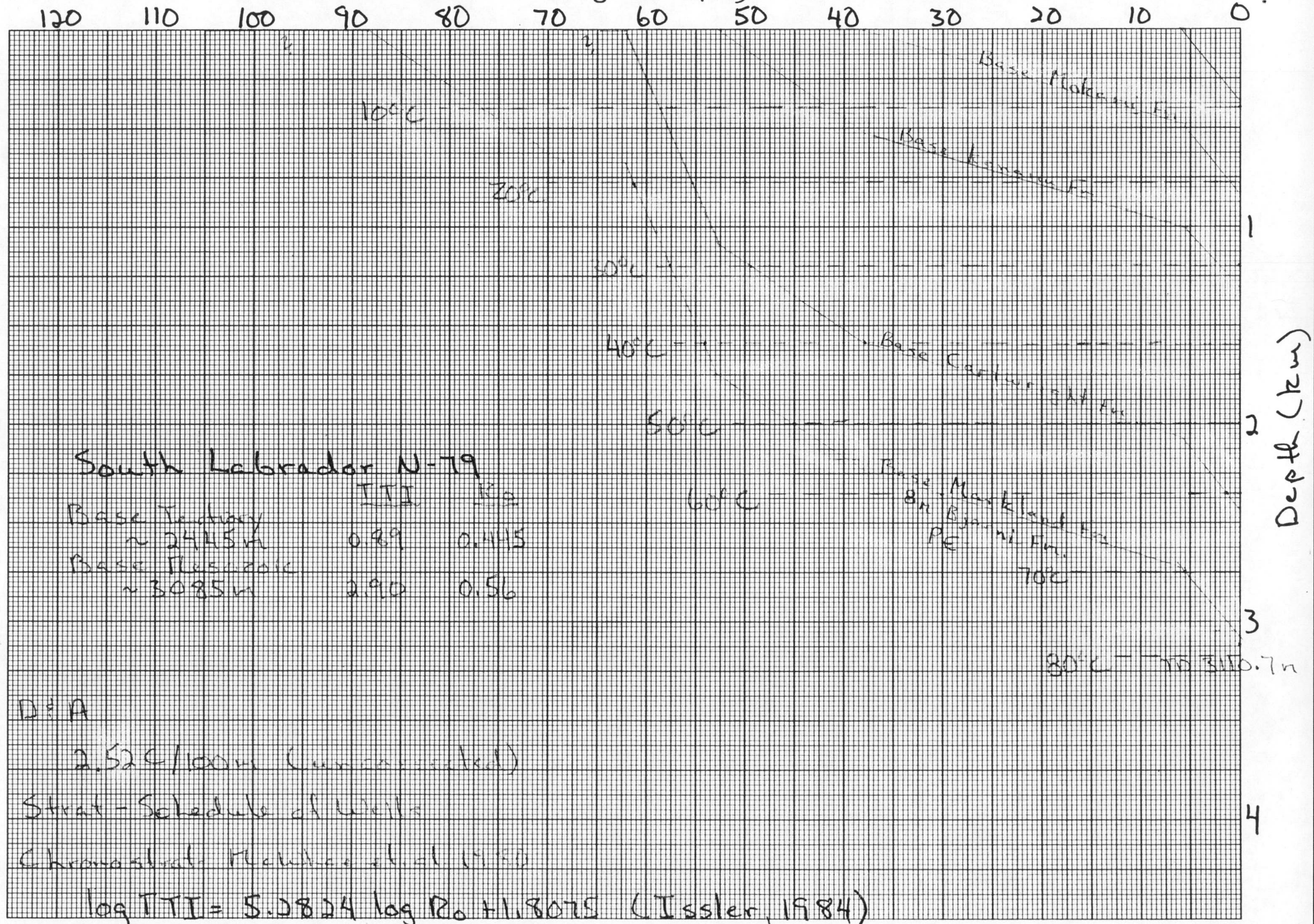

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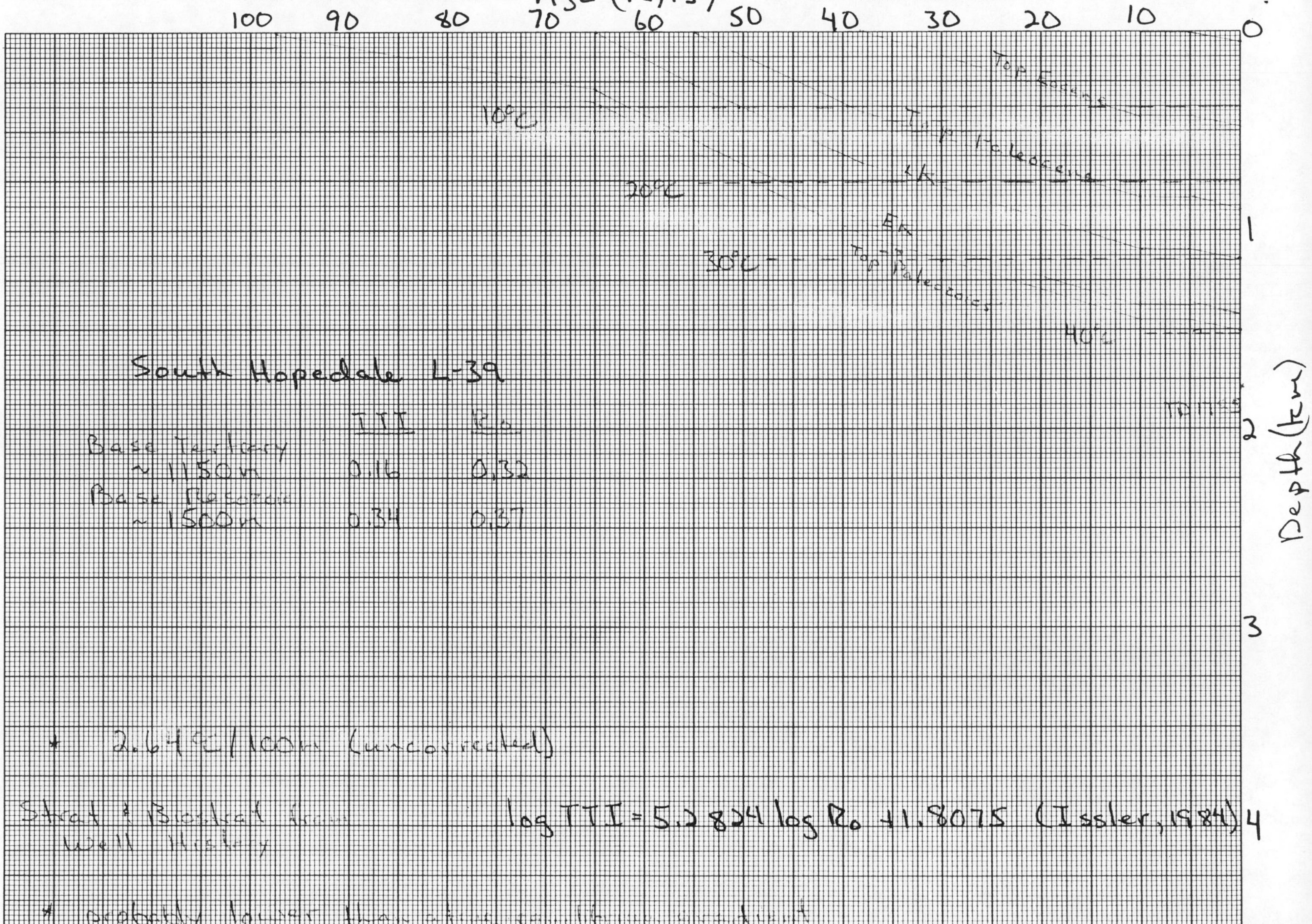
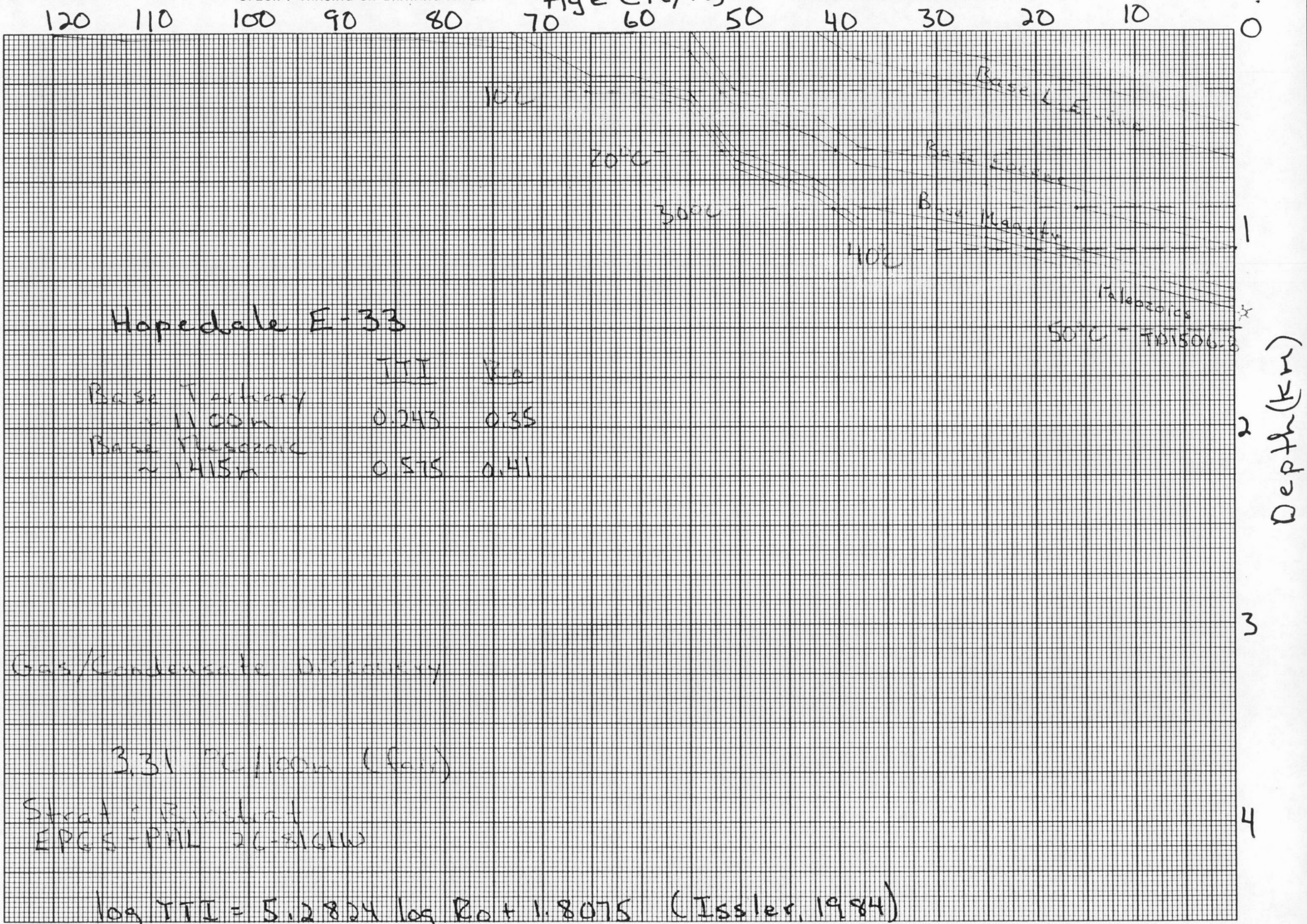
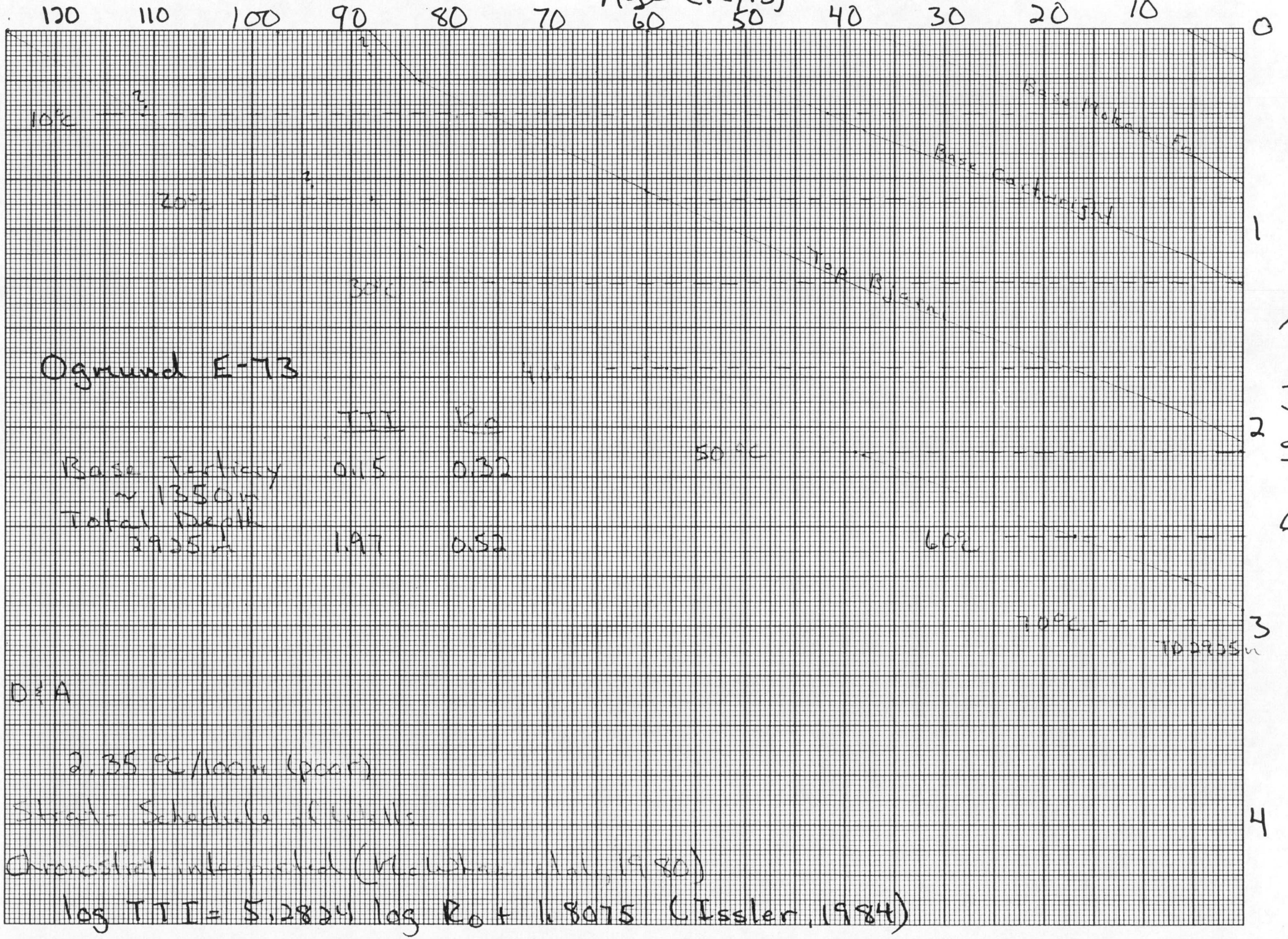
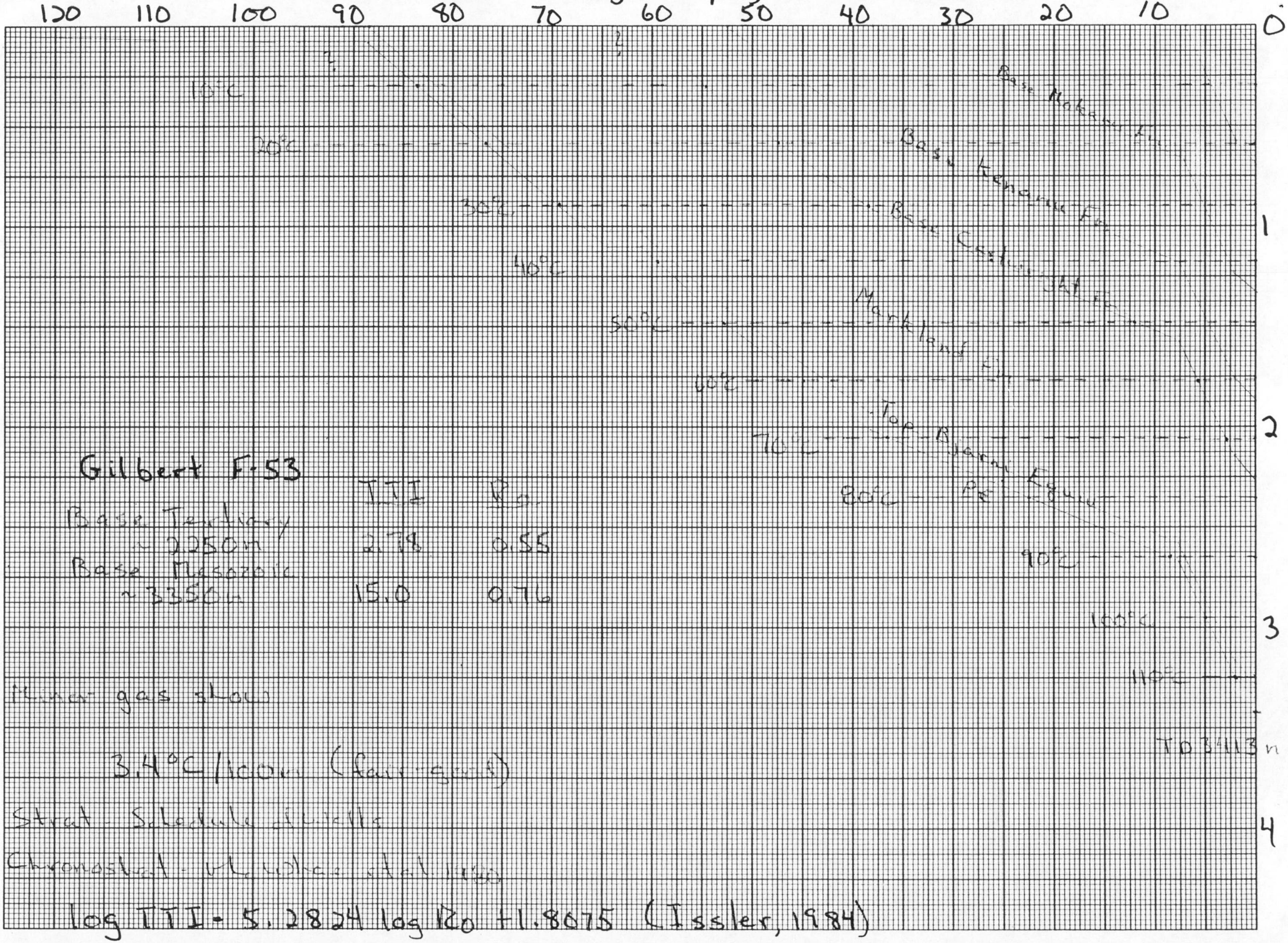
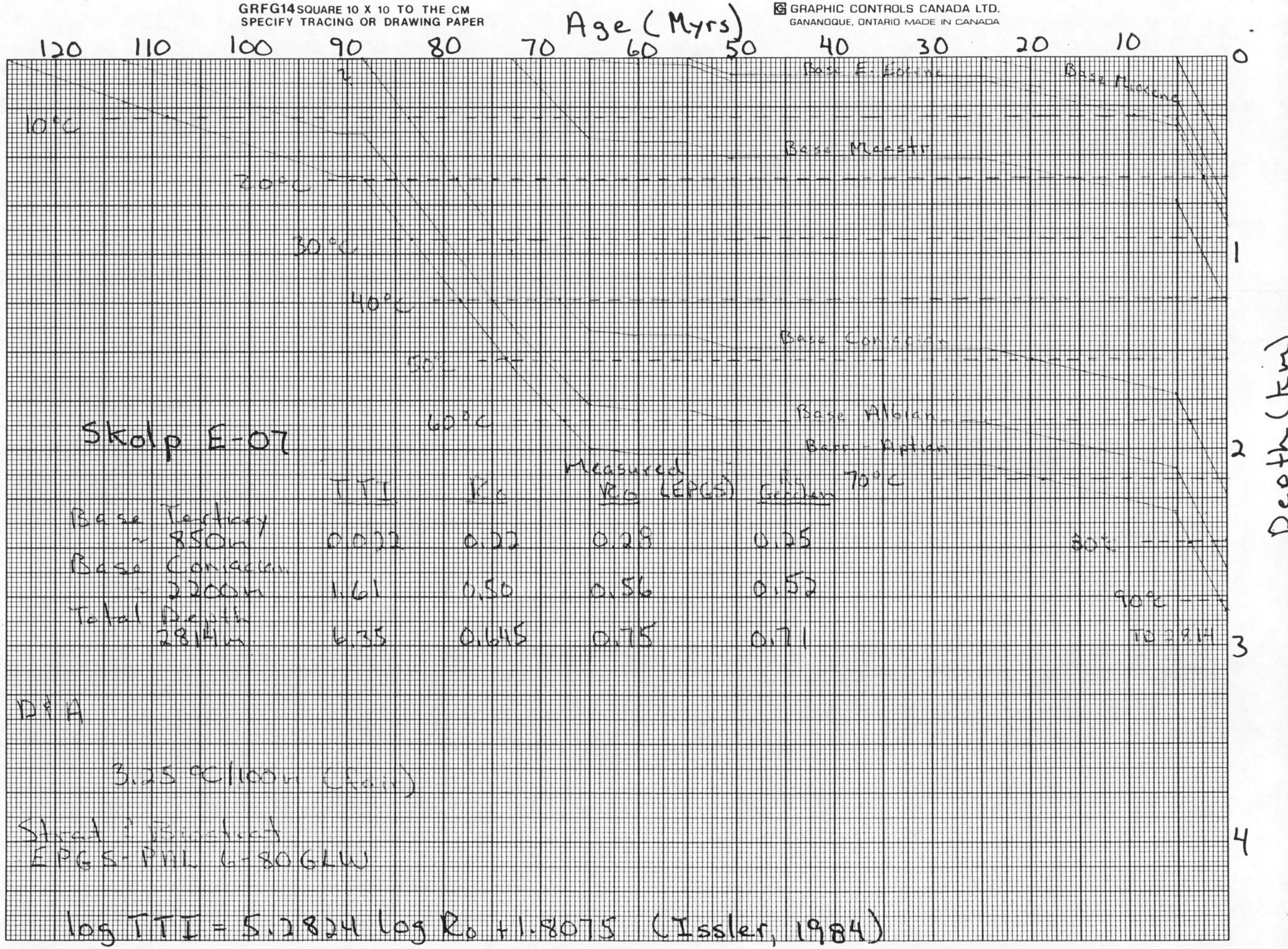



Age (Myrs)
120 110 100 90 80 70 60 50 40 30 20 10 0
Depth (km)
0 1 2 3 4
10°C
20°C
30°C
40°C
50°C
Base L.E.
Base
Base Maastr.
Paleozoics
TD 1506.3
Hopedale E-33
TTI Ro
Base Tertiary ~1100m 0.243 0.35
Base Mesozoic ~1415m 0.575 0.41
Gas/Condensate Discovery
3.31 °C/100m
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)


Age (Myrs)
120
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
Depth (km)
Base Mokami Fm
Base Cartwright
Top Bjarni
10°C
20°C
30°C
40°C
50°C
60°C
70°C
TD 2935m
Ogmund E-73
TTI
Ro
Base Tertiary
~ 1350m
0.15
0.32
Total Depth
2935m
1.97
0.52
D&A
2.35 °C/100m (poor)
Strat- Schedule (Wells)
Chronostrat- interpreted (McWhae et al, 1980)
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)


Age (Myrs)
120 110 100 90 80 70 60 50 40 30 20 10 0
Depth (km)
0 1 2 3 4
10°C
20°C
30°C
40°C
50°C
60°C
70°C
80°C
90°C
100°C
110°C
Base Mokami Fm
Base Kenamu Fm
Base Cartwright Fm
Markland Fm
Top Bjarni Fm
TD 3413 m
Gilbert F-53
TTI Ro
Base Tertiary ~2250m 2.78 0.55
Base Mesozoic ~3350m 15.0 0.76
Minor gas show
3.4°C/100m (fair-good)
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)


Age (Myrs)
120 110 100 90 80 70 60 50 40 30 20 10 0
Depth (km)
1 2 3 4
Base E. Eocene
Base Miocene
Base Maestr
Base Coniacian
Base Albian
Base Aptian
10°C
20°C
30°C
40°C
50°C
60°C
70°C
80°C
90°C
TD 2814
Skolp E-07
TTI
Ro
Measured Ro (EPGS)
Ro Gelchen
Base Tertiary ~ 850m
0.022
0.22
0.28
0.25
Base Coniacian ~ 2200m
1.61
0.50
0.56
0.52
Total Depth 2814m
6.35
0.645
0.75
0.71
D & A
3.25 °C/100m (Fair)
Strat & Geochem
EPGS-PAL 6-80 GLW
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)

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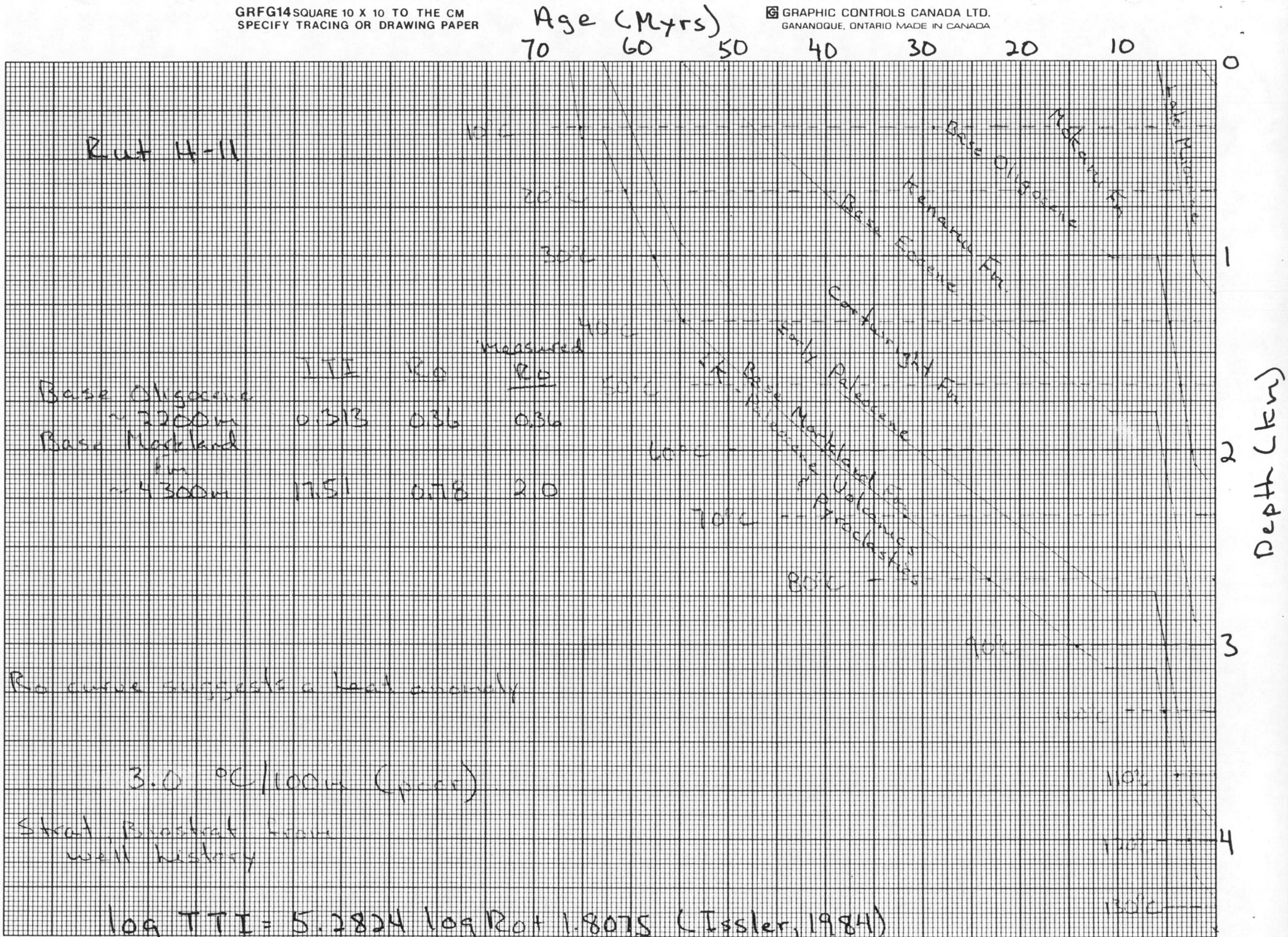

TD 4466.2

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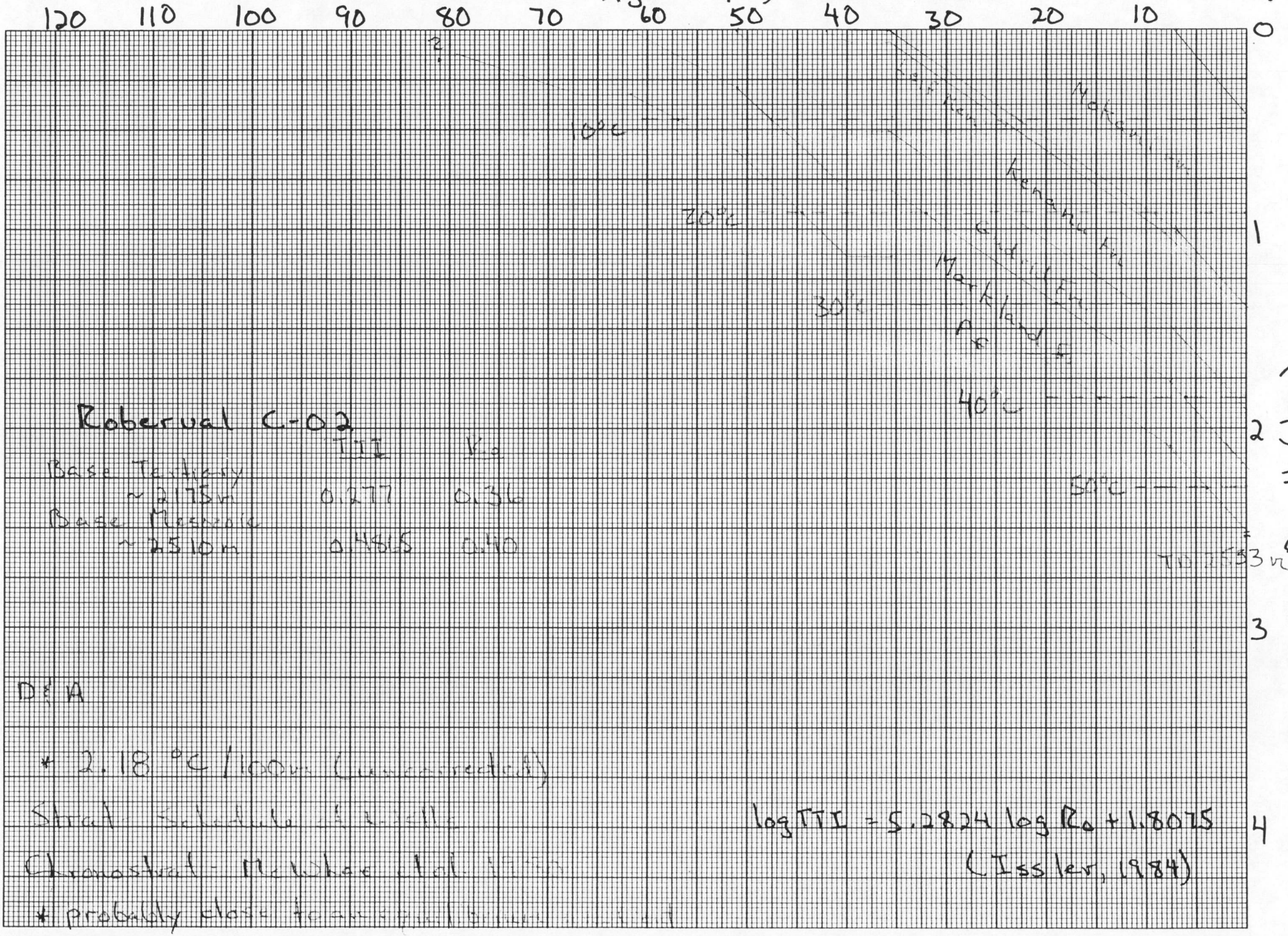

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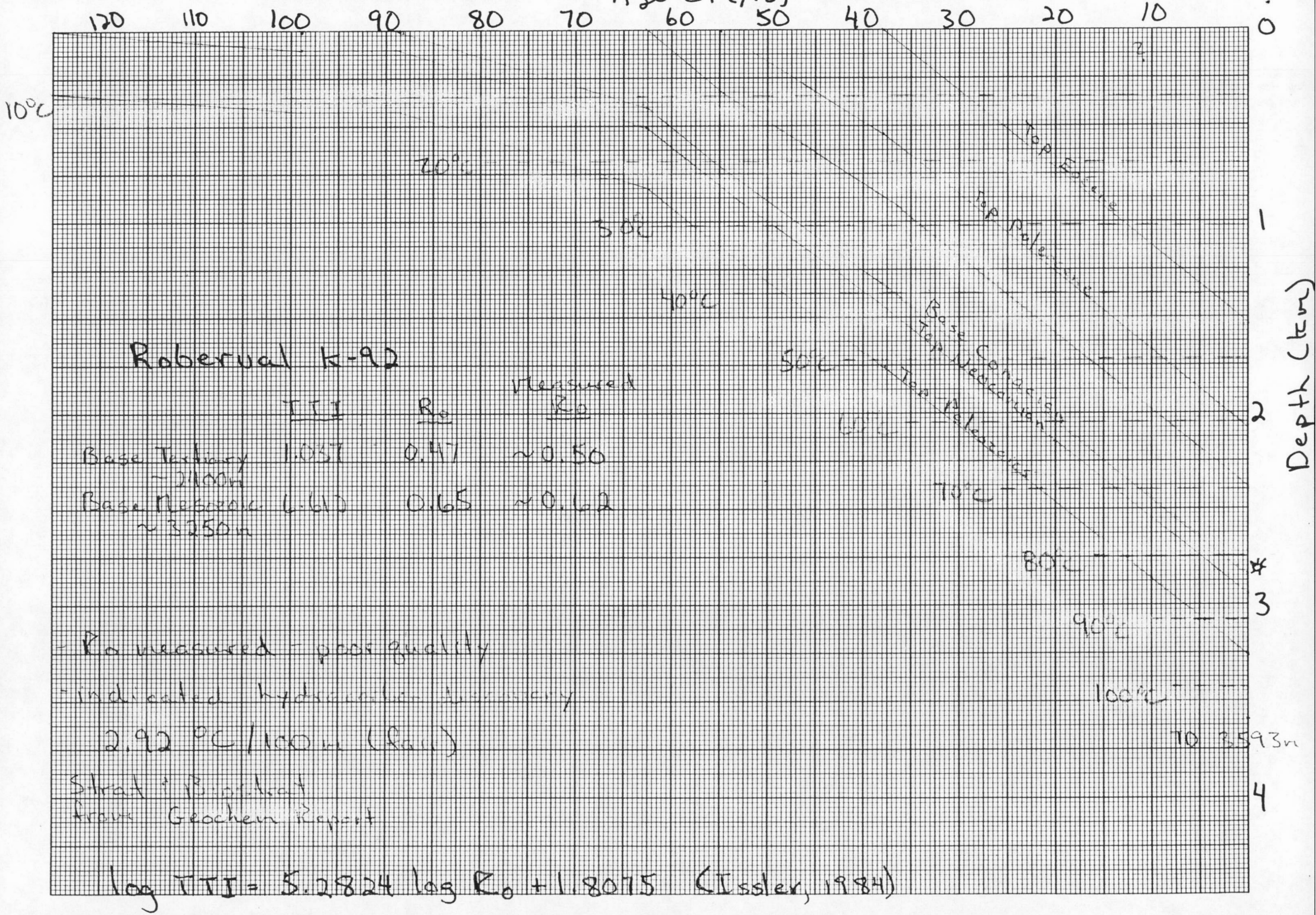

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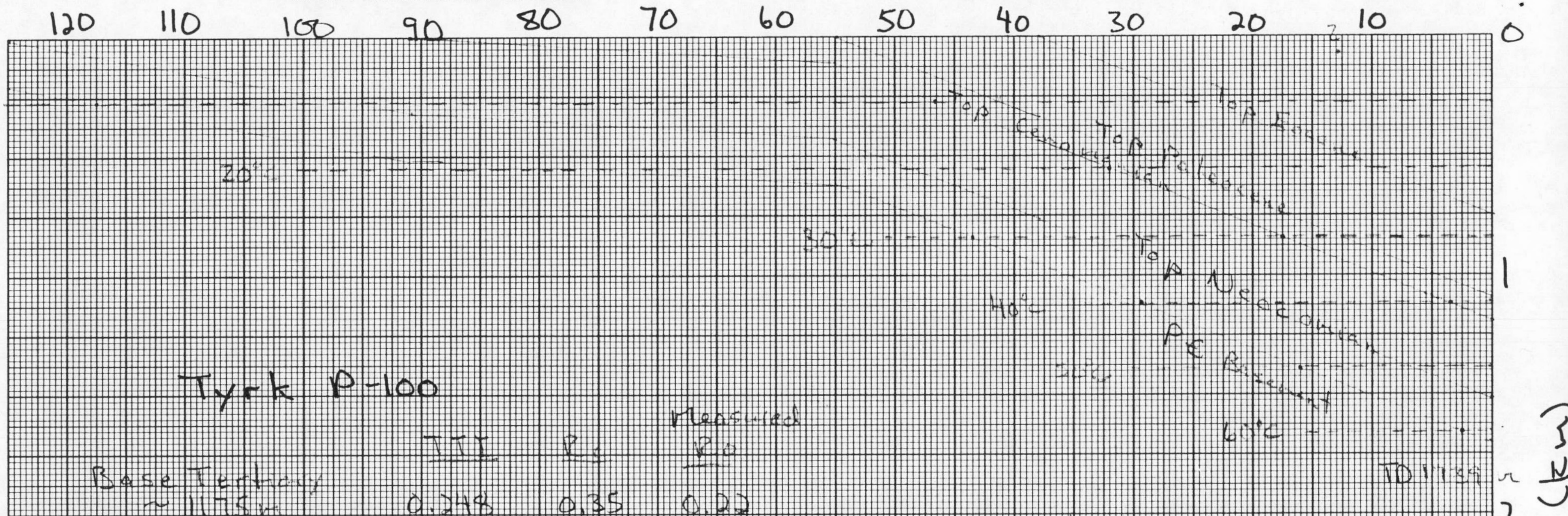


Tyrk P-100

	TTI	R_o	Measured R_o
Base Tertiary ~1175m	0.248	0.35	0.22
Base Mesozoic ~1700m	1.11	0.46	0.25

Measured Ro ~ poor

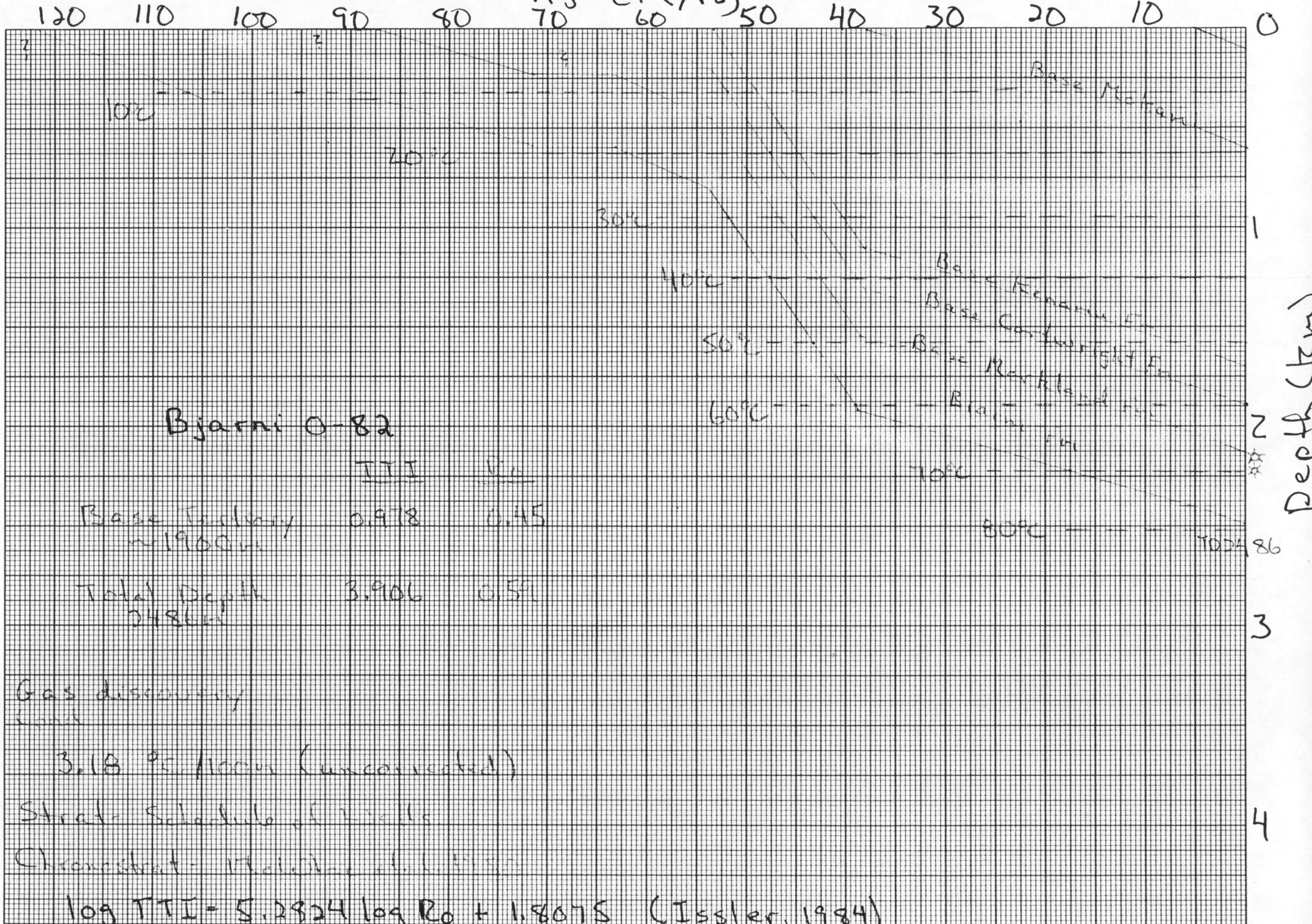
Trace gas

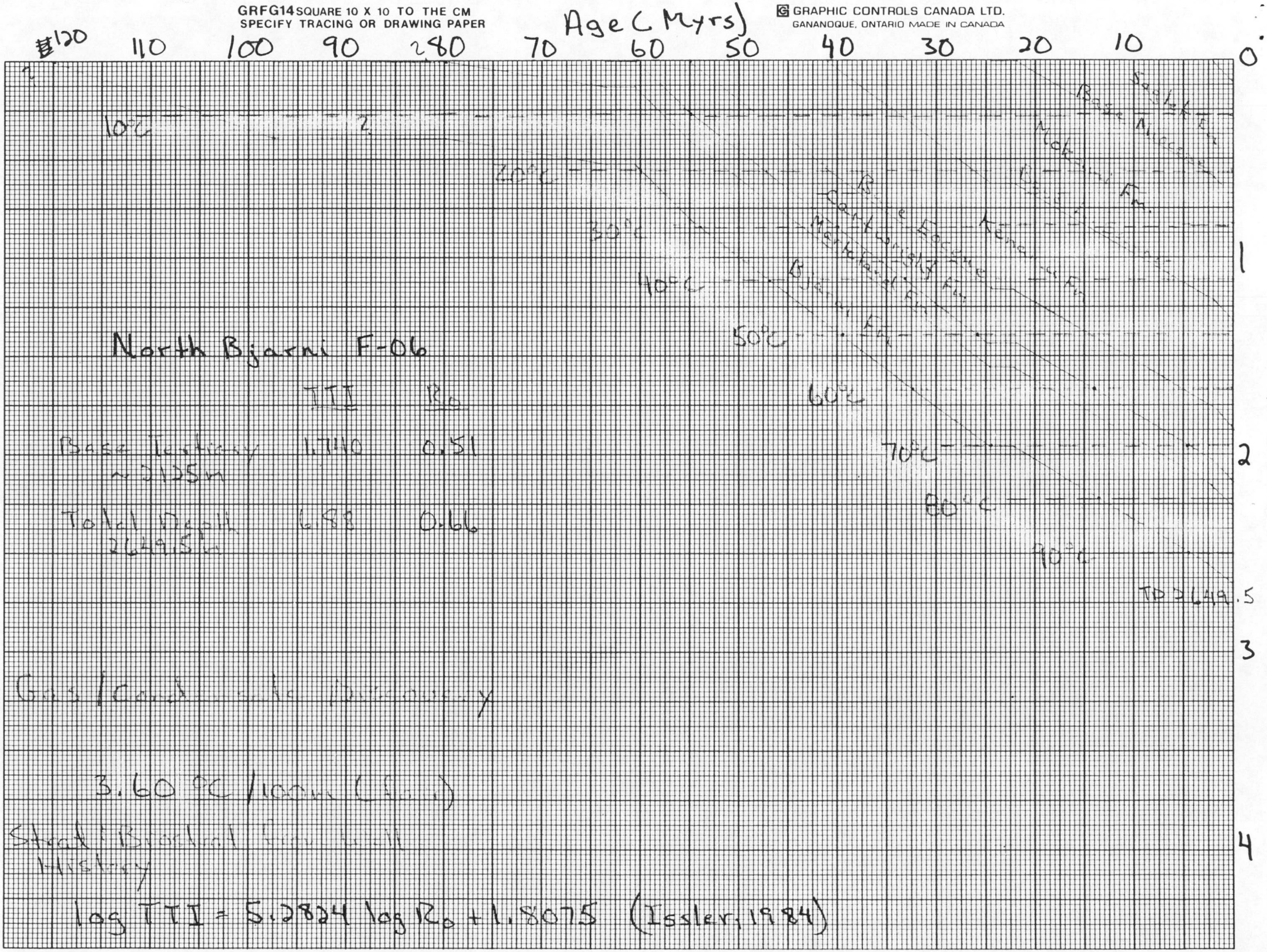
3.6 °C/100m (fair)

Strat - Schedule of Wells

Biostrat - Geochem Report - Well History

$\log TTI = 5.2824 \log R_o + 1.8075$ (Issler, 1984)


Age (Myrs)
120
110
100
90
80
70
60
50
40
30
20
10
0
Depth (km)
1
2
3
4
10°C
20°C
30°C
40°C
50°C
60°C
70°C
80°C
Base Mekam
Base Banquereau Fm
Base Cartwright Fm
Base Markland
Fm
TD 2486
Bjarni O-82
TTI
Base Tertiary 0.978 0.45
~1900m
Total Depth 3.906 0.59
2486m
Gas discovery
3.18 °C/100m (uncorrected)
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)


Age (Myrs)
120
110
100
90
80
70
60
50
40
30
20
10
0
Depth (km)
1
2
3
4
10°C
20°C
30°C
40°C
50°C
60°C
70°C
80°C
90°C
Base Saglek Fm
Mokami Fm
Kenamu Fm
Cartwright Fm
Markland Fm
Bjarni Fm
TD 2649.5
North Bjarni F-06
TTI
Ro
Base Tertiary
~2125m
1.740
0.51
Total Depth
2649.5m
6.88
0.66
Gas / Cond
3.60 °C / 100m
Strat / Burial / Geothermal
History
log TTI = 5.2824 log Ro + 1.8075 (Issler, 1984)

APPENDIX II - Source Rock Evaluation Summaries

Roberval K-92

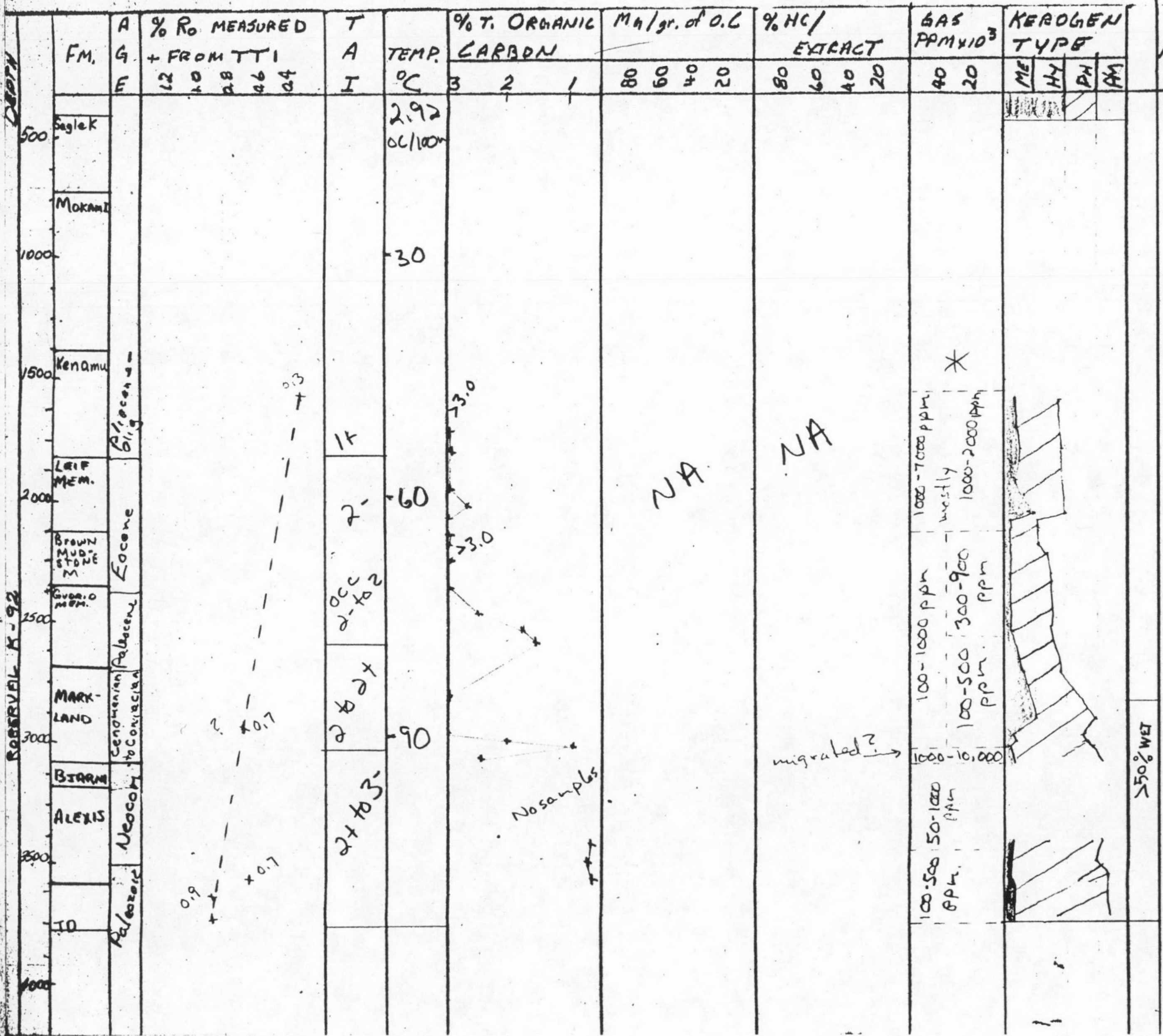
Rut H-11

Skolp E-07

Tyrk P-100

North Leif I-05

Pothurst P-19



REMARKS + COMMENTS

Roberval K-92

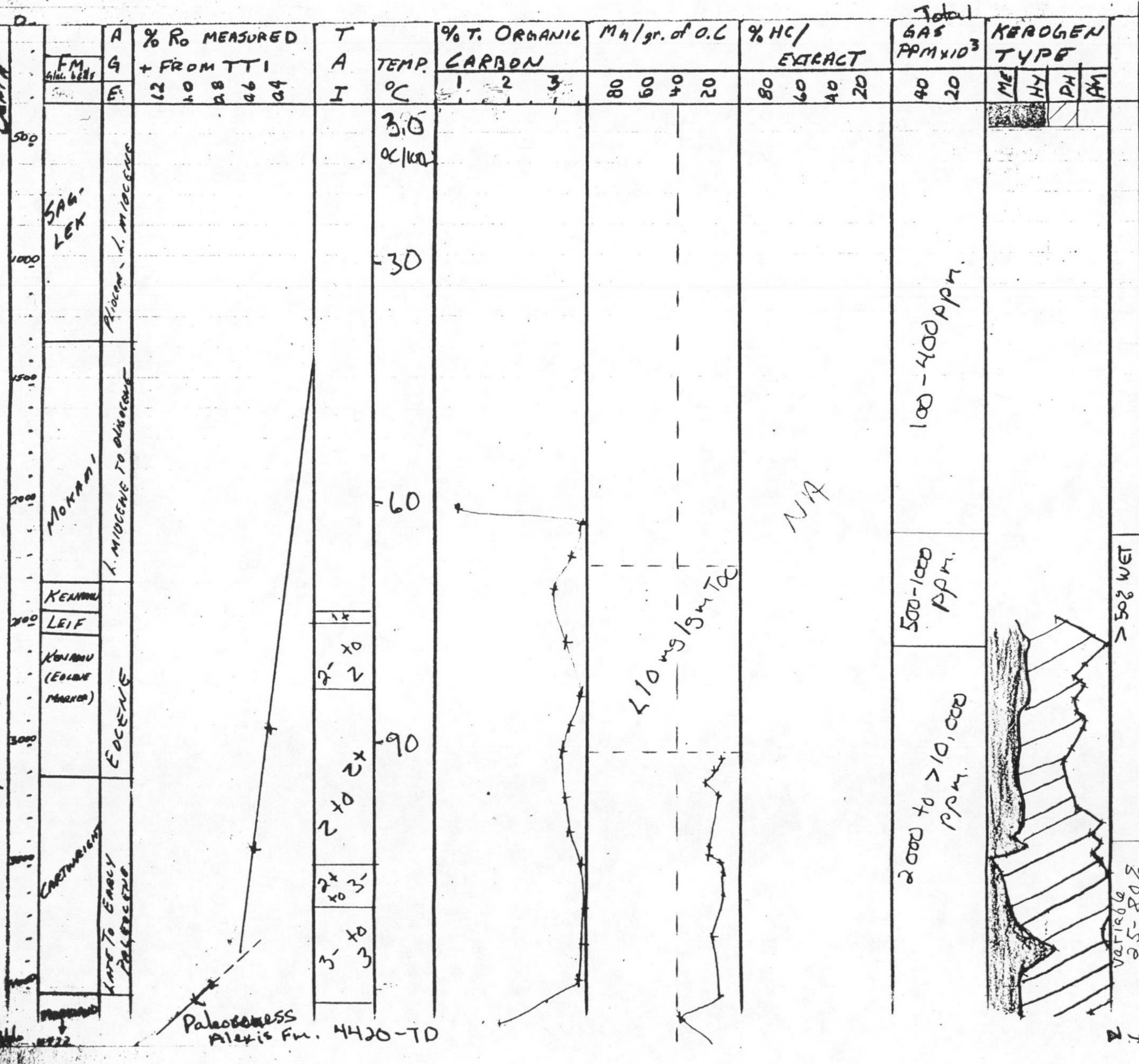
% Ro data below 2500 m possibly unreliable

Cuttings gas must be interpreted
* qualitatively (relatively)

Low OM in dolomites in lower portion of well (near TD)

HC discovery

Well - RUT H-11



REMARKS + COMMENTS

RUT H-11

Pristane/phytane generally >3.0 (gas prone)

Van Krevelen - mostly type III
Atomic H/C 0.75 - 1.0
O/C 0.1 - 0.19

Rock Eval (a) Mokami Fm. 1322-2331m gas prone

(b) Kenamu Fm. 2331-3125m mostly oil or oil/gas prone

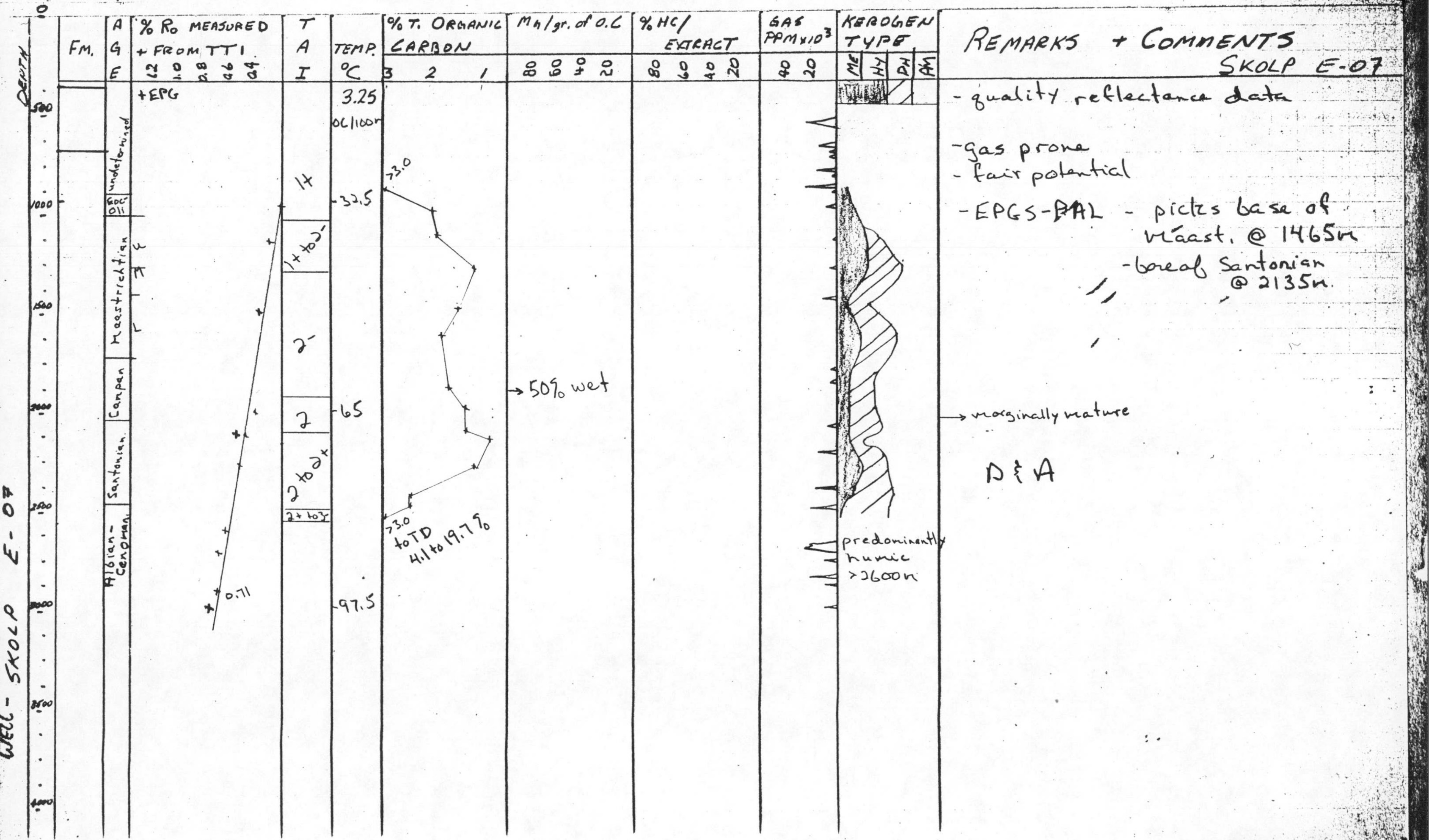
(c) Cartwright Fm. mostly oil or oil/gas prone

(d) Markland Fm. gas prone

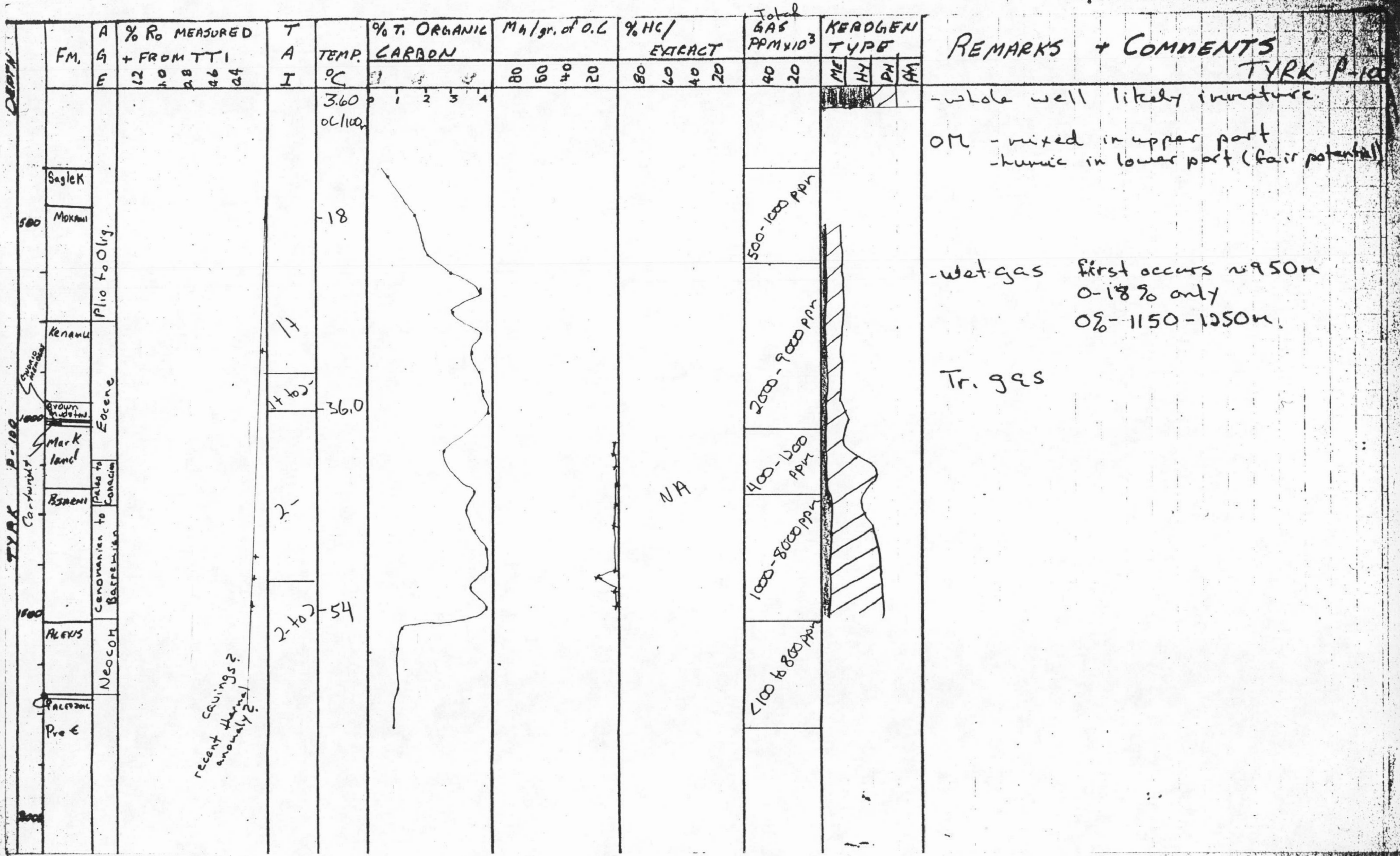
→ marginally mature 2740m

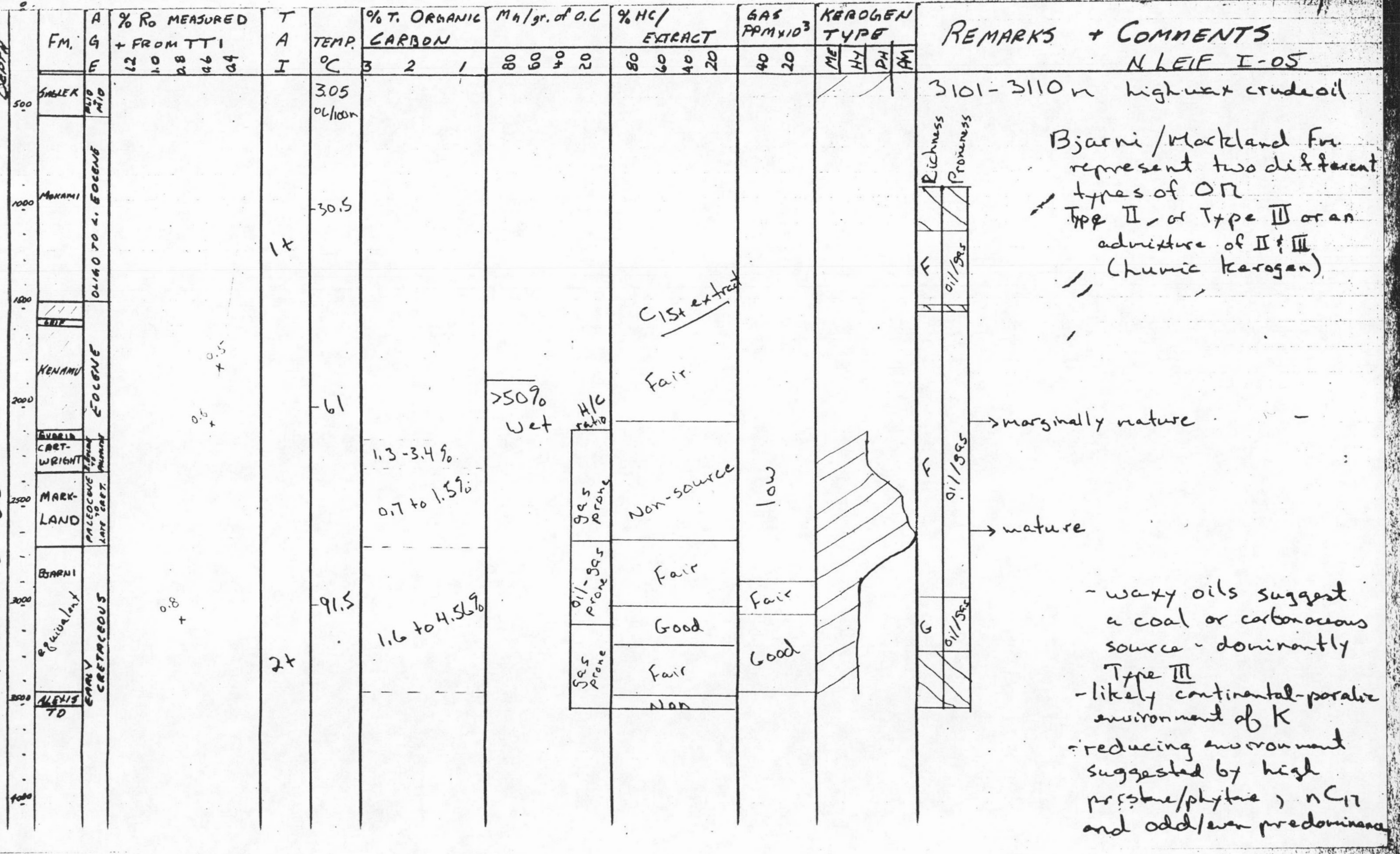
→ mature 3480m

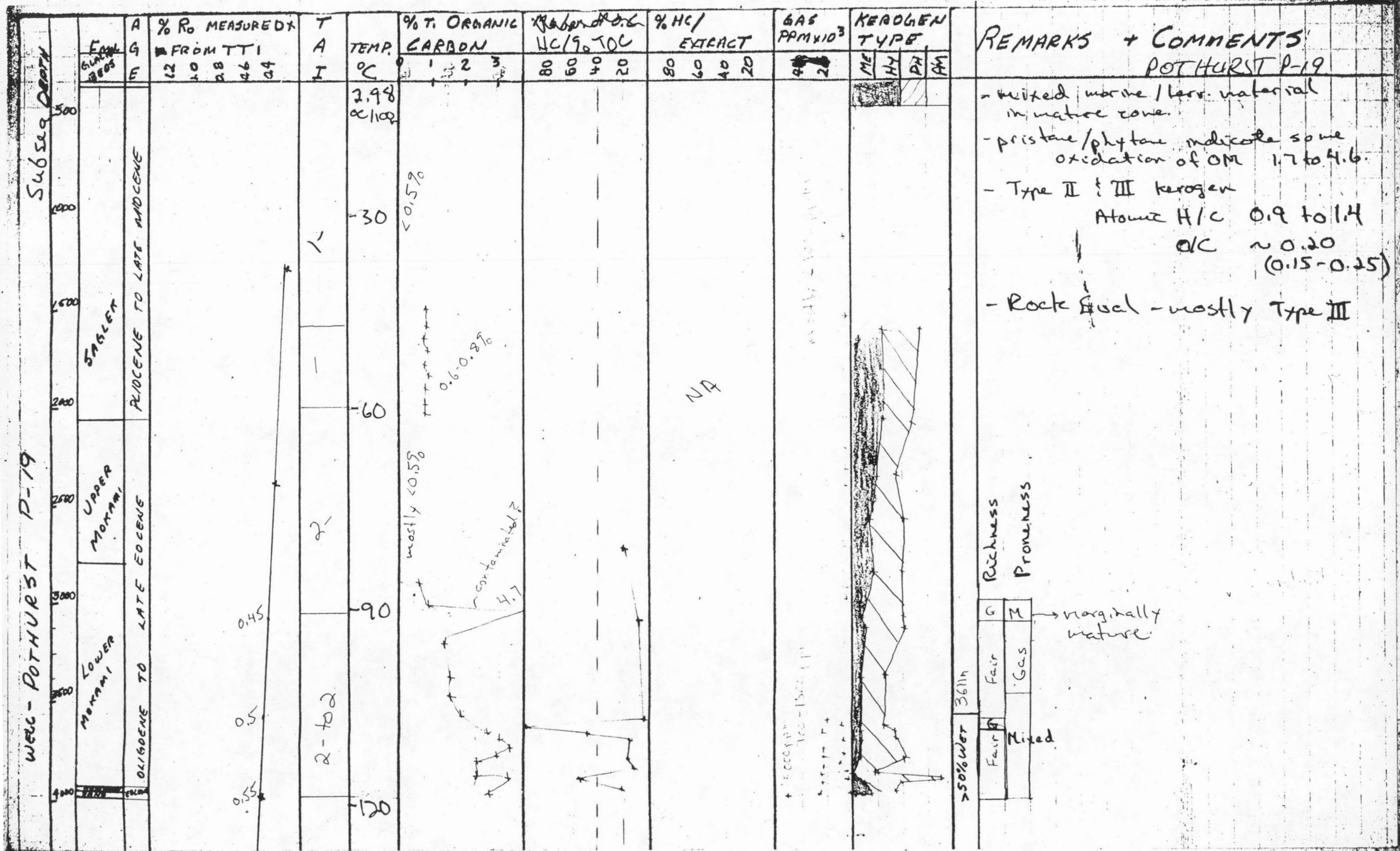
→ overmature (due to diabase intrusion)



WELL - SKOLP E-07
DEPTH
500
1000
1500
2000
2500
3000
3500
4000
FM.
AGE
% Ro MEASURED + FROM TTI
1.2 1.0 0.8 0.6 0.4
+EPG
0.71
TAI
TEMP. °C
3.25
°C/100m
32.5
65
97.5
% T. ORGANIC CARBON
3 2 1
3.0
to TD 4.1 to 19.7 %
Mh/gr. of O.C
80 60 40 20
→ 50% wet
% HC/ EXTRACT
80 60 40 20
GAS PPM x 10^3
40 20
KEROGEN TYPE
ME HY PH AM
predominantly humic >2600m
undetermined
Eoc-Oli
Maastrichtian
U
M
L
Campan
Santonian
Albian-Cenoman.
1+
1+ to 2-
2-
2
2 to 2+
2+ to 3-
REMARKS + COMMENTS
SKOLP E-07
- quality reflectance data
- gas prone
- fair potential
- EPGS-BAL - picks base of Maast. @ 1465m
- boreal Santonian @ 2135m.
→ marginally mature
D & A


DEPTH
500
1000
1500
2000
TYRK P-100
FM.
AGE
% Ro MEASURED + FROM TTI
TAI
TEMP. °C
% T. ORGANIC CARBON
Mh/gr. of O.C
% HC/ EXTRACT
Total GAS PPM x10³
KEROGEN TYPE
ME
HY
PH
AM
REMARKS + COMMENTS
TYRK P-10
Saglek
Mokami
Kenamu
Brown
Mark land
Bjarni
Alexis
Paleozoic
Pre €
Plio to Olig.
Eocene
Paleo to Conacian
Cenomanian to Barremian
Neocom
Cartwright
1+
1+ to 2-
2-
2- to 2
3.60 °C/100m
18
36.0
54
NA
500-1000 ppm
2000-9000 ppm
400-1200 ppm
1000-8000 ppm
<100 to 800 ppm
cavings?
recent thermal anomaly?
-whole well likely immature
OM - mixed in upper part
-humic in lower part (fair potential)
-wet gas first occurs ~950m
0-18% only
0%- 1150-1250m.
Tr. gas


WELL - N. LEIF I-05
DEPTH
FM.
AGE
% Ro MEASURED + FROM TTI
1.2 1.0 0.8 0.6 0.4
TAI
TEMP. °C
% T. ORGANIC CARBON
3 2 1
Mn/gr. of O.C
80 60 40 20
% HC/EXTRACT
80 60 40 20
GAS PPM x 10^3
40 20
KEROGEN TYPE
ME HY PH AM
REMARKS + COMMENTS
N LEIF I-05
500
1000
1500
2000
2500
3000
3500
4000
SABLE K
MOKAMI
LEIF
KENAMU
GUDRID
CART-WRIGHT
MARK-LAND
BJARNI
equivalent
ALEXIS
TD
PLIO MIO
OLIGO TO L. EOCENE
EOCENE
PALEOCENE
PALEOCENE TO LATE CRET.
EARLY CRETACEOUS
0.5
0.6
0.8
1+
2+
3.05
OL/100m
30.5
61
91.5
1.3 - 3.4 %
0.7 to 1.5 %
1.6 to 4.56 %
>50%
Wet
H/C ratio
gas prone
oil-gas prone
gas prone
C15+ extract
Fair
Non-source
Fair
Good
Fair
Non
low
Fair
Good
Richness
Proneness
F
oil/gas
F
oil/gas
G
oil/gas
3101-3110 m high wax crude oil
Bjarni/Markland Fm. represent two different types of OM
Type II, or Type III or an admixture of II & III (humic kerogen)
→ marginally mature
→ mature
- waxy oils suggest a coal or carbonaceous source - dominantly Type III
- likely continental-paralic environment of K
- reducing environment suggested by high pristane/phytane, nC17 and odd/even predominance


WELL - POTHURST P-19
Subsea Depth
500
1000
1500
2000
2500
3000
3500
4000
Fm. Glacial Beds
SAGLEK
UPPER MOKAMI
LOWER MOKAMI
AGE
PLIOCENE TO LATE MIOCENE
OLIGOCENE TO LATE EOCENE
EOCENE
% Ro MEASURED ✕
FROM TTI
1.2 1.0 0.8 0.6 0.4
0.45
0.5
0.55
TAI
1
2
2 - to 2
TEMP. °C
2.98 °C/100
-30
-60
-90
-120
% T. ORGANIC CARBON
0 1 2 3
<0.5%
0.6-0.8%
mostly <0.5%
contaminated?
4.7
HC/% TOC
80 60 40 20
% HC/ EXTRACT
80 60 40 20
NA
GAS PPM x10³
KEROGEN TYPE
ME HY PH AM
>50% WET
3611m
Richness
Proneness
G
M
→ marginally mature
Fair
Gas
Mixed
REMARKS + COMMENTS
POTHURST P-19
- mixed marine / terr. material in mature zone.
- pristane/phytane indicate some oxidation of OM 1.7 to 4.6.
- Type II & III kerogen
Atomic H/C 0.9 to 1.4
O/C ~0.20 (0.15-0.25)
- Rock Eval - mostly Type III