Time and Temperature in Petroleum Formation: Application of Lopatin's Method to Petroleum Exploration: Discussion[1]

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Waples (1980) presented an extremely useful method for estimating the effects of time and temperature in petroleum formation by utilizing burial history diagrams (Van Hinte, 1978) and chemical reaction rate theory (Lopatin, 1971). Fundamental to his approach was the calculation of time-temperature indices (TTIs). This parameter represents the amount of time spent in a particular temperature interval by a specific geologic horizon (e.g., formation top). As Waples noted (p. 924-925), the TTI calculation is useful in determining: (1) how deep to expect to find preserved accumulations of oil, wet gas, or dry gas; (2) the aerial extent of source units that have entered the generative window; and (3) the timing of hydrocarbon generation.

The method proposed by Waples is useful in determining 1 and 2 of the preceding. It is inaccurate, however, for determining 3.

Figure 1 shows Waples' example of a burial-history diagram for three horizons A, B, and C. Table 1 shows his TTI calculations for these horizons. Let us focus on the curve for horizon A. Figure 1 shows a fairly constant accumulation rate during ~125 to ~80 m.y. At ~80 m.y., however, a short-lived uplift event occurred. This event was followed by a lower average accumulation rate during the final ~80 m.y. During this uplift event, horizon A rose from a temperature interval of 80 to 90°C to one of 70 to 80°C and then fell back through the 80 to 90°C interval (Fig. 1).

In estimating the interval and total TTI for horizon A, however, Waples erred in his estimation of time and temperature effects. He considered that because horizon A passed twice through the 70 to 80°C and 80 to 90°C temperature intervals, the amount of time spent in each of these temperature intervals (ΔTime) equals the sum of the amount of time spent in the first pass through plus the second pass through these temperature intervals. Therefore, in Table 1 he summed these values. Although this works for his choice of example, as a general rule it does not. This is because the second pass through the temperature intervals was (obviously) not coeval with the first pass, but rather some time later. Waples' approach results in an artificial increase in the Δ Time value that is calculated; this in turn is manifest as an erroneously optimistic TTI (Table 1).

The correct format for estimating TTIs is given in Table 3 and Figure 2. Figure 2 shows a burial-history curve for an arbitrary unit X. Accumulation was constant through the first 47 m.y., at which time an uplift event of unit X occurred. Following this uplift, renewed accumulation occurred during the span 40 to 0 m.y. Using Waples' approach (Table 2) we see that maturation (TTI = 15) occurred at 30.24 m.y., or after passing through the 100 to 110°C temperature interval. Using

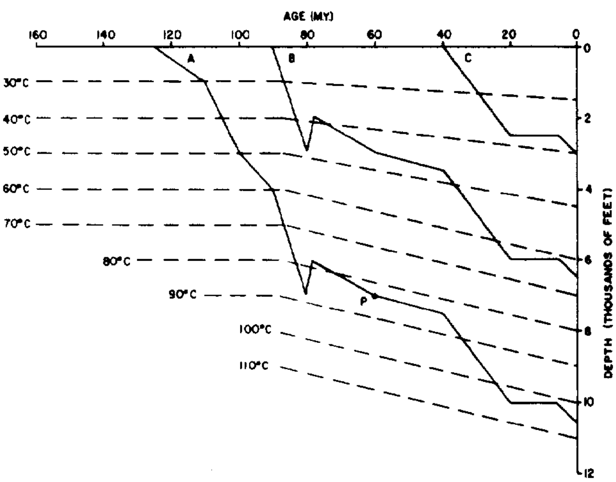

FIG. 1—Burial-history model for horizons A, B, and C (from Waples, 1980 (Fig. 6).

Table 1. Calculation of Present TTI for Horizon A

Temperature Interval (°C)	r^n	Δ Time (m.y.)	Interval TTI	Total TTI
20-30	2^{-8}	15	0.06	0.06
30-40	2^{-7}	5	0.04	0.10
40-50	2^{-6}	5	0.08	0.18
50-60	2^{-5}	10	0.31	0.49
60-70	2^{-4}	3.5	0.22	0.71
70-80	2^{-3}	(3.5 + 6.5)	1.25	1.96
80-90	2^{-2}	(4.5 + 37.5)	10.5	12.5
90-100	2^{-1}	10.5	5.3	17.8
100-110	2^{0}	24	24.0	41.8

From Waples (1980, Table 3).

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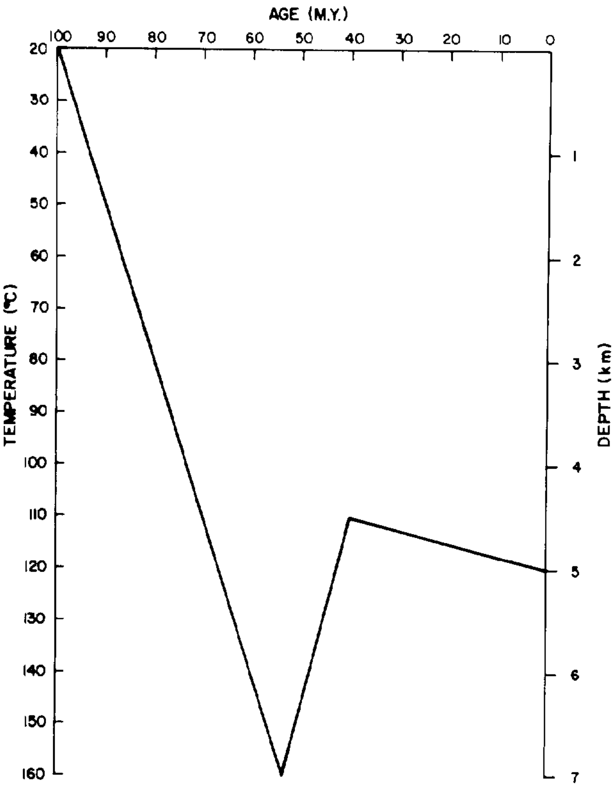

FIG. 2—Burial-history model for horizon X.

Table 2. Calculation of Present TTI for Horizon X by Waples' Method

Temperature Interval (°C)	r^n	Δ Time, (m.y.)	Interval TTI	Total TTI
20-30	2^{-8}	3.36	0.013	0.013
30-40	2^{-7}	3.36	0.026	0.039
40-50	2^{-6}	3.36	0.053	0.092
50-60	2^{-5}	3.36	0.105	0.197
60-70	2^{-4}	3.36	0.210	0.407
70-80	2^{-3}	3.36	0.420	0.827
80-90	2^{-2}	3.36	0.840	1.667
90-100	2^{-1}	3.36	1.680	3.347
100-110	2^{0}	3.36	3.360	6.707
110-120	2^{1}	3.36 + 2.26 + 40	91.92	98.627
120-130	2^{2}	3.36 + 2.6	23.84	122.467
130-140	2^{3}	3.36 + 2.6	47.68	170.147
140-150	2^{4}	3.36 + 2.6	95.36	265.507
150-160	2^{5}	3.36 + 2.6	190.72	456.227

the approach preferred here (Table 3), maturation (TTI = 15) occurred at 33.60 m.y., or after passing through the 110 to 120°C temperature interval.

The importance of this difference in method is clear: lumping the two (or more) fractions of the Δ Time (for a given temperature interval) as one earlier Δ Time yields artificially high total TTIs, and thus overly optimistic maturity estimates. The preferred method presented here does not suffer from this shortcoming. Although the difference in age of thermal maturity in this example is minor (3.36 m.y. difference), it clearly may be more significant elsewhere unless the exact time-temperature pathway is reproduced.

Either method may be used for the determination of whether a basin will be oil-, wet gas-, or dry gas-prone and the aerial extent of source units that have entered the generative window.

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Table 3. Preferred Method for Calculation of Present TTI for Horizon X

Temperature Interval (°C)	r^n	Time (m.y.)	Interval TTI	Total TTI
20-30	2^{-8}	3.36	0.013	0.013
30-40	2^{-7}	3.36	0.026	0.039
40-50	2^{-6}	3.36	0.053	0.092
50-60	2^{-5}	3.36	0.105	0.197
60-70	2^{-4}	3.36	0.210	0.407
70-80	2^{-3}	3.36	0.420	0.827
80-90	2^{-2}	3.36	0.840	1.667
90-100	2^{-1}	3.36	1.680	3.347
100-110	2^{0}	3.36	3.360	6.707
110-120	2^{1}	3.36	6.720	13.427
120-130	2^{2}	3.36	13.440	28.867
130-140	2^{3}	3.36	26.880	53.747
140-150	2^{4}	3.36	53.760	107.747
150-160	2^{5}	5.96	190.720	298.227
150-140	2^{4}	2.62	41.920	340.147
140-130	2^{3}	2.62	20.960	361.107
130-120	2^{2}	2.62	10.480	371.587
120-110	2^{1}	42.62	85.240	456.827