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Porosity and Thermal Maturity of Limestone Bodies in Jurassic Swift Formation, Williston Basin, North Dakota

by

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POROSITY AND THERMAL MATURITY OF LIMESTONE BODIES IN JURASSIC SWIFT FORMATION, WILLISTON BASIN, NORTH DAKOTA

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INTRODUCTION

This report describes the porosity and thermal maturity of limestone sand bodies in the lower part of the Swift Formation of northwestern North Dakota. Wire-line logs are the primary sources of data. The work reported here is part of an ongoing project to investigate the porosity of carbonate rocks in a wide variety of depositional and diagenetic settings.

The distribution, morphology, and depositional environment of basal Swift "carbonate" sand bodies have been investigated by Langtry (1982a, 1982b), who described them as elongate offshore bars deposited within the subtidal zone of a shallow shelf, cut in places by channel-like features, and enclosed by shaley sediments. These bodies can be recognized on wire-line logs as intervals of relatively low gamma-ray intensity and relatively high resistivity (fig. 1). They reach a maximum thickness of about 150 ft (45 m).

Reconnaissance work by Langtry (1982a) identified 53 apparently distinct Swift sand bodies in the western half of North Dakota. Her area of detailed study, which is adopted for this report, includes parts of Burke, Renville, Mountrail, and Ward Counties (fig. 2), where more than two dozen sand bodies of widely varying geometry and thickness are concentrated.

The Swift Formation is not a usual exploration target in North Dakota. Complete modern log suites through the Swift are uncommon. The only core Langtry (1982a) could locate (fig. 2) from a Swift sand body reveals a clean, coarsening-upward, packstone-grainstone facies composed mainly of well-rounded, sand-sized mollusk grains. Density, neutron, and acoustic logs also indicate that this cored body is a clean limestone.

Sand bodies in the basal Swift Formation all have roughly similar gamma-ray and resistivity signatures, and Langtry assumed that all are carbonate bodies like that penetrated by the cored well. However, data from available porosity logs, interpreted using standard two-log crossplots and the three-log M-N plot for mineral identification (Schlumberger, 1979), strongly suggest that in many places the sand bodies have appreciable shale and/or quartz contents.

The porosity-log data indicate that mineral composition varies from body to body and within a given body, and that the clean limestone sand recovered in the cored 1-35 Abrahamson well is atypical. The adjective "carbonate" is frequently not applicable to the sand bodies studied by Langtry (1982a, 1982b).

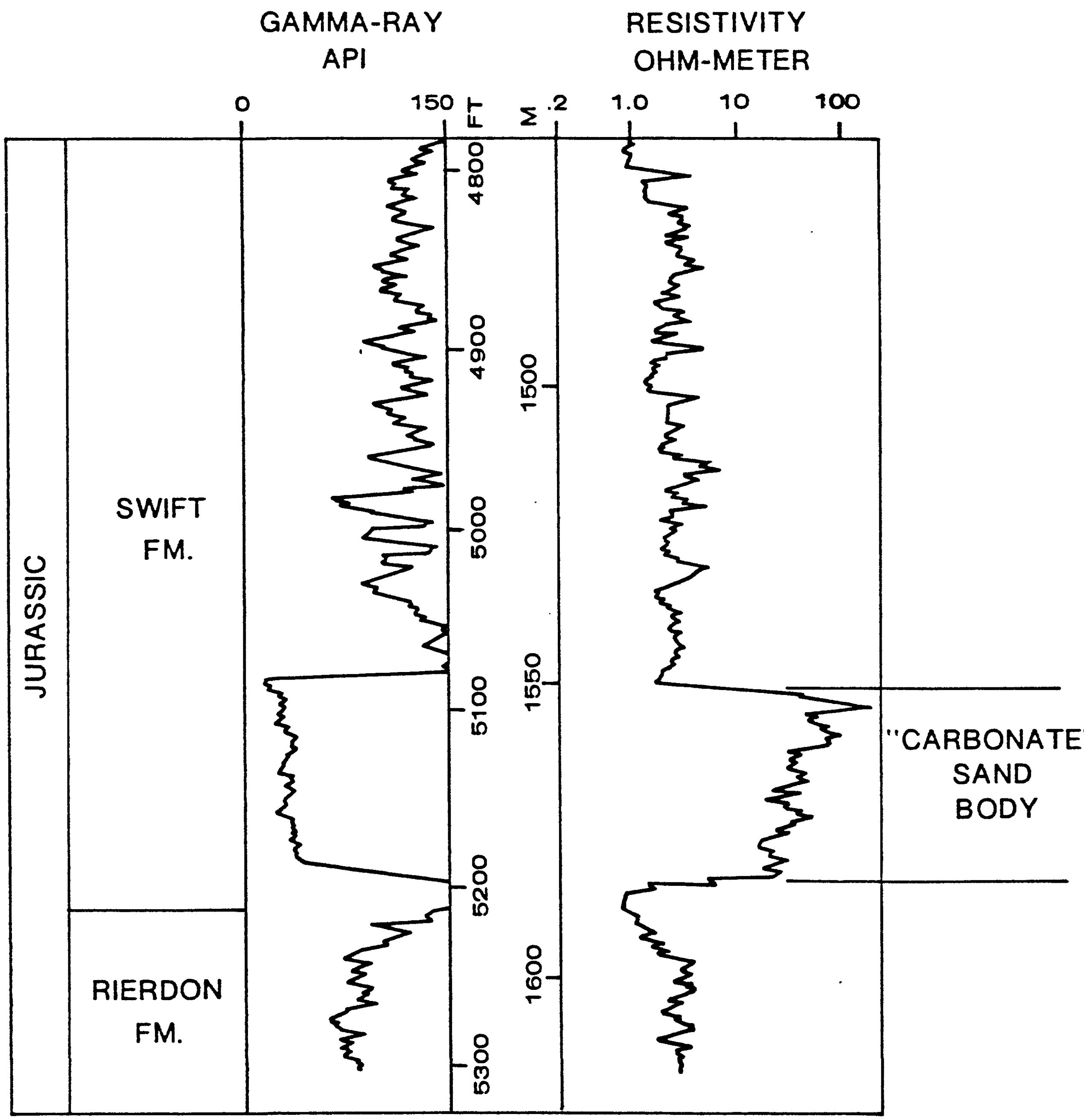

Figure 1.--Gamma-ray and resistivity signatures of a relatively thick lower Swift "carbonate" sand body. Well is the cored Terra Resources, Inc., 1-35 Abrahamson, Sec. 35, T155N, R88W. (After Langtry, 1982b).

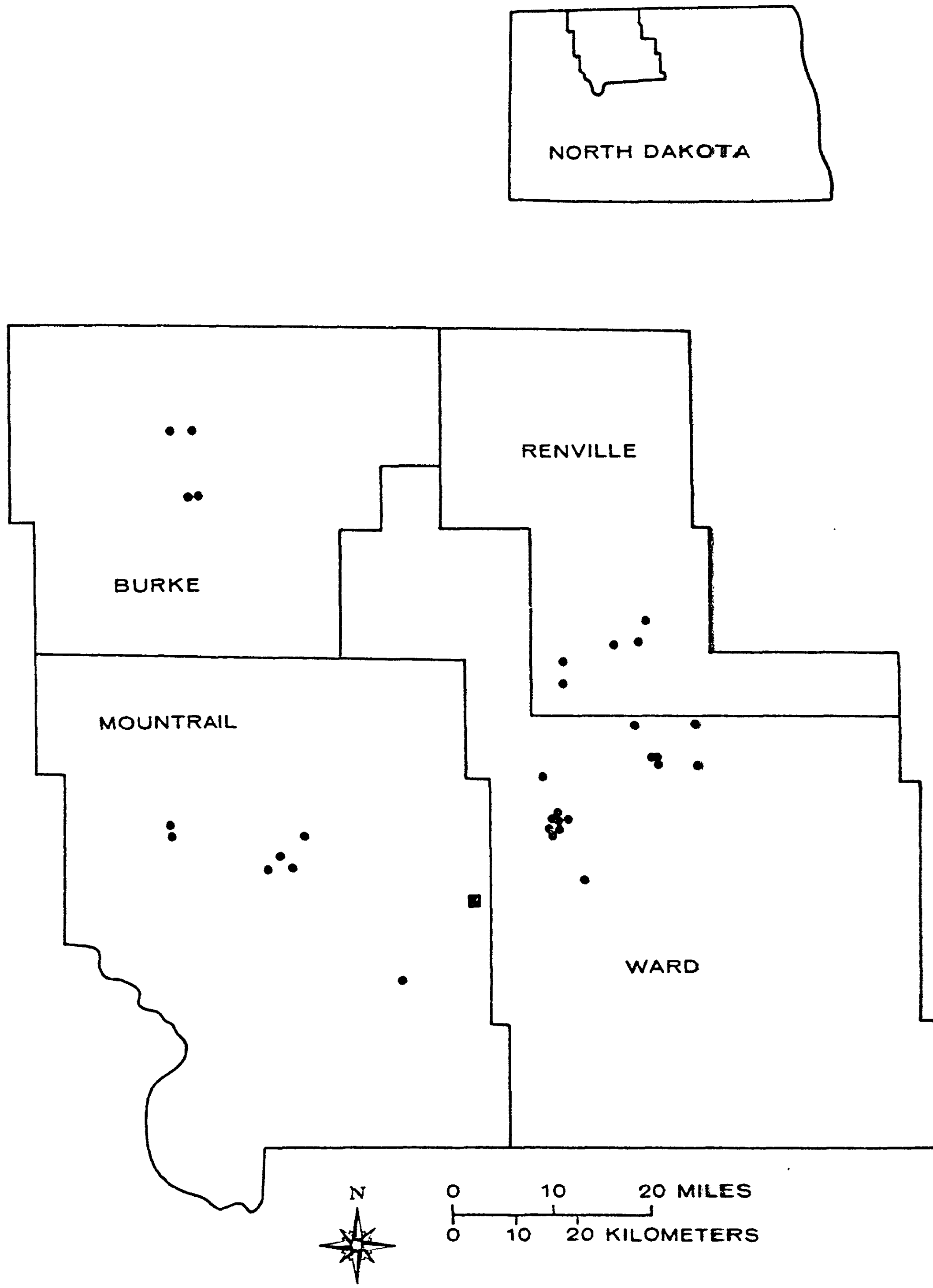

Figure 2.--Map of study area showing locations of cored well (square) and wells where porosity of limestone sand bodies is determined (circles). Wells are listed in Appendix.

DATA SET

The density, neutron, and acoustic logs examined in this study were found by methodically canvassing the list of wells given by Langtry (1982b). Data were relatively scarce because many of the listed wells predate development of modern porosity logs, and in the more recent wells, porosity logs were not often run in the Swift Formation. In addition, a significant proportion of the available porosity-log data in lower Swift sand bodies was not used in the present study because the interval penetrated is not a clean limestone. The following guidelines, empirically developed for this specific area and formation and reflecting the need to make the best of sparse log data, were applied to the initial data set to select Swift sand-body intervals of limestone, and to determine the porosity of these intervals:

1. Gamma-ray intensity (corrected to a 9-in. wellbore and 10.5-lb mud) was used as an indicator of terrestrial-clastic content. Intervals with a corrected gamma-ray intensity less than 43 API units were classified as "limestone."
2. The acoustic log was sensitive to minor amounts of shale in the "limestone" intervals. Travel time increased as gamma-ray intensity increased, and was thus considered an unreliable indicator of porosity and not used for that purpose.
3. The density log was least sensitive to minor lithology variations in Swift limestone intervals, and was the preferred log for porosity determinations. If the density log was not available, porosity was estimated from the neutron log, but with the additional requirement, due to the sensitivity of the neutron log to clay-bound water, that corrected gamma-ray intensity be less than 33 API units.

The final data set, obtained using the above guidelines, consists of 42 log intervals from 32 wells (fig. 2), and is tabulated in the Appendix. It is thought to be a representative sampling of lower Swift limestone sand bodies in the study area.

POROSITY

Porosities of basal Swift limestone sand bodies are relatively low, ranging from near zero to 12 percent, with most values falling between 2 and 8 percent (fig. 3). Burial depths range between 3,800 and 6,000 ft (1,160-1,830 m).

The plot of porosity versus depth of Swift limestone sand bodies in the study area (fig. 4) shows considerable scatter, reflecting local variations in the evolution of carbonate porosity. There is also a weak inverse correlation between porosity and depth (represented on figure 4 by an exponential regression curve). The decrease of porosity with depth is poorly defined in this small data set, and cannot be considered a fact. The authors speculate, however, that the effect is real and is analogous to that documented (with a much larger data set) for limestones of the South Florida basin (Schmoker and Halley, 1982). Following this premise, the porosity of basal Swift limestone bodies, considered in a generalized regional setting, reflects compaction, rather than depositional factors, with compaction used here in a broad sense to include all mechanisms of porosity loss after burial (Halley and Schmoker, 1982).

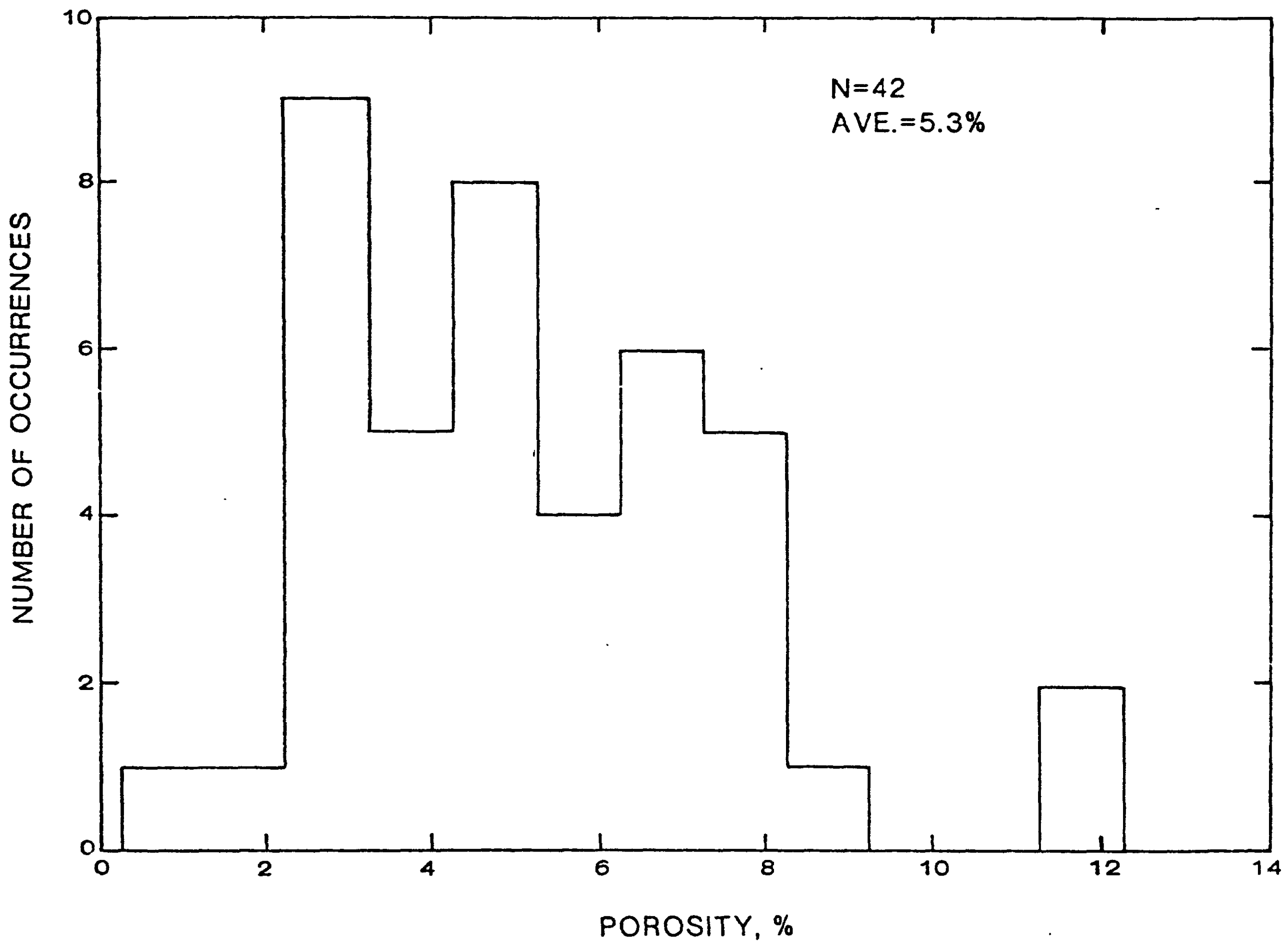

Figure 3.--Porosity distribution for Swift limestone bodies. Data are tabulated in Appendix and located on figure 2.

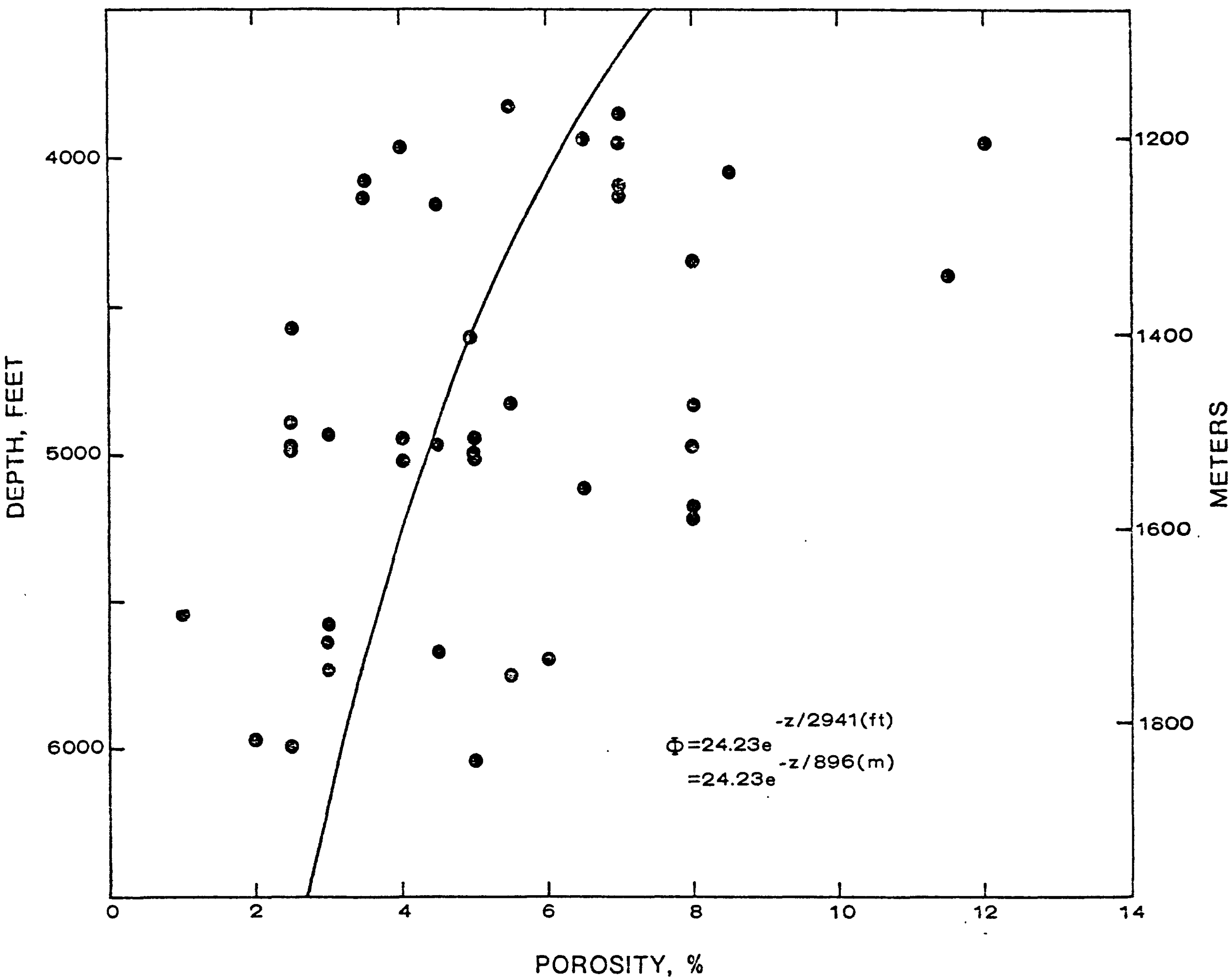

Figure 4.--Porosity-depth values and least-square exponential fit to Swift limestone data. The exponential regression curve has a correlation coefficient of -0.45 and a standard error of estimate (root-mean-square of porosity deviations about exponential curve) of 2.2%.

THERMAL MATURITY AND HYDROCARBON POTENTIAL

Values of Lopatin's time-temperature index (TTI) for estimating the thermal maturity of kerogen, and the temperature-age model from which these values are calculated, are shown for the Swift Formation in figure 5. The computation of TTI values follows Waples' (1980) approach, with the calculation and summing of the maturity acquired in each million-year interval done by computer. The temperature-age model (fig. 5) assumes a decline in mean surface temperature from 70°F (21°C) at deposition to the current value of 42°F (6°C), and a constant temperature gradient through time, equal to the present gradient, of 1.8°F/100 ft (3.3°C/100 m) (Geothermal Survey of North America Subcommittee, 1976).

Because the effect of temperature in the TTI calculation is exponential whereas that of time is linear, computed levels of organic metamorphism at low temperatures (shallow burial) are insignificant, even over long time spans (Gretener and Curtis, 1982). Thus, TTI values calculated for the first 100 million years of burial of the Swift Formation are so low (less than 0.6) that detailed temperature-age modeling of this interval is unnecessary. In addition, the assumption of a constant temperature gradient through time, dictated by a lack of data indicating otherwise, limits the resolution of the TTI calculation. For these reasons, it is felt that a temperature-age history more complex than the four straight-line segments of figure 5 would be superfluous.

Maturity values for the Swift Formation in the study area do not exceed 5 TTI units (fig. 5), a level well below the approximate oil-generation threshold of 15 TTI units (Waples, 1980). It is very unlikely that thermogenic hydrocarbons have been generated from organic matter within or in proximity to the Swift Formation in the study region.

The basal Swift sand bodies, isolated and enclosed in shaly sediments, could be effective stratigraphic traps. However, the general lack of oil reservoirs throughout the central Williston basin shallower than the depth of thermal maturity argues against oil migration from underlying thermally mature sources. It is possible that biogenic gas, generated from organic matter at low temperatures by anaerobic microorganisms, is trapped by lower Swift sand bodies (Langtry, 1982a). The likely average porosity of such reservoirs would be between 2 and 8 percent (fig. 3), which is low but could be adequate if natural fracture systems are present.

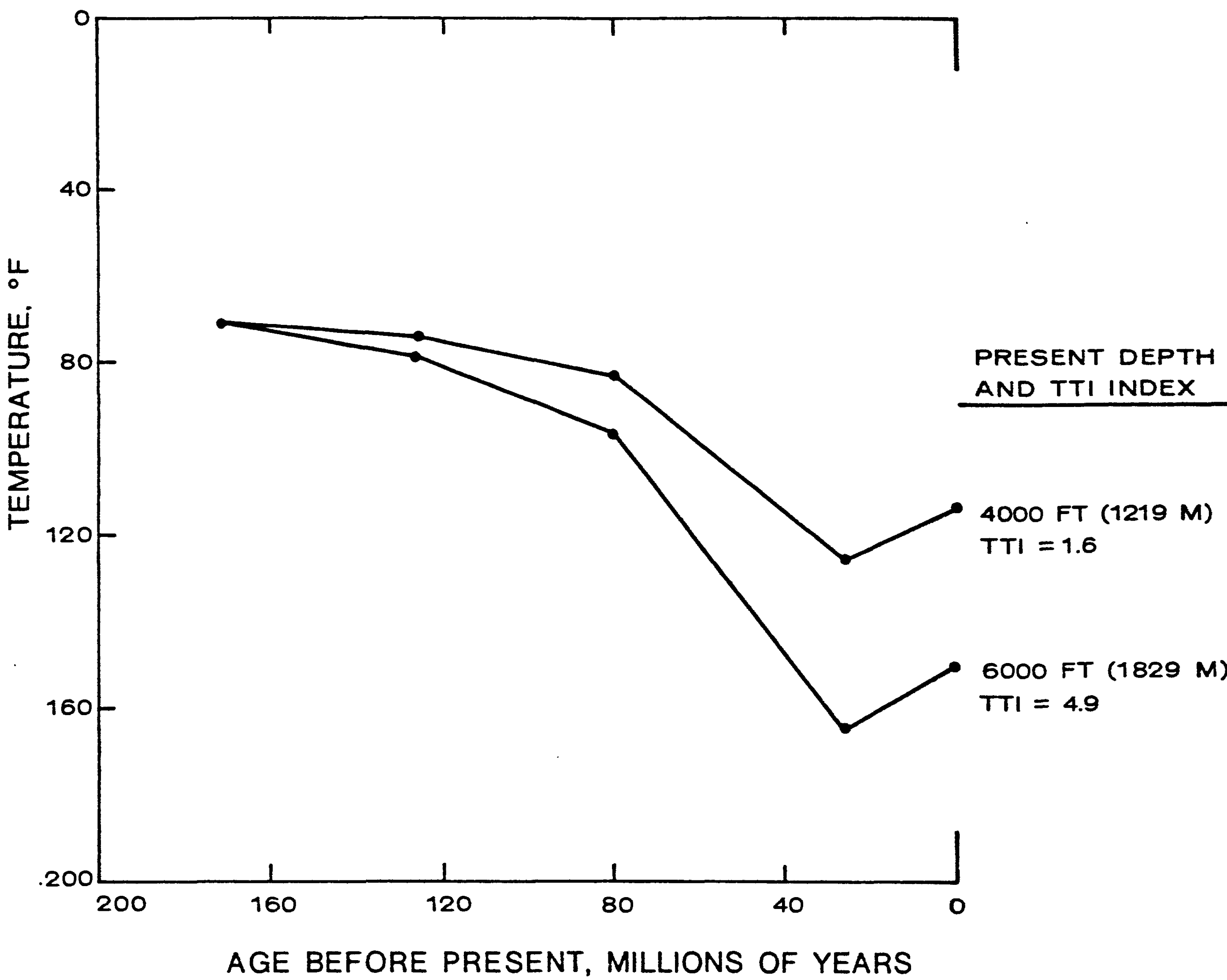

Figure 5.--Temperature-age model and Lopatin's time-temperature index (TTI) for Swift Formation in study area. °C=(°F-32)/1.8.

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APPENDIX

Wells and data used in the present study. "NO." is North Dakota Geological Survey well number; "NAME, LOCATION" lists well name, and location (in parentheses) by section, township, and range; "DEPTH" is top and bottom log depth, in feet and (meters), of limestone intervals; "POR." is average log-derived porosity of interval, to nearest one-half percent.

NO.	NAME, LOCATION	DEPTH	POR.
	(BURKE COUNTY)		
6081	Monsanto Co. 8-2 N.B.S.U. (15-162-92)	4,595 - 4,609 (1,400.6-1,404.8)	5.0
6397	Monsanto Co. 1 Owings (18-161-91)	4,977 - 4,988 (1,517.0-1,520.3)	2.5
7843	Monsanto Co. 1 Grandall (13-161-92)	4,956 - 4,964 (1,510.6-1,513.0)	8.0
8089	Texas Oil & Gas Corp. 1 Sawyer State (13-162-92)	4,559 - 4,572 (1,389.6-1,393.6)	2.5
	(MOUNTRAIL COUNTY)		
5088	Shell Oil Co. 21-35 Texel (35-156-93)	6,037 - 6,049 (1,840.1-1,843.7)	5.0
5333	Shell Oil Co. 44X-26 (26-156-93)	5,949 - 5,974 (1,813.3-1,820.9)	2.0
		5,974 - 6,001 (1,820.9-1,829.1)	2.5
6179[1/]	Terra Resources, Inc. 1-35 Abrahamson (35-155-88)	5,084 - 5,146 (1,549.6-1,568.5)	6.5
		5,146 - 5,192 (1,568.5-1,582.5)	8.0
6376	Thomson Petroleum, Inc. 2 Harstad et al (10-155-91)	5,623 - 5,650 (1,713.9-1,722.1)	3.0
		5,650 - 5,674 (1,722.1-1,729.4)	4.5
		5,674 - 5,715 (1,729.4-1,741.9)	6.0
6402	Thomson Petroleum, Inc. 1 Corpron-State (16-155-91)	5,749 - 5,755 (1,752.3-1,754.1)	3.0

1/ Cored.

NO.	NAME, LOCATION	DEPTH	POR.
6538	Thomson Petroleum, Inc. 1-14 Jellesed Federal (14-155-91)	5,737 - 5,750 (1,748.6-1,752.6)	5.5
6635	Brownlie, Wallace, Armstrong, and Bander 36-44 Hovda (36-156-91)	5,521 - 5,554 (1,682.8-1,692.9)	1.0
		5,554 - 5,578 (1,692.9-1,700.2)	3.0
7471	Marathon Oil Co. 10-21 Bartleson (10-153-89)	5,204 - 5,209 (1,586.2-1,587.7)	8.0
	(RENVILLE COUNTY)		
4943	Depco, Inc. 1 Anderson (26-159-85)	3,933 - 3,940 (1,198.8-1,200.9)	6.5
		3,940-3,952 (1,200.9-1,204.6)	12.0
5433	Kissinger Petroleum Corp. 9-28 Lewis (28-159-85)	4,041 - 4,048 (1,231.7-1,233.8)	8.5
6334	Tuthill & Barbee 1 G. Schultz et al (3-158-86)	4,376 - 4,382 (1,333.8-1,335.6)	11.5
6344	Sunbehm Gas, Inc. 1 Carlson (13-159-85)	3,801 - 3,840 (1,158.5-1,170.4)	5.5
		3,840 - 3,861 (1,170.4-1,176.8)	7.0
6371	Tuthill & Barbee 1 R.D. Johnson et al (15-158-86)	4,342 - 4,350 (1,323.4-1,325.9)	8.0
	(WARD COUNTY)		
6201	Caroline Hunt Trust Estate 1 Helseth (2-157-85)	4,065 - 4,080 (1,239.0-1,243.6)	3.5
		4,080 - 4,086 (1,243.6-1,245.4)	7.0
6459	Hunt Energy Corp. 1 Kilene (22-155-86)	4,960 - 4,966 (1,511.8-1,513.6)	4.5
6502	North Central Oil Corp. 1 Linnertz (2-157-84)	3,941 - 3,946 (1,201.2-1,202.7)	7.0
6932	Samedan Oil Corp. 1 Kliser (20-156-86)	4,806 - 4,821 (1,464.9-1,469.4)	5.5
		4,821 - 4,836 (1,469.4-1,474.0)	8.0

NO.	NAME, LOCATION	DEPTH	POR.
7009	Inexco Oil Co. 1-30 Gary (30-156-86)	5,014 - 5,018 (1,528.3-1,529.5)	4.0
7043	Inexco Oil Co. 1-32 Norgard (32-157-86)	4,873 - 4,881 (1,485.3-1,487.7)	2.5
7695	Inexco Oil Co. 2-30 Federal Deaver (30-156-86)	4,983 - 4,993 (1,518.8-1,521.9)	5.0
7698	Inexco Oil Co. 1-19 Emma (19-156-86)	4,916 - 4,931 (1,498.4-1,503.0)	3.0
		4,931 - 4,941 (1,503.0-1,506.0)	5.0
????	Inexco Oil Co. 1-19 Henry (19-156-86)	4,968 - 4,981 (1,514.2-1,518.2)	2.5
7910	Marathon Oil Co. 26-31 Stordal (26-157-84)	3,947 - 3,956 (1,203.0-1,205.8)	4.0
8056	Inexco Oil Co. 2-19 Caroline (19-156-86)	4,936 - 4,940 (1,504.5-1,505.7)	4.0
8376	Inexco Oil Co. 3-30 Federal-Gary (30-156-86)	4,990 - 4,996 (1,521.0-1,522.8)	5.0
8578	Petroleum, Inc. 1 Rudie (19-157-84)	4,119 - 4,132 (1,255.5-1,259.4)	7.0
8763	Petroleum, Inc. 1 Streitz (19-157-84)	4,134 - 4,138 (1,260.0-1,261.3)	3.5
8790	Petroleum, Inc. 2 Rudie (19-157-84)	4,148 - 4,151 (1,264.3-1,265.2)	4.5