GEOLOGY AND ESTIMATED RECOVERABLE GAS RESERVES OF THE NORTH SLOPE (ONSHORE) OF ALASKA.

by
Dr. James D. Lowell
Consulting Geologist
Denver, Colorado
June 28, 1976

Introduction

The purpose of this report is to demonstrate that, based on known geologic conditions, estimated remaining recoverable gas reserves of the Alaska North Slope (onshore), while significant, are less than previous estimates that did not properly take critical geologic relationships into account.

The report is divided into two major parts, first, discussion of North Slope geology with emphasis on the Prudhoe Bay accummulation, and second, consideration of North Slope gas reserves. Discussed briefly are three other sedimentary basins, Yukon Kandik, Middle Tanana, and Copper River, which are on or relatively near the proposed Alcan route (Pl. 1), but have much less potential than the North Slope for major gas reserves.

North Slope Geology

The general configuration of the North Slope Basin is defined by structure contours which are drawn on top of basement and show a strongly asymmetric trough deepest along the western end of the Brooks Range (Pl. 2). Exploratory well control and oil and gas fields are also plotted. As of January 1, 1975, fifty-two exploratory wells were drilled between the Arctic National Wildlife Range and Naval Petroleum Reserve Number 4. In addition, thirty-seven test wells and forty-five core holes were drilled on NPR-4 in the time period of 1945-1955. During 1975, thirteen more exploratory wells were drilled, including two on NPR-4. Two additional exploratory wells were drilling at the year's end. Drilling thus far has established two important facts: 1) the giant Prudhoe Bay oil and gas field, located more than 150 miles from the deepest part of the basin is the only field being commercially developed at this time; and 2) a very special combination of structure, reservoir, unconformity, and source rock has led to the large hydrocarbon accumulation at Prudhoe and this combination is unlikely to occur anywhere else onshore west of the Canning River.

Plate 3 shows a diagrammatic cross-section from the Brooks Range to the Barrow Arch on which Prudhoe field is located (see Pl. 2 for line of section A-A'). The main reservoir is porous and permeable sandstone of the Sadlerochit Formation of Triassic and Permian age. In the Prudhoe Bay portion of the Barrow Arch, Lower Cretaceous marine shales have been deposited above an unconformity (erosion surface) which has cut progressively across older rocks such that Lower Cretaceous shale lies directly on Triassic-Permian reservoir. This is the single most important relationship for the entrapment of petroleum at Prudhoe as can be seen from the following discussion.

According to geochemical studies (Pl. 4) the Lower Cretaceous marine shale has the highest content of organic matter and is by far the best source rock in the entire North Slope stratigraphic section to supply hydrocarbons to potential surrounding reservoirs. The Jurassic marine shale is also a good source rock, but it is not in contact with all the Prudhoe Bay reservoirs (which, in addition to the Sadlerochit, include the Upper Jurassic Kuparuk River sandstone, Lower Jurassic Sag River sandstone, and Pennsylvanian-Mississippian Lisburne carbonate rocks) as is the Lower Cretaceous shale. Furthermore, the presence of an impermeable zone at the top of the Triassic (Shublik Formation shales and limestones) restricts migration from the potential Jurassic source into the underlying Sadlerochit. Morgridge and Smith (1972) found that all pre-Jurassic rocks investigated have low oil-generating potential. It is critical, then, for a Prudhoe-type and size accumulation that rich Lower Cretaceous marine shales be juxtaposed with potential reservoirs, particularly Sadlerochit sandstones to allow migration of hydrocarbons from the shale into the sandstone. The shale, in turn, serves as an impervious seal for hydrocarbons trapped in the sandstone. The juxtaposition must also take place where the Lower Cretaceous is thin for only here has organic material (the precursor to petroleum) been highly concentrated. To the south where the Lower Cretaceous is much thicker, organic material is more finely disseminated and the unit is not a good source rock. This difference in source rock capability is indicated on Plate 3 by a color contrast within the Lower Cretaceous between the organically rich thin marine shale and the organically lean thick more continental rocks.

A sequential evolution of North Slope geology emphasizing the Prudhoe Bay Field is given on Plate 5. In stage A the main Permian-Triassic reservoirs were derived from what is presently the north. Southward spreading and laterally migrating braided streams resulted in a highly porous and permeable uniform blanket deposit over the entire field area (Morgridge and Smith, 1972). During Upper Jurassic-Lower Cretaceous uplift in stage B much of the earlier Paleozoic-Triassic deposits were eroded in the vicinity of Prudhoe and had more of the Permian-Triassic been cut out, as indeed it has been to the east, the Prudhoe Bay field would not exist today. In Cretaceous time (stage C) thrusting caused the Brooks Range to rise in the south which in turn furnished sediments that were shed to the north and provided source and seal shales across the Prudhoe structure. Continued sediment supply from the south and sagging of the continental margin on the north throughout the Late Cretaceous and Tertiary (stage D) has brought the North Slope to its present configuration wherein the thickest Tertiary section is developed offshore. A thickness of 8000 feet of Upper Cretaceous-Tertiary sediments has buried Lower Cretaceous source rocks deeply enough that higher temperatures and compaction at those levels have respectively generated petroleum and squeezed it into adjacent reservoirs.

A cross-section through NPR-4 (Pl. 6) demonstrates that the ingredients to create another Prudhoe Bay Field are lacking there. Permian-Triassic reservoirs are missing because of onlap on the pre-Mid-Devonian basement to the north and they are not in contact with Lower Cretaceous sourcing shales.

Plate 7 summarizes the possibility of locating another field comparable to the Prudhoe Bay Field. The northern distribution of the Permian-Triassic Sadlerochit reservoir sandstones is shown as being limited by truncation on the east and onlap on the west in NPR-4. The probability of another Prudhoe-type accumulation existing along the Sadlerochit zone of truncation is greatest offshore, but the difficulty of developing offshore fields in the Arctic and the problem of building gas pipelines through the scoring, gouging and plowing zones may considerably prolong the time when any such field, if found, can become available as a source of gas to the lower 48. From the structure contours on Plate 7, it can be seen that the Prudhoe structure has drained hydrocarbons over a great distance, especially from the south and east; a very substantial drainage area is another condition that must exist for a large accumulation of hydrocarbons. The onlap distribution of the Sadlerochit (Pl. 7) taken in conjunction with the lack of contact of the Sadlerochit with the Lower Cretaceous source shale (Pl. 6) reveals that the chance for a Prudhoe-type accumulation in NPR-4 is virtually nil.

Estimated Recoverable Gas Reserves

Considering the poor likelihood for a gas accumulation comparable to the size of Prudhoe to be found anywhere onshore on the Alaska North Slope west of the Canning River, estimated reserves of future recoverable gas, especially gas that is economically producible, should be carefully tempered. For example, the only other gas field of any size on the North Slope is Gubik (Pl. 2) with estimated reserves of 300 billion cubic feet. This field, however, has never been produced. Moreover, the reservoir at Gubik is lower Upper Cretaceous shoreline sandstone and comparable Cretaceous sandstones in the Oumalik well to the west (Pl. 2) have poor reservoir quality. "The reservoirs (at Oumalik) are poor because of the excessive amount of carbonate (calcite and particularly dolomite) cement present. Furthermore, in all but three samples, the primary pore pattern is unfavorable, because well over 60 percent of the pore wall area is coated with clay" (Robinson, 1956). These cementation and clay-plugging problems are likely to plague the bulk of Cretaceous reservoirs on the North Slope.

It is evident from the foregoing that information is sufficient to reveal the geologic parameters which control the occurrence of large hydrocarbon accumulations on the onshore North Slope of Alaska. Exploration is sufficiently advanced to invalidate the volumetric reserve assessment approach. This is a technique most frequently used in frontier areas where no well control is available, in which volume of sediment (completely lumped together without regard to its lithologic makeup) is multiplied by a recovery number (X cubic feet of gas per cubic unit - taken from some producing basin or basins) to yield estimated reserves. In the absence of any geologic information other than rough basin size and thickness of sedimentary section, the volumetric method may be acceptable but later experience proves it is almost always too high. Where geologic control is available estimations by volume should be avoided. Clearly, the speculative recoverable 41.8 trillion cubic feet of gas for the onshore North Slope estimated by Klein et al, (1974) using the volumetric method (modified in some unspecified way) is too high.

Later estimates of undiscovered recoverable reserves of gas on the onshore North Slope made by the United States Geological Survey (Miller et al, 1975) are based on more geological input and seem more reasonable:

95% probability that at least this much is present	Statistical Mean	5% probability that at least this much is present
14 TCFG	28 TCFG	49 TCFG

In good accord with the USGS estimates, I consider the most likely ultimate recoverable undiscovered gas reserves for the entire onshore North Slope are in the range of 25 trillion cubic feet of gas. Of this amount, only about one half will be available to exploration because the remaining one half is probably located beneath the Arctic National Wildlife Range. Furthermore, the timing of discovery of much of the available gas reserves may be many years in the future because of the remoteness, weather severity and harsh operating conditions associated with arctic exploration and production.

Other Possible Gas Reserves

Three other sedimentary basins (Yukon-Kandik, Middle Tanana, and Copper River) lie athwart or near the route of the Alcan pipeline. The first well Louisiana Land & Exploration Company, Doyon Ltd. No. 1, Sec. 32, T 10N, R 27E to be drilled in the Yukon-Kandik Basin is located about 150 miles northeast of Fairbanks and is currently drilling below 8000 feet as part of a four well exploratory program for this region. The presence of several volcanic sequences detracts from the prospectiveness of the Yukon-Kandik Basin. It is of interest that the Alaska Scouting Service (May 26, 1976) reported that "some very hard formations have reportedly made for slow drilling" in the well now underway.

The only deep well in the Middle Tanana Basin is the Union Oil Company of California Nenana No. 1 (Sec. 7, T 4S, R 10W) which was drilled to a depth of 3062 feet after having penetrated approximately 3000 feet of non-marine Tertiary rocks before bottoming in the Birch Creek schist. This well together with the fact that the basin is simply an alluvial plain punctuated with monadnocks or small hills of basement clearly rules out the presence of significant gas reserves.

Eight holes, ranging in depth from 2793 to 8837 feet, have been drilled in the Copper River Basin. All of the wells were dry with no reported shows of oil or gas and no drill stem tests conducted.

Even limited geologic information makes highly suspect the volumetrically derived speculative reserves of

11.4 TCFG for the Yukon-Kandik Basin and 1.2 TCFG for the Copper River Basin (Klein et al, 1974). In much better accord with the geologic observation that reservoir rocks are poor in all three basins is the U.S.G.S. estimate (Miller et al, 1975) of recoverable gas reserves ranging from 0 (95% probability) to 5 (5% probability) TCFG with a statistical mean of 2 TCFG for <u>all</u> of the interior basins of Alaska (excludes North Slope and Gulf of Alaska). The proposed Alcan pipeline is ideally routed to deliver the anticipated amounts of gas that may be found in the Yukon-Kandik, Middle Tanana, and Copper River basins.

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KEY WELLS

NORTH SLOPE BASIN

Gulf Oil Corporation - Colville Delta State #1
Mobil-Phillips-SOCAL - West Staines State 18-9-23
Atlantic Richfield Co. - North Prudhoe Bay State #1
Mobil-Phillips - Mikkelsen Bay State #13-9-19
Home Oil Co. - Bush Federal #1
Union Oil Co. of California - Kalubik Creek #1
Shell Oil Company - Lake 79 Federal No. 1
Atlantic Richfield Co. - West Sak River State #1
Placid Oil - PLAGHM Beechey Point #1
Mobil Oil Corp. - Beli Unit #1
BP Oil Corporation - Sag Delta 31-11-16
Texaco, Inc. - W. Kurupa #1
Texaco, Inc. - East Kurupa Unit #1
Atlantic Richfield - Nora Federal No. 1
Atlantic Richfield Co. - Susie Unit No. 1
Pan American Petroleum Corp. - Kavik No. 1
Exxon - Canning River Unit B-1
Texaco, Inc. - West Kavik Unit No. 1
Mobil - West Staines State #2
Humble Oil & Refining Co. - East Mikkelsen Bay State #1
Mobil Phillips - Kadler State 15-9-16
Exxon Corp. - Alaska State A#1
Atlantic Richfield Co. - Delta State No. 1
Atlantic Richfield - Prudhoe Bay State No. 1
Hamilton Brothers - Kup Delta 51-1
Sinclair Oil & Gas Co. - Colville No. 1
U. S. Navy - Cape Halkett #1
Forest Oil Corp. - Lupine Unit #1
Exxon Corp. - Canning River Unit Block A#1
AMOCO Production Co. - Aufeis Unit #1
Atlantic Richfield Co. - Kavik Unit #3
Atlantic Richfield Co. - Kavik Unit #2
Mobil Oil Corp. - Echooka Unit #1
Forest Oil Corp. - Kemik Unit #1
McCulloch Oil Corp. - Fin Creek Unit #1
Atlantic Richfield Co. - Lake State No. 1 (24-10-15)
Hamilton Bros., et al., Milne Point 18-1

YUKON-KANDIK BASIN

Louisiana Land & Exploration Co. - Doyon Ltd. #1

MIDDLE TANANA BASIN

Union Oil Co. of California - Nenana No. 1

COPPER RIVER BASIN

Aledo Oil Co. - Alaska O&G Dev. Co. - Eureka No. 1
Union Oil Co. of California - Tazlina Unit No. 1
Aledo Oil Co. - Eureka #2
Pan American Petroleum Corp. - Moose Creek Unit No. 1
Mobil Oil Company - Salmon Berry Lake Unit No. 1
Consolidated Oil & Gas, Allied & Embassy Miami - Tawawe Lake Unit #1
Atlantic Refining Co. - Rainbow No. 1
Atlantic Refining Co. - Rainbow Federal No. 1

LIST OF ILLUSTRATIONS

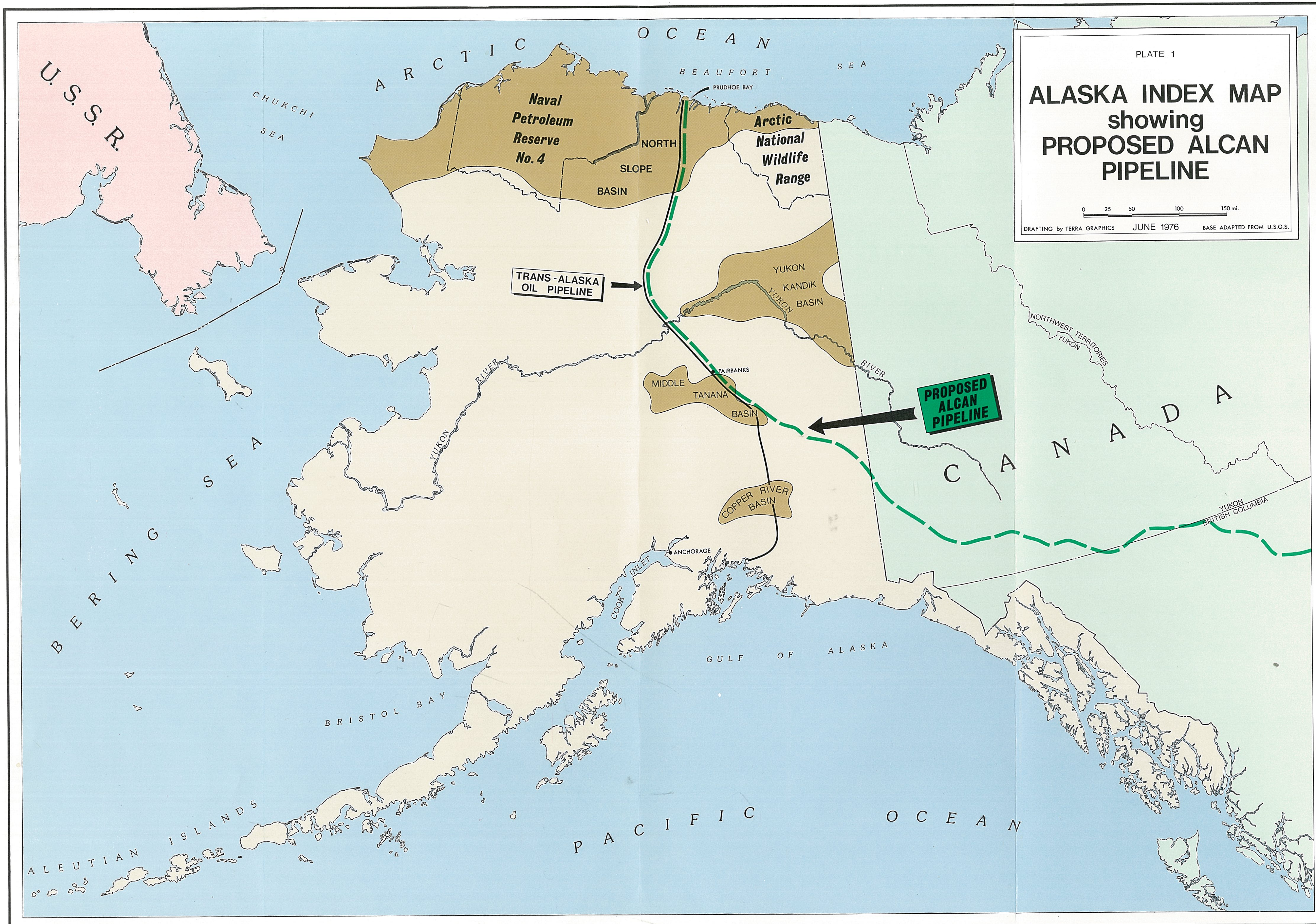
PLATE 1
ALASKA INDEX MAP showing PROPOSED ALCAN PIPELINE
0 25 50 100 150 mi.
DRAFTING by TERRA GRAPHICS
JUNE 1976
BASE ADAPTED FROM U.S.G.S.
ARCTIC OCEAN
BEAUFORT SEA
CHUKCHI SEA
PRUDHOE BAY
U.S.S.R.
Naval Petroleum Reserve No. 4
NORTH SLOPE BASIN
Arctic National Wildlife Range
TRANS-ALASKA OIL PIPELINE
YUKON KANDIK BASIN
YUKON
FAIRBANKS
MIDDLE TANANA BASIN
PROPOSED ALCAN PIPELINE
RIVER
NORTHWEST TERRITORIES
YUKON
CANADA
YUKON RIVER
BERING SEA
COPPER RIVER BASIN
ANCHORAGE
COOK INLET
YUKON
BRITISH COLUMBIA
GULF OF ALASKA
BRISTOL BAY
ALEUTIAN ISLANDS
PACIFIC OCEAN

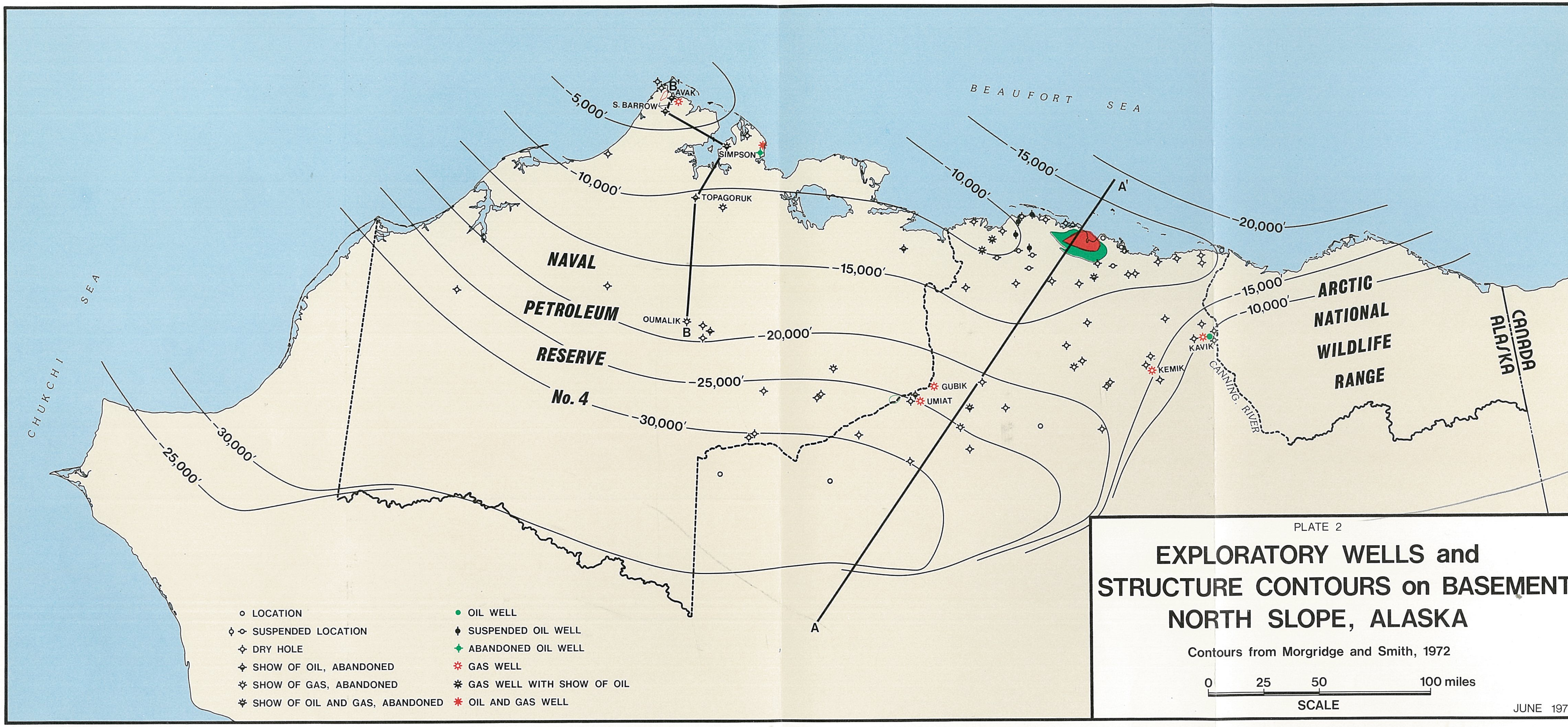

PLATE 2

EXPLORATORY WELLS and STRUCTURE CONTOURS on BASEMENT NORTH SLOPE, ALASKA

Contours from Morgridge and Smith, 1972

JUNE 1976

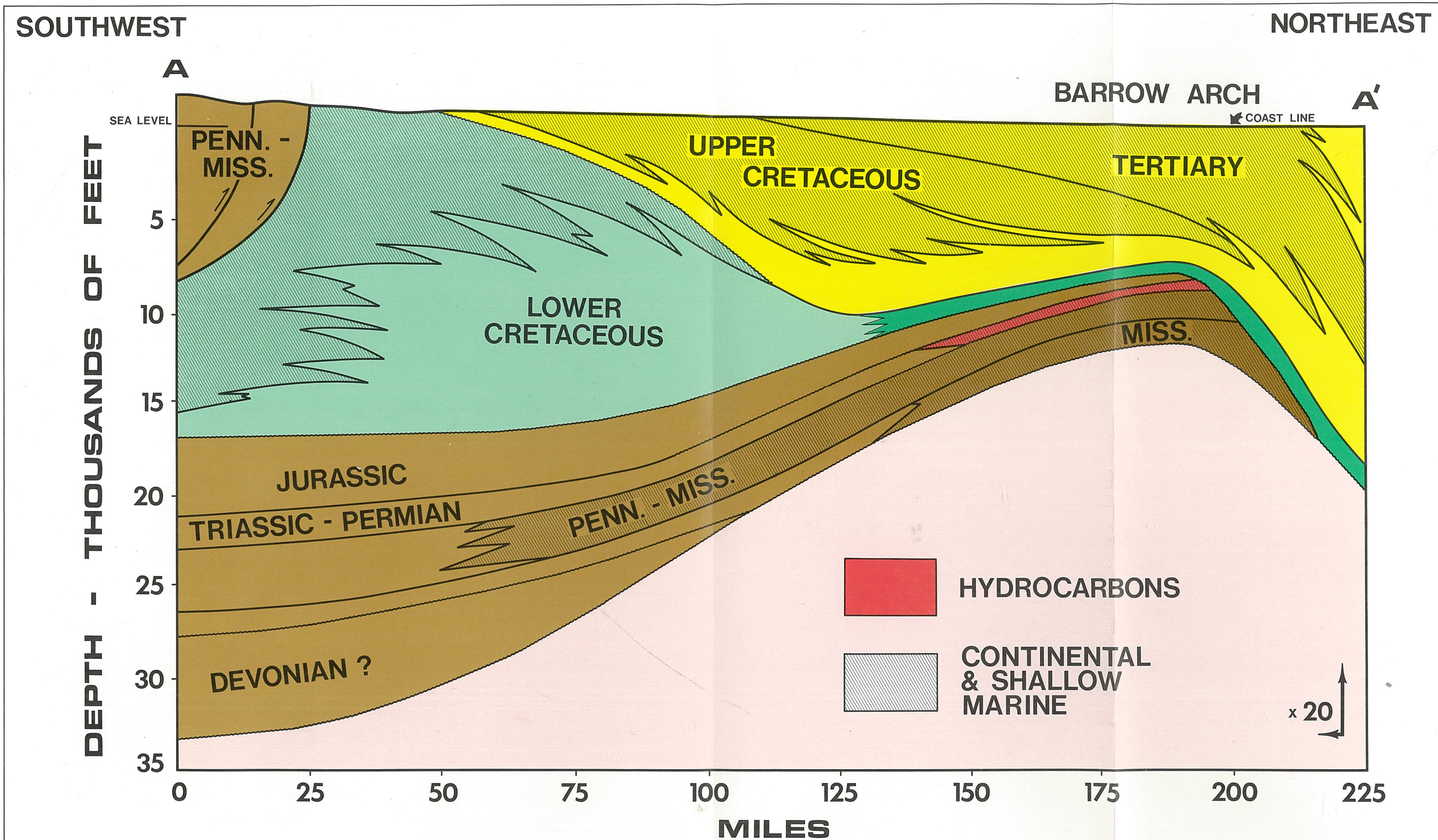

PLATE 3

SCHEMATIC CROSS SECTION THROUGH PRUDHOE BAY

(MODIFIED FROM MORGRIDGE & SMITH 1972)

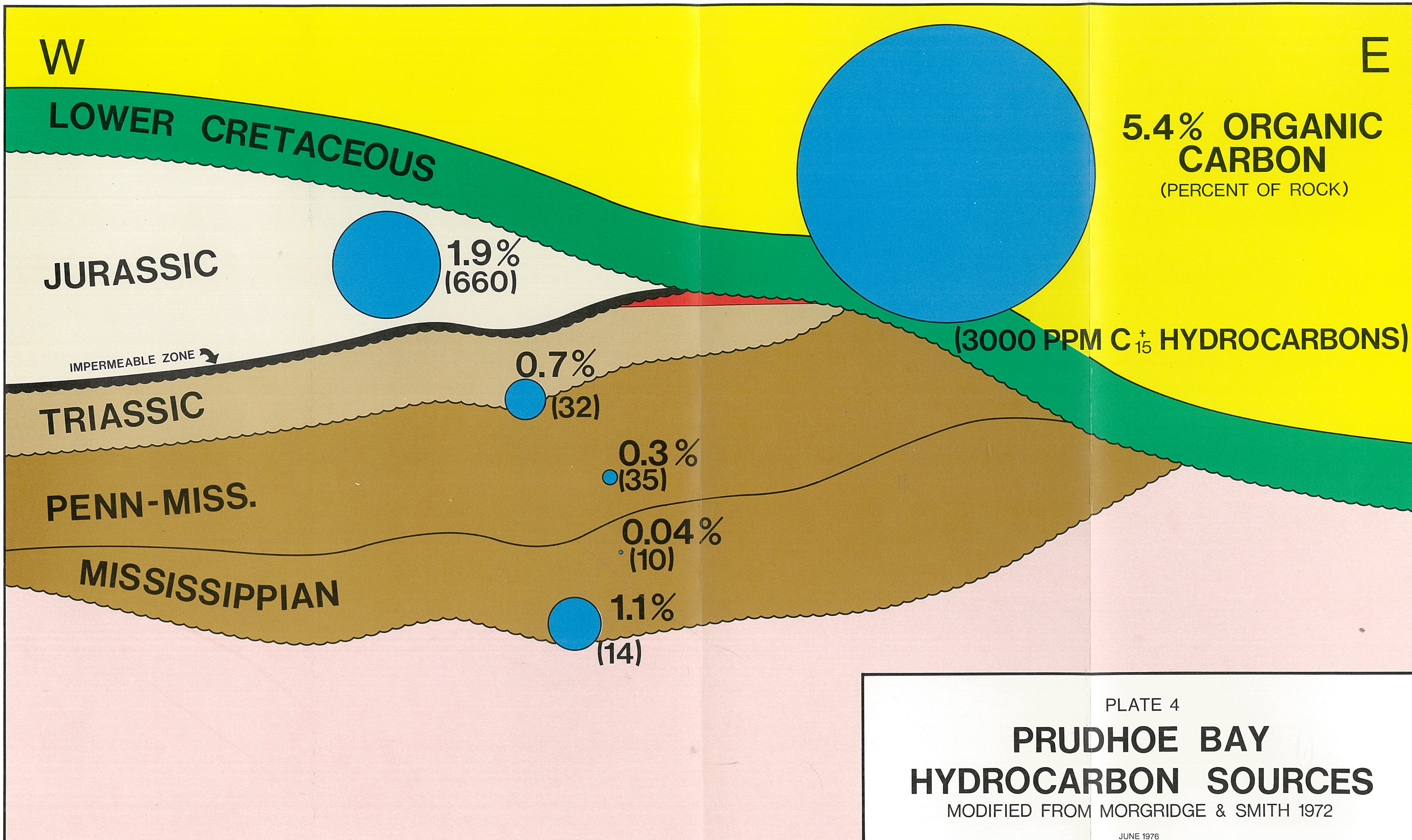

PLATE 4

PRUDHOE BAY HYDROCARBON SOURCES

MODIFIED FROM MORGRIDGE & SMITH 1972

JUNE 1976

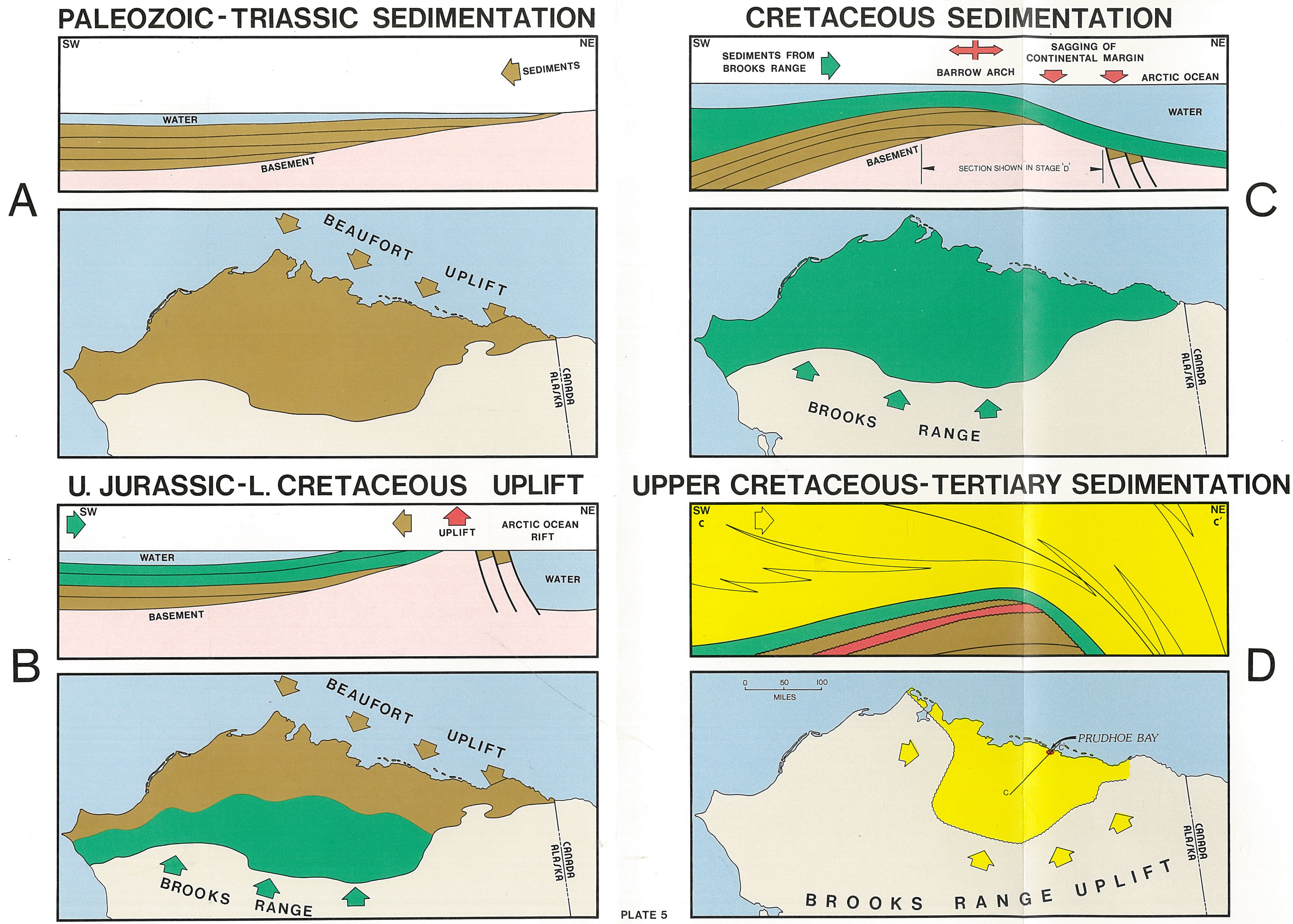

PLATE 5

EVOLUTION OF NORTH SLOPE GEOLOGY

MODIFIED FROM RICKWOOD 1970 – MORGRIDGE & SMITH 1972

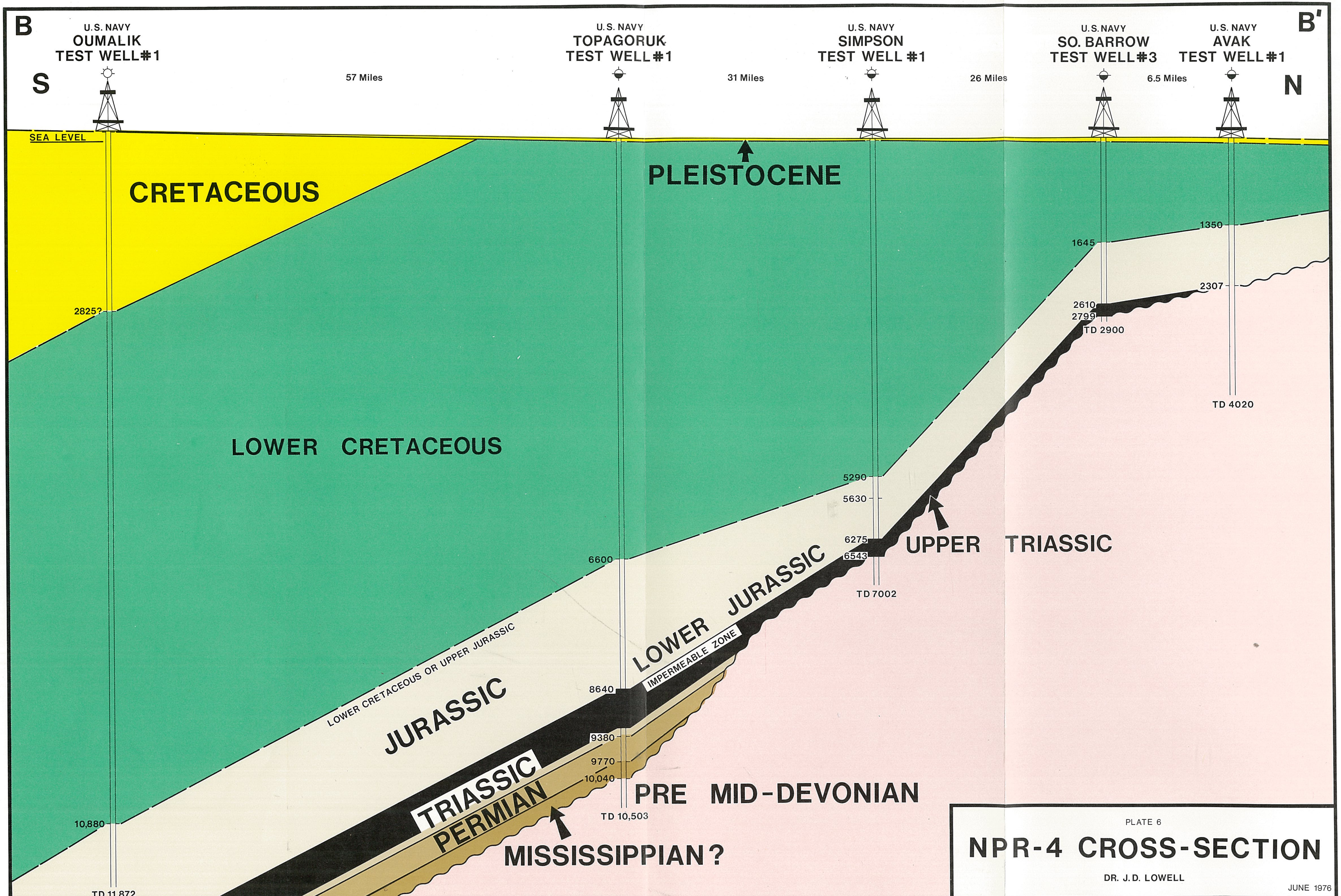

PLATE 6

NPR-4 CROSS-SECTION

DR. J.D. LOWELL

JUNE 1976

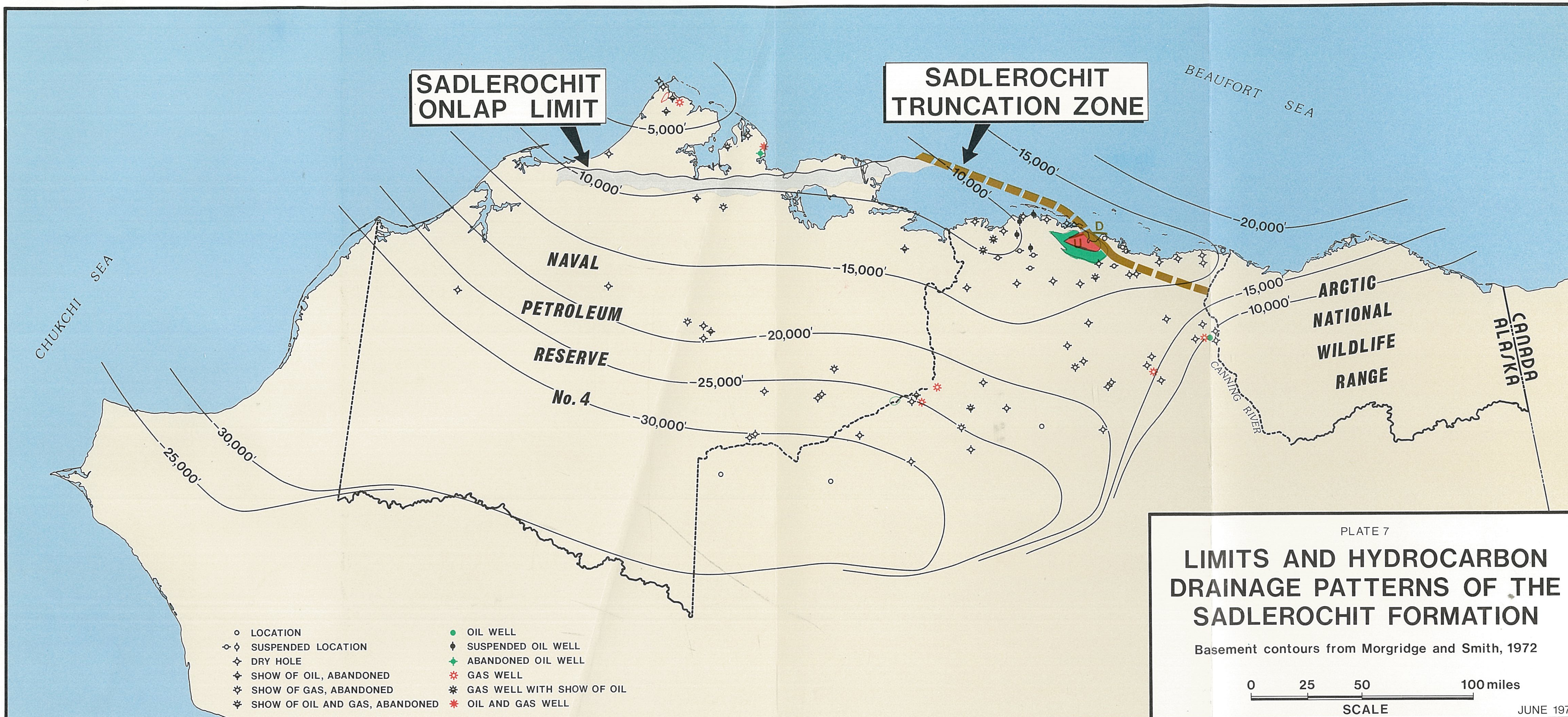

PLATE 7

LIMITS AND HYDROCARBON DRAINAGE PATTERNS OF THE SADLEROCHIT FORMATION

Basement contours from Morgridge and Smith, 1972

JUNE 1976

AREY LAGOON
KAKTOVIK LAGOON
JAGO LAGOON
CANNING
KATAKTURUK
HULAHULA
OKPILAK
JAGO
BEAUFORT
LAGOON
AICHILAK
DEMARCATION BAY