PETROLEUM EXPLORATION OF NPRA, 1974-1981
Final Report

VOLUME 1

TGZ 0170

PETROLEUM EXPLORATION

OF NPRA, 1974-1981

FINAL REPORT

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USGS-Husky Contract No. 14-08-0001-16474
Husky-Tetra Tech Subcontract No. GC-81-5
Tetra Tech Report No. 8200

March 31, 1982

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INTRODUCTION

The National Petroleum Reserve in Alaska (NPRA), a federal petroleum reserve on the Alaskan North Slope, covers over 36,000 sq mi (93,240 sq km), extending from the Colville River westward to the 162° parallel and northward to the Chukchi and Beaufort Seas (fig. 1). Petroleum exploration activity in this area from 1944 through 1981 focused on acquiring seismic reflection, gravity, and aeromagnetic data, and drilling test and development wells. This activity is summarized in table 1. The wells drilled are identified in Appendix A.

The U. S. Navy conducted the first full-scale exploration program on the Reserve. Work on this program, called "Pet-4," began in 1944, 21 years after an Executive Order established the Reserve and called it Naval Petroleum Reserve No. 4 (NPR-4). The program, which ended in 1953, resulted in the drilling of 45 shallow core-test wells and 36 test wells, including four in the Barrow area. Additionally, the Navy acquired nearly 3,400 line miles of seismic reflection data, nearly 400 seismic refraction profiles, gravity data from more than 6,000 stations, and 12,600 flight line miles of aeromagnetic data. These data provided a data base for subsequent exploration on the North Slope. Discoveries reported included three oil fields (Umiat, Fish Creek, and Simpson) and two gas fields (South Barrow and Gubik).

The Navy started its second NPR-4 exploration program in 1972 and, from 1974 to June 1977, completed seven test wells outside the Barrow area, nearly 7,700 line miles of seismic surveys, and gravity surveys at more than 30,000 stations. In April 1976, jurisdiction of the Reserve was transferred from the Secretary of the Navy to the Secretary of the Interior, as mandated by Public Law 94-258; the name of the Reserve was changed to National Petroleum Reserve in Alaska. The exploration program was assigned to the U. S. Geological Survey on 1 June 1977.

The Survey continued to explore and evaluate NPRA petroleum resources, develop the South Barrow gas field and produce gas, and rehabilitate areas disturbed by previous exploration efforts. As a basis for decisions on future management, the Survey defined ten exploration plays, based on geologic and geophysical characteristics, and established a program to test each with at least two wells. Assessment was the prime objective, but the Survey designated an indicated structure

TABLE 1.--NPRA exploration summary

Year	Event
1917	Discovery of large oil seepages near Cape Simpson.
1921	First "oil claim" staked on the North Slope.
1923	Executive Order established Naval Petroleum Reserve No. 4 (NPR-4) north of the Brooks Range.
1926	U. S. Geological Survey completed a study that showed the potential for petroleum accumulation in numerous anticlines in the NPR-4.
1944-1953	U. S. Navy conducted a full-scale exploration program comprising extensive geological and geophysical surveys and the drilling of 45 shallow core-test wells and 36 test wells, including four wells in the Barrow area.
1953-1974	U. S. Navy drilled seven development wells in the Barrow area.
1974-1977	U. S. Navy, in an extensive data gathering and evaluation program that began in 1972, drilled four additional wells in the Barrow area and seven deep test wells in the northeast NPR-4, acquired nearly 7,700 line miles of seismic reflection data, and gathered gravity data at more than 30,000 stations.
1976	Public law 94-258 transferred jurisdiction of NPR-4 to the U. S. Department of the Interior and changed its name to National Petroleum Reserve in Alaska (NPRA).
1977-1981	The U. S. Geological Survey, continuing the Navy's 1981 exploration program, drilled five development wells, an extension well, and 21 test wells; acquired about 5,700 line miles of seismic reflection data; gathered gravity data at more than 27,000 stations; conducted limited aeromagnetic surveys; and collected rock, gas, or fluid from all wells for geochemical analysis.

for each test well location because discovery was a secondary objective. As new data accumulated, subdivision of the ten original plays into 17 formed the basis for a resource assessment published by the Secretary of the Interior in 1979.

The Survey completed 21 test wells widely scattered outside the Barrow area (for a total of 28 in the program), about 5,700 line miles of seismic surveys, gravity surveys at more than 27,000 stations, and limited aeromagnetic surveys. The test wells drilled from 1975 through 1981 are identified in table 2 and figure 2. Of these wells, Walakpa 1 discovered gas, and Walakpa 2 confirmed that the gas field extends at least 4 mi (6 km) from the discovery well. Good gas and oil shows were observed at several of the test wells.

TABLE 2.--NPR-4 and NPRA test wells, 1975-1981

[The Navy's exploration program included the test wells drilled from 1975 through 1977; the U. S. Geological Survey drilled the rest of the test wells. All wells are outside the Barrow area.]

Year	Test wells drilled
1975	Cape Halkett 1
1976	South Harrison Bay 1, East Teshekpuk 1
1977	Atigaru Point 1, West Fish Creek 1, W. T. Foran 1, South Simpson 1
1978	Drew Point 1, Ikpikpuk 1, Inigok 1, North Kalikpik 1, Kugrua 1, South Meade 1, Tunalik 1
1979	J. W. Dalton 1, Lisburne 1, Peard 1, Seabee 1, East Simpson 1, Walakpa 1
1980	Awuna 1, West Dease 1, East Simpson 2
1981	North Inigok 1, Koluktak 1, Kuyanak 1, Tulageak 1, Walakpa 2

Government contractors and subcontractors accomplished the tasks in this reconnaissance exploration program. Through FY 1974, Tetra Tech, Inc., provided exploration and interpretation services for the program as a contractor to the U. S. Navy. In FY 1975, Husky Oil NPR Operations, Inc., became the prime contractor for operations on the Reserve and Tetra Tech became the principal subcontractor responsible for interpreting geologic and geophysical NPRA data. Additionally, in FY 1981 Tetra Tech was under contract to the Survey to monitor NPRA environmental, construction, geophysical, and drilling activities; provide geologic support; and interpret the geophysical data acquired in FY 1981.

This report summarizes the results of Tetra Tech's work on the reconnaissance exploration program conducted from FY 1974 through FY 1980 to evaluate the hydrocarbon potential of the NPRA. Table 3 provides a summary of the seismic program, including surveys conducted in the Barrow area in FY 1972 and FY 1973 to delineate the Barrow gas field. In the northern coastal plain, the seismic grid average was 7 mi by 9 mi (8-mi loop average, 63 sq mi per loop), and in the southern folded belts, 10 mi by 15 mi (12-mi loop average, 150 sq mi per loop), as indicated in figure 3. More detailed information on the seismic program is provided in Appendix B, which also includes an alphanumeric listing of all seismic lines recorded that are pertinent to this report.

In the overall NPRA program, Tetra Tech's support included, but was not limited to:

- Design and layout of the geophysical program and maintenance of data quality control, both in the field and during processing.
- Interpretation of nearly 13,000 line miles of seismic profiles.
- Regional studies of the rock units on the North Slope to provide a geologic evaluation of the seismic data.
- Acquisition and interpretation of gravity and aeromagnetic data.
- Recommendation of prospects for drilling, including wildcat and development wells in the Barrow area. (Some recommendations were accepted, but Tetra Tech did not select the well locations.)

This report is Tetra Tech's final geophysical and geological report on the NPRA exploration program. The report contains structure (time and depth) and isopach maps constructed from

TABLE 3.--Seismic program summary, FY 1972-FY 1980

Fiscal year	Area surveyed	Operating dates	Number of crews	Number of seismic lines	Total line miles
1972	Barrow	04/26/72-05/15/72	1	10	62
1973	Barrow	11/30/72-12/20/72	1	5	32
1974	Barrow and zone A[1]	03/01/74-05/15/74	3	52	1,062
1975	Iko Bay, Barrow, Coastal, Teshekpuk Lake, northern foothills	11/19/74-05/23/75	4	61	2,440
1976	Simpson, western sector	01/23/76-05/05/76	2	30	1,440
1977	Northern foothills thrust belt of the Brooks Range	01/20/77-05/23/77	5	64	2,639
1978	Barrow, southern foothills, Umiat, Driftwood	01/13/78-05/31/78	4	65	1,916
1979	Barrow, southern foothills, Umiat, Driftwood	01/08/79-05/03/79	3	76	1,901
1980	Fortress Mountain, Lisburne, Meat Mountain, Tunalik	01/06/80-04/30/80	2	52	1,096

[1]Zone A extends southeastward along the Arctic Coast from Dease Inlet to the Colville River.

data acquired through FY 1980. An overall summary of the tectonics and stratigraphy of the NPRA is provided, including geologic isopach and lithofacies maps constructed for all formations. The report also presents sand thickness and average porosity maps of potential reservoir units, results of geochemical and paleoenvironmental studies, and detailed studies of several seismic horizons. Interpretations of data acquired in the FY 1981 seismic program are provided in a separate report (Patterson and others, 1982).

Information acquired from exploratory wells was used to prepare the report. Many of these wells were drilled prior to 1972; six were completed in FY 1981 (Awuna 1, Koluktak 1, Kuyanak 1, North Inigok 1, Tulageak 1, and Walakpa 2), and eight were drilled in the Barrow area and three at Umiat (excluding development and step-out wells). See previous Tetra Tech reports, the most pertinent of which are listed in the bibliography, for additional information on geophysical and geologic interpretations of NPRA data.

INTERPRETATION PROGRAM

The exploration and interpretation program described in this report is the result of services provided by Tetra Tech to the federal NPRA exploration program from FY 1972 through FY 1980. This work included geophysical and geologic studies, development of a computerized geophysical data base, and related activities.

GEOPHYSICAL STUDIES

The various geophysical studies of the NPRA completed by Tetra Tech dealt mainly with design of geophysical surveys; seismic structure, velocity, and stratigraphic analyses; potential field investigations; and seismic-geologic correlations. Reconnaissance surveys covered all of the NPRA with a regional seismic grid. Design specifications for the surveys focused on grid placement, basic seismic field parameters, and specifications for acquisition of potential field data. Tetra Tech supervised much of the acquisition and processing of data. The energy sources used were dynamite, "mud gun," and Vibroseis; some data acquired in the Barrow area were high-resolution data.

Many seismic reflectors were correlated regionally and locally. Originally, only the more obvious reflectors were mapped, but as additional well control led to identification and study of potential reservoirs, the number of reflectors mapped was increased. The list of mapped reflections presently comprises a group of 13 "Pebble Shale" and pre-Cretaceous horizons, 11 post-"Pebble Shale" horizons, and three form-line horizons in the overthrust area in the south. A correlation chart of current names for mapped seismic horizons is provided in "Parastratigraphic Units" in "NPRA Stratigraphy."

Structure maps (time and depth) were prepared for all seismic horizons except for the form-line horizons, which are illustrated in time only. Additionally, 20 isopach maps were generated between various seismic horizons. The depth and isopach maps, based on seismic interpretations, were contoured by computer, primarily for regional studies. Manually contoured time maps show the structural detail.

Discrepancies that exist between the geophysical and geological maps are indicated on the maps and discussed in the report. Geophysical depths and isopachs were based on seismic reflectors that may or may not represent geologic units; the data shown at well locations on maps is geologic well data, which may differ from seismic contours. Where a unit is shown to be thin or absent at well locations, the seismic contours may reflect an underlying unit. Limits of seismic resolution may result in improper location of truncations and lapouts.

The velocity studies completed for the report generally dealt with accurate determination of depth and isopach values, or identification and analysis of velocity anomalies. Regional velocity fields were developed to calculate depth and isopach data as well as identify velocity anomalies of potential exploration significance. Detailed velocity studies conducted near several proposed wells focused on predicting geopressure and identifying potentially gas-prone regions. Analysis and correction of short-wave surface and subsurface velocity anomalies in the time domain was a required procedure in regions where velocity anomalies create apparent structures of the same or greater magnitude than actual structure (see "Velocity Studies" and "Tunalik Study").

Stratigraphic analyses of many seismic reflectors were done, most notably the "Simpson sandstone," Sag River Sandstone, and Neocomian sandstones at Tunalik 1. Reprocessing frequently was required for making stratigraphic interpretations.

Gravity and magnetic data were compiled, edited, reduced, and interpreted. These data were especially useful for basement studies (both depth to basement and rock type), location of carbonate rocks, and delineation of faulting. Information derived from potential field studies was integrated into the seismic interpretation. (A summary of this work is in preparation as a separate final report.)

To identify the acoustic interfaces that cause the various mappable seismic reflections, phase and polarity characteristics of the seismic data were studied in detail. The results were verified using synthetic seismograms. As necessary, check-shot survey data were examined and reinterpreted to compile a consistent data set. Results of the correlation studies are summarized in a seismic-parastratigraphic correlation chart, and time to seismic events in wells is shown.

Because of the large volume of data, particularly from seismic surveys, Tetra Tech developed an interpretive

geophysical data base from 1979 through 1981 to computerize as much of the NPRA data as possible. The data base, and accompanying computer software, provide a centralized facility for storing the multitude of numbers (presently about 250,000 records) resulting from geophysical investigations. Performance of a large volume of calculations, such as depth and isopach values, was accomplished, including determination of velocity values from stacking velocity data. In 1981, display techniques were used at various stages of interpretation, culminating in the production by computer of all final depth and isopach maps for this report; the maps required only limited hand editing. Among the maps generated with display techniques were shotpoint base maps; posted maps displaying time, velocity, depth, or isopach values; posted and contoured maps; final contoured maps; three-dimensional perspectives and interpreted section plots in both time and depth.

Many short-term special geophysical studies also were performed at client request. These studies included studies of the Barrow gas fields and analysis of "first-break" velocities.

GEOLOGICAL STUDIES

Geological studies of the NPRA completed by Tetra Tech focused on information compilation, structural-tectonic investigations, stratigraphic-paleoenvironmental analyses (see "Tectonic Framework" and "Geologic History"), and determination of hydrocarbon potential (see "Geochemical Study"). Detailed information on the stratigraphy and depositional history of the NPRA and surrounding northern Alaskan area was compiled from published information and reports. All of the reports prepared contain some correlation sections for the interval studied; the sections were made from correlated well logs, published literature, or both. Foraminiferal and palynologic data were compiled to facilitate correlation.

Because of nomenclature difficulties associated with facies changes, Tetra Tech developed a parastratigraphic nomenclature and later updated it for this report (see "Parastratigraphic Units"). This classification is a practical time-rock-stratigraphic system derived from the original well log correlations that were guided by micropaleontology. The well correlations were compared to the seismic horizons, and the regional stratigraphy of the NPRA was analyzed using seismic-stratigraphic concepts (Payton, 1977). To accompany the regional correlation sections, compressed seismic sections were used to better

show the relationship between parastratigraphic units and seismic horizons.

Subsurface geologic maps were made of all significant, mappable geologic horizons that were recognized in work conducted from 1974 to 1981. Isopach, net sand, potential reservoir thickness, and average porosity maps were prepared. Additionally, sand-shale ratio and clastic ratio (lithofacies) maps were generated in 1980 and 1981.

A chart prepared in 1979 redefined correlations of all lithostratigraphic units below the Torok Formation (Gowen and others, 1979). This chart was updated in 1980 to add Torok and higher tops, and in 1981 to prepare this report. Additionally, a chart of all parastratigraphic tops was compiled by Guldenzopf and others (1980) and updated in 1981. Micropaleontologic zone tops determined by Anderson, Warren, and Associates (AWA) and Biostratigraphics, Inc., were charted for foraminifera, dinoflagellates, and spores and pollen.

Stratigraphic-paleoenvironmental studies, which were based on well logs, published and unpublished geological reports, and well cuttings defined potential reservoir trends and possible prospects in the northern half of the NPRA; these studies were reported separately or in annual geological summary reports. In studies of the depositional environments of the Sadlerochit Group and the Torok "Fortress Mountain" in the Texaco Kurupa wells, well cuttings and cores were examined. Other studies dealt with depositional environments and regional correlation of the "Upper Kingak" (Guldenzopf and others, 1980), and in 1981, the "Upper Kingak," "Lower Kingak," and Torok-Nanushuk. Seismic stratigraphy of the Lisburne and Endicott Groups was compiled in 1980.

NPRA STRATIGRAPHY

Identification and distribution of stratigraphic units was a major part of the geologic and geophysical effort to evaluate hydrocarbon potential in the NPRA. Tetra Tech used a dual stratigraphic classification for regional geologic studies (fig. 4). One of these systems is an informal parastratigraphic classification that subdivides major depositional sequences. The parastratigraphic nomenclature, introduced by Guldenzopf and others (1980), allows interpreters to make maps of units that change facies.

The second system is the conventional lithostratigraphic classification that consists of recognized formal and informal rock units. This familiar nomenclature was developed over several decades, primarily by Survey geologists. Tetra Tech used this classification in previous reports and its use is continued here. In this report, the lithostratigraphic names are applied as strictly as possible in accordance with the "Code of Stratigraphic Nomenclature" (American Commission on Stratigraphic Nomenclature, 1961) and International Stratigraphic Guide (1976).

PARASTRATIGRAPHIC UNITS

The parastratigraphic system is based on seismic stratigraphy, with interpretations showing that primary seismic reflections are parallel to stratal surfaces and unconformities. Thus, using this system, seismic sections are interpreted as a record of chronostratigraphic (time-stratigraphic) depositional and structural patterns rather than as a record of time-transgressive lithostratigraphic (rock-stratigraphic) patterns (Payton, 1977, pp. 51 and 53). For example, the Sag River Sandstone and its time equivalents were mapped and identified as a unit, even where it is siltstone or shale. The parastratigraphic system facilitates the construction of lithofacies and potential reservoir maps.

Eleven major parastratigraphic units were devised to identify stratigraphic units uniformly regardless of facies changes within units in the NPRA. These major units are subdivided further, as appropriate, to conform as closely as possible to depositional sequence boundaries (figs. 4-6). In ascending order, the major parastratigraphic units are O-S, D, M, P, PR, TR, J, Ka, Kb, T, and Q. The uppercase letters identifying the units represent geologic periods; lowercase

letters and numbers are used to denote subdivisions of the time units.

The system consists of time-rock stratigraphic units established by conventional well-log correlation techniques and verified, within resolution limits, by seismic stratigraphy and biostratigraphy (fig. 6). Some later modifications of the system were based mainly on seismic or biostratigraphic data. Parastratigraphic correlations beyond well control are governed by seismic stratigraphy only. This section of the report describes the parastratigraphic units and their major subdivisions.

Unit O-S (Ordovician-Silurian)

The "Argillite" basement rocks in the Prudhoe Bay Field and Barrow area of Alaska were specified as Ordovician-Silurian by Carter and Laufeld (1975). These rocks comprise the O-S parastratigraphic unit described in this report. This unit, along with the D unit and some younger rocks, is below seismic horizon 1500 (seismic maps 1, 2; fig. 4). Horizon 1500 is the "Acoustic basement" throughout the NPRA. A computer-generated illustration of horizon 1500 is provided in figure 7.

The O-S unit is not yet separable seismically from younger rocks that also are present in places below the "Acoustic basement" away from the Barrow Arch. (See figure 8, which identifies Paleozoic tectonic elements in the NPRA, and figures 9 through 28.) Near the Arctic Coast, horizon 1500 correlates closely, within 100 ft (30 m), with the top of unit O-S (figs. 29-32). Exceptions are at East Simpson 1 and East Simpson 2 where no acoustic interface is present near the O-S unit. The East Teshekpuk 1, Inigok 1, and Tunalik 1 wells did not reach unit O-S, but the event that is correlated regionally as horizon 1500 was penetrated in these wells (figs. 9-12).

As originally conceived, horizon 1500 was the "Economic basement." In early wells drilled in the Arctic Coastal Plain and the Barrow area, horizon 1500 was thought to be about at the contact between overlying layered sedimentary rocks and metasedimentary rocks that were dated as Ordovician-Silurian by Carter and Laufeld (1975) in the Barrow area. Tracing this horizon to the south and to other areas of the NPRA led to an assumption that horizon 1500 was the top of the "Argillite"; however, this original assumption now is known to be incorrect.

Southward from the Barrow area, horizon 1500 probably overlies different rock types at different locations. Some

of these rocks may be slightly altered sedimentary rocks to low-grade metasedimentary rocks. The rocks may be as old as Ordovician-Silurian (the true "Argillite" sequence) or Early(?)-Middle Devonian, as seen at Topagoruk 1 and South Meade 1, or as young as Mississippian. The rocks belong to lithostratigraphic units that are unnamed, to a part of the Neruokpuk Group, or to the Devonian or Mississippian part of the Endicott Group. The rocks overlain by horizon 1500 also may be Mississippian carbonates equivalent to the Wachsmuth or Alapah Limestone of the Lisburne Group.

The layered character of some of the rocks below horizon 1500 cannot be seen, probably because of steep dip. In many places, structural complications may terminate coherent reflectors that are below the horizon. Such reflectors appear on one seismic line but not on others, so they are not regionally mappable. As the 1500 horizon is the deepest coherent reflector that can be traced regionally from one line to another, it is the effective "Acoustic basement" (figs. 12, 17-20, 32).

Unit D (Devonian)

Unit D, which is Devonian, consists of steeply dipping basement rocks identified at Topagoruk 1 and South Meade 1. The unit includes interbedded clastics and carbonaceous seams.

Unit D, like unit O-S, underlies horizon 1500 and is part of the "Acoustic basement." As stated earlier, unit D cannot be separated seismically from unit O-S using present data.

Unit M (Late Mississippian)

The M unit, which is Late Mississippian, has two subdivisions, units M-1 and M-2 (seismic maps 3-8; figs. 33-36). Unit M-1, the lower subdivision, is early-middle Meramecian, and unit M-2, the upper subdivision, is middle-late Meramecian to Chesterian. Unit M-2 is subdivided further into units M-2a and M-2b. Unit M-2a contains relatively more interbedded shales than the overlying M-2b. At Inigok 1, the top of unit M-1 coincides with the contact between the Endicott and Lisburne Groups, and unit M-2 correlates with the Alapah Formation. Inigok 1 was selected as the "type" well for the M-1, M-2, and P parastratigraphic units (figs. 33, 34) because it contains the most complete section of these rocks penetrated to date on the NPRA. However, as the Endicott is a time-transgressive lithostratigraphic unit, the Endicott-Lisburne contact in the well is somewhat arbitrary.

In other wells north of Inigok 1, the Endicott-Lisburne contact is within the overlying M-2 unit, and basal clastic

rocks assigned to the Endicott Group are included in M-2. Farther south, the Endicott-Lisburne contact occurs in older rocks (Nilsen and others, 1980, p. 12-13). In outcrops in the central Brooks Range, the uppermost formation of the Endicott (Kayak Shale) is Early Mississippian, and the M-1 unit top, as defined, is within the overlying Lisburne Group.

Minor revisions in the parastratigraphic terminology will be necessary in the future if the units are used for a wider area. The most logical approach would be to define M-1 as Early Mississippian and M-2 as Late Mississippian; all of the rocks described here then would be defined as sub-divisions of M-2 unit. However, revision would require more time and study. In this report, the Endicott at Inigok 1, as well as all laterally equivalent rocks, is in unit M-1.

The top of the M-1 unit is near seismic horizon 1400 (seismic maps 3, 4; figs. 17-19), which was reached only at Ikpikpuk 1 and Inigok 1. At these locations, horizon 1400 is within unit M-2, about 175 ft (53 m) above the log top of unit M-1. Horizon 1500 (seismic maps 1, 2) was penetrated at about 19,580 ft (5,968 m) at Inigok 1; the strata below horizon 1500 are Mississippian and are part of unit M-1.

The top of the M-2 unit is seismic horizon 1300 (seismic maps 6, 7), which is at 15,718 ft (4,791 m) at Inigok 1 and correlates within 50 ft (15 m) of the top of the unit. Elsewhere, the horizon correlates with the top of unit M-2 only in the broadest sense, because a significant acoustic interface is not present at or near the top of the unit. At East Teshekpuk 1, horizon 1300 is about 100 ft (30 m) above unit M-2; at Atigaru Point 1, Ikpikpuk 1, and Cape Halkett 1, horizon 1300 is about 100 ft (30 m), 275 ft (84 m), and 400 ft (122 m), respectively, below the top of unit M-2 (figs. 9-11, 29-32). The unit may be present at West Fish Creek 1, but horizon 1300 was not reached at this location.

Units M-1 and M-2 were identified only in the northeastern part of the NPRA. However, rocks of unknown age in the deepest part of the Meade Basin may include an M-2 erosional remnant that is overlain by younger rocks. To determine the limits of units M-1 and M-2, the Inigok 1 synthetic seismogram was matched to the line 7X-75 seismogram at the well location. Seismic horizons 1300 and 1400 were traced in all directions from Inigok 1.

The M-1 unit laps out against the Meade Arch west of Inigok 1 and the Umiat Platform south of Inigok 1 (fig. 35). Horizon 1400 onlaps the Fish Creek Platform to the north, and unit M-1 is probably absent or only discontinuously distributed over the platform (figs. 37-40). North of Inigok 1, unit M-1

is truncated and overlain by the M-2 unit. Unit M-2 is truncated and regionally overlain by the P unit (figs. 19, 20), and may underlie horizon 1500 on the Oumalik High.

Rocks that are equivalent to the M-1 unit were identified at East Simpson 2 from 7,152 to 7,428 ft (2,180 to 2,264 m). Palynologic data indicate that these rocks are early Meramecian. The M-1 strata dip more steeply and strike in a different direction than the overlying Shublik Formation. Seismogram sections indicate discontinuous seismic reflectors or "pods" at the level of the M-1 strata at East Simpson 2 and elsewhere on the Simpson Peninsula.

At W. T. Foran 1 and Cape Halkett 1, steeply dipping clastics and redbeds below the Lisburne carbonates also are associated with seismic "pods." The age of these rocks is not known, because no fossils were recovered from the clastics. The rocks at W. T. Foran 1 and Cape Halkett 1 are considered to be part of unit M-1, but alternatively, they could be designated as part of unit M-2.

Distribution of the M-1, M-2, and P parastratigraphic units is shown in figures 35, 36, 41, and 42. Both M-1 and M-2 were folded and block-faulted on a broad scale. North of the Fish Creek Platform, the discontinuous distribution of M-1, and possibly M-2, may be related to tectonic activity during late Meramecian time (see "Geologic History"). The Fish Creek Platform perhaps was uplifted, block-faulted, and eroded during the same time that M-1 and M-2 were being deformed in the Umiat Basin. Gentle uplift and block-faulting of the M-1 and M-2 units probably continued through latest Mississippian time; the uppermost M-2 unit (Mamet zones 18 and 19) is thinner over the Fish Creek Platform than at Inigok 1. The thinning of these rocks across tectonic highs may result from post-Meramecian erosion, slow deposition, or both. Between Inigok 1 and Seabee 1, cross sections E-E' and F-F' (figs. 17-20, 21-24) show that the upper part of the M-2 unit is thicker below seismic horizon 1300; evidence of folding and faulting also is shown.

Several seismic reflectors were not reached by the Inigok 1 well. It is inferred that the reflectors are within the M-1 unit because they appear to be related to the same seismic sequence. Unit M-1 thickens rapidly south of Inigok 1 (figs. 23, 24). The contact between M-1 and the basement probably is more than 35,000 ft (10,668 m) deep in the Umiat Basin.

The M-1 unit and the overlying M-2 unit may be present in the center of the Oumalik High, where a series of reflectors of unknown affinities underlies horizon 1500. These reflectors are folded and block-faulted, as are units M-1 and M-2 in the

Inigok 1 area. However, it seems more likely that the lower reflectors in the Oumalik High originate from metasediments in the D or O-S parastratigraphic units, because M-1 and M-2 seismic reflectors cannot be traced confidently from the Umiat Basin to the Oumalik High. Horizon 1400 onlaps the Fish Creek Platform to the north, Meade Arch to the west, and Umiat Platform to the south. Unit M-2 may underlie horizon 1500 on the Oumalik High.

Unit P (Pennsylvanian-Permian)

The P unit is Pennsylvanian to Early Permian (seismic maps 9-13; figs. 43, 44). This unit is subdivided into two units: P-1, the lower unit, and P-2, the upper unit. Unit P-1 is dominantly Pennsylvanian and mainly coincides with the Wahoo Limestone of the Lisburne Group. In the NPRA subsurface, the age range of the Wahoo is Early Pennsylvanian to Early Permian. The overlying P-2 unit (fig. 4) generally coincides with an argillaceous limestone informally called the "Transition Zone"; this rock unit probably is part of the Lisburne Group, but it also resembles the overlying Joe Creek Member of the Echooka Formation. The age of the P-2 unit is Early Permian.

At Inigok 1, the top of the P unit is seismic horizon 1200 (interpreted but not mapped) at 14,026 ft (4,275 m), as shown in figures 19 and 20. Elsewhere, this horizon is difficult to separate from the top of the relatively thin PR unit, which is Permian.

The P unit extends across the NPRA, and is thinner in the eastern half of the Reserve (figs. 11, 19, 31, 39, 41, 42). Along the Arctic Coast near the Fish Creek Platform, the PR unit rests directly on the Pennsylvanian P-1 unit. The P unit thickens southward toward Inigok 1. At Inigok 1, the uppermost part of unit P contains rocks of earliest Permian age. These Permian rocks underlie a regional unconformity that separates unit P from the overlying PR unit (fig. 44). Well data and seismic stratigraphy indicate that the P unit thickens westward from the Meade Arch-Oumalik High trend. West of the Meade Arch, unit P-2 unconformably overlies unit P-1 and thickens greatly toward Tunalik 1. In the Tunalik Basin, unit P-2 probably thickens even more.

East of the Meade Arch, seismic stratigraphy suggests that the PR and TR units immediately overlie the P unit (figs. 11, 12). At Inigok 1, unit PR directly overlies the P-2 unit; to the north of Inigok 1, unit PR progressively overlies older parts of unit P-1. Detailed correlation shows that unit P-1 thins over the Fish Creek Platform because of truncation, and is progressively overlain by unit PR, and then by unit TR.

Unit PR (Permian)

The PR unit, which has two subdivisions, coincides with the Echooka Formation (seismic maps 9, 10; figs. 45, 46). Unit PR-1, the lower subdivision, represents the Joe Creek Member of the formation, and unit PR-2, the upper subdivision, corresponds to the Ikiakpaurak Member (fig. 4). These subdivisions are not shown on most cross sections because the PR unit is relatively thin.

Seismic horizon 1100, which seems to approximate the top of the Paleozoic section, represents unit PR, except where the unit is absent or less than 100 ft (30 m) thick (limit of seismic resolution). Where unit PR is absent or thin, horizon 1100 is near the top of unit P, as shown along the northeastern coast of the NPRA from J. W. Dalton 1 through South Harrison Bay 1 in figures 41 through 46.

Unit TR (Triassic)

Unit TR includes the "Ivishak sandstone" within the Sadlerochit Group; the "Ivishak" is the main hydrocarbon reservoir in the Prudhoe Bay Field. This Triassic unit (seismic maps 14-24; figs. 47-50) is subdivided into three units: TR-1, TR-2, and TR-3. TR-3 is subdivided further into the TR-3a and TR-3b units. In most wells, unit TR-1 coincides with the Kavik Shale, and unit TR-2 corresponds to the "Ivishak sandstone" of the Prudhoe Bay area, or its equivalents. Unit TR-3a coincides with the Shublik Formation, and unit TR-3b with the Sag River Sandstone and equivalent rocks.

Seismic horizon 1040 ("basal Shublik") is near the top of unit TR-2, as shown in seismic maps 14 and 15. This seismic event probably is generated by the high-velocity limestones near the bottom of the Shublik Formation in unit TR-3a. Horizon 1040 generally is about 110 ft (34 m) above unit TR-2. The range of values is from 26 ft (8 m) above TR-2 at Peard 1 to 209 ft (64 m) above TR-2 at Atigaru Point 1. The standard difference is 60 ft (18 m).

South of lat 70°N a higher amplitude event is mapped instead of horizon 1040. This event is horizon 1020 (seismic maps 17, 18). Around Inigok 1, these two horizons are inseparable, but the horizons diverge westward. Horizon 1020 was not penetrated by any other well so its exact para-stratigraphic correlation is unknown.

Seismic horizon 1000 (seismic maps 20, 21) normally correlates with an acoustic interface at or very near (within

25 ft, or 8 m) the top of unit TR-3b in the northern half of the NPRA. However, at West Dease 1, East Teshekpuk 1, and Atigaru Point 1, horizon 1000 lies near the middle of the overlying J-1a unit. At seven wells, mostly in the north-central part of the Reserve, the horizon correlates with the top of unit J-1a; these wells are Drew Point 1, Ikpikpuk 1, Kugrua 1, Kuyanak 1, East Simpson 1, East Simpson 2, and South Simpson 1. Figure 51 is a computer-generated illustration of horizon 1000.

South of Inigok 1, horizon 0900 converges downward toward horizon 1000 until horizon 1000 appears to be truncated. Farther south from Inigok 1, unit TR-3b (seismic maps 23, 24) and the overlying J-1 unit are either absent or very thin; if these units are present at all, they are too thin to be resolved seismically. Horizons 0900 and 1000 and horizon 1020 form a reflector couplet that is traceable all across the northern part of the Reserve, except for the Barrow High-Barrow Arch trend. Triassic rocks were deposited across the width of the Reserve, and unit TR is absent only on the Barrow High and along the coastline of the Beaufort Sea.

Unit TR-1 onlaps the Barrow High-Meade Arch beneath unit TR-2 along a line just north of Peard 1, South Meade 1, South Simpson 1, and J. W. Dalton 1, as shown in figure 47. Unit TR-2 (fig. 48) is overlapped by TR-3 along a line from the Skull Cliffs area of the Chukchi Sea coast to near Kuyanak 1, South Simpson 1, and East Simpson 2. Unit TR-3 (figs. 49, 50) laps out on the Barrow High, and progressively younger subdivisions of the unit disappear by onlap onto the pre-existing high. Unit TR-3a laps out just north of South Barrow 3 and Iko Bay 1; unit TR-3b extends to just north of South Barrow 13 and is not present in the rest of the South Barrow field west of the "Disturbed Zone" (figs. 52, 53). The basal "Pebble Shale" unconformity truncates units TR-1, TR-2, and TR-3 northward beneath the Beaufort Sea and east of J. W. Dalton 1.

East of Drew Point 1, the TR unit was uplifted with the Barrow Arch and truncated and overlain by the Neocomian Ka-1b unit (figs. 29-32), as described later in this report. In this area, unit Ka-1b consists of the "Pebble Shale" unit with its associated basal sandstones. Progressively older subdivisions of the TR unit are truncated northward. Unit TR-3b is truncated between Cape Halkett 1 and W. T. Foran 1, and is absent at J. W. Dalton 1. Units TR-1 and TR-2 are truncated farther to the north, offshore from the NPRA.

Unit J (Jurassic and Early Cretaceous)

Unit J is mainly Jurassic (seismic maps 25-33). The unit has two main subdivisions: unit J-1, which is subdivided into J-1a, J-1b, and J-1c, and unit J-3, which is subdivided into J-3a (comprising units J-3aI and J-3aII), J-3b, and J-3c (see "Jurassic Study"). Unit J-1, the oldest of these subdivisions, coincides with the "Lower Kingak," and includes all rocks between unit TR-3b and the mid-Jurassic unconformity (fig. 54). Unit J-3 and the Ka-1a parastratigraphic unit (described later) comprise the "Upper Kingak" (figs. 55-60). Presently, biostratigraphic evidence is insufficient to create a J-2 unit. Rocks that would represent unit J-2 are assumed to be absent because of nondeposition or erosion during the time of the mid-Jurassic unconformity.

Seismic horizon 0900 (seismic maps 25-27) corresponds most closely with the top of unit J-1. The horizon is one-half cycle above the contact, and is generated by a negative acoustic interface at or very near the mid-Jurassic unconformity. Exceptions are at Atigaru Point 1 and South Meade 1, which are 222 ft (68 m) and 146 ft (45 m), respectively, above the unconformity; South Simpson 1, which is one-half cycle above an acoustic interface 184 ft (56 m) below the unconformity; Tunalik 1, which is one-half cycle above an interface 152 ft (46 m) above the unconformity; and Ikpikpuk 1 where horizon 0900 correlates with unit J-3aI 224 ft (68 m) above the unconformity. In the eastern NPRA, horizon 0900 downlaps to the level of horizon 1000 (top of the Triassic). South of Inigok 1, unit J-1 is too thin to be resolved seismically, or is absent (figs. 17, 19, 20).

Formerly, at the base of unit J-1c, the "lower Jurassic shoulder" on well logs was correlated near seismic horizon 0950. (Horizon 0950 was picked on seismic sections, but not mapped.) However, where unit J-1c is thin, as at Ikpikpuk 1, separation of horizon 0950 from horizon 0900 is difficult. Likewise, unit J-3aI is generally thinner than the limits of seismic resolution. Thus, creating a J-2 unit that could be correlated seismically would be difficult without using different seismic acquisition and/or processing techniques.

Seismic horizon 0850 subdivides unit J-3 (seismic maps 28, 29). West of the Meade Arch, this horizon is near the top of unit J-3a; east of the Meade Arch, it is within unit J-3b. At Peard 1, Kugrua 1, and South Meade 1, horizon 0850 correlates very closely with unit J-3aII; correlation is also good at Walakpa 2, Kuyanak 1, and South Harrison Bay 1 where the acoustic interface that generates horizon 0850 lies 38 ft (12 m) below, 76 ft (23 m) above, and 30 ft (9 m) above unit J-3aII, respectively. At Inigok 1, North Inigok 1, and

Tunalik 1, horizon 0850 correlates closely with unit J-3b. At West Fish Creek 1, the horizon is about 220 ft (67 m) above unit J-3aII, and at Ikpikpuk 1 it is 395 ft (120 m) above the unit.

This discrepancy is caused by the difficulty in correlating logs and seismic horizons from one side of the Meade Arch to the other. Markers are relatively clear west of the Meade Arch, because the Jurassic section there contains interbedded fine sandstones, siltstones, and shales. East of the Arch, this section consists mostly of caving shales and siltstones that are relatively featureless on logs and seismic sections, and biostratigraphic zoning is complicated by cavings. Correlation cross section B-B' (fig. 9) shows this contrast.

In the northwestern NPRA, the top of unit J-3c is near horizon 0800 (seismic maps 31, 32; fig. 4); elsewhere, the top of unit J-3c is near horizon 0720. Horizon 0800 was drilled only at Tunalik 1 and Kugrua 1. At Tunalik 1, horizon 0800 results from an acoustic interface about 105 ft (33 m) above the mid-Neocomian unconformity. Horizon 0800 was truncated by horizon 0720 (seismic maps 34, 35) just northeast of Kugrua 1. At Kugrua 1, the event is generated by the top of unit J-3 just below the basal "Pebble Shale" unconformity. The mid-Neocomian unconformity was not identified at Kugrua 1.

Unit Ka (Neocomian, Aptian-Albian, Cenomanian)

The Ka unit has three main subdivisions: units Ka-1 (seismic maps 34-45), Ka-2 (seismic maps 46-52) and Ka-3 (seismic maps 50-52). Unit Ka-1, the oldest of these subdivisions is divided further into units Ka-1a and Ka-1b. Ka-1a is the uppermost part of the Kingak Formation, including the Neocomian sandstones in Tunalik 1, and Ka-1b coincides with the "Pebble Shale" unit and "Pebble Shale" sandstone (seismic map 45; figs. 55, 60-62).

Unit Ka-1b is absent over part of the Fish Creek Platform, as at West Fish Creek 1 (figs. 37-40), and may be absent over part of the Wainwright Arch (figs. 9-12). The unit unconformably overlies progressively older rocks northward over the Barrow High and Barrow Arch. Unit Ka-1b is the main cap rock and may be the main source rock for the hydrocarbons at Prudhoe Bay. Because this unit may be in contact with any of the parastratigraphic units previously discussed, the subcrop limits of all underlying units were mapped carefully.

Unit Ka-2, defined mostly on the basis of seismic character, corresponds to an early stage of the Torok-Nanushuk sequence,

including rocks deposited in basin, slope, marine shelf, and continental environments. In compressed seismic sections, unit Ka-2 contains lower angled, less well defined clinoform beds than the overlying Ka-3 unit, which may indicate a more rapid and uniform deposition rate for unit Ka-2 (figs. 11, 12). Unit Ka-3, the uppermost subdivision, corresponds to the remaining part of the time-transgressive Torok-Nanushuk sequence; this may indicate a more sporadic depositional history for the Ka-3 unit, as its clinoform beds are relatively steeper and more variable than those in the underlying Ka-2 unit.

The base of unit Ka-1a is near horizon 0800 (mid-Neocomian unconformity), as shown in seismic maps 31 and 32. This horizon is truncated to the northeast of Tunalik 1 by horizon 0720 (seismic maps 34, 35; figs. 11, 12).

The reflector couplet that is formed by horizons 0700 and 0720 (seismic map 45; figs. 9-12) very nearly represents unit Ka-1b, and is traceable all across the northern two-thirds of the NPRA. Horizon 0720 is near the base of unit Ka-1b, and horizon 0700, the primary seismic marker over most of the NPRA, correlates very closely with the top of unit Ka-1b in most areas. Figure 63 is a three-dimensional perspective of horizon 0700.

Horizon 0720 (seismic maps 34, 35), normally mapped on a peak on seismic sections, is difficult to map because of variations in the thickness and presence of basal "Pebble Shale" sandstones, as well as velocity variations of basal underlying eroded sediments. These variations result in numerous phase reversals and zones that are void of primary events.

Figure 64 illustrates the basal "Pebble Shale" unconformity, showing that horizon 0720 truncates horizon 1000. Close correlation of horizon 0720 with the basal "Pebble Shale" unconformity is apparent in all Barrow wells, Iko Bay 1, Peard 1, Kugrua 1, South Meade 1, Ikpikpuk 1, and North Kalikpuk 1. The horizon is one-half cycle above the event generated by the acoustic interface at the basal "Pebble Shale" unconformity (or the top of the "Pebble Shale" sandstone overlying the unconformity) at West Dease 1, Drew Point 1, J. W. Dalton 1, W. T. Foran 1, Cape Halkett 1, East Teshekpuk 1, East Simpson 1, East Simpson 2, South Simpson 1, Walakpa 1, and Walakpa 2. Horizon 0720 is one-half cycle below the unconformity at West Fish Creek 1 and Tunalik 1, and is within unit Ka-1 at South Harrison Bay 1 and Tulageak 1, about 100 ft (30 m) and 150 ft (46 m) above the unconformity, respectively. No acoustic interface is present near the basal "Pebble Shale" unconformity in North Inigok 1,

Kuyanak 1, and Atigaru Point 1. In these three wells, the phantom event mapped as horizon 0720 is within 200 ft (61 m) of the unconformity.

The top of unit Ka-1b normally is characterized by a low-velocity zone that results in a peak on the NPRA seismic data; the trough preceding this peak is mapped as horizon 0700. The negative acoustic interface controlling horizon 0700 is within 20 ft (6 m), plus or minus, of the top of unit Ka-1b with few exceptions. At Ikpikpuk 1, West Dease 1, South Simpson 1, North Kalikpik 1, and Cape Halkett 1, the difference between the acoustic interface and unit Ka-1b is 36 ft (11 m), 50 ft (15 m), 60 ft (18 m), 68 ft (21 m), and 69 ft (21 m) ft, respectively.

Horizon 0700 is not mapped across part of the Fish Creek Platform, probably because of subaqueous erosion (figs. 11, 12). However, some remnants of unit Ka-1b are locally present across this area, and North Kalikpik 1 penetrated such a remnant. In well log sections, unit Ka-1b is correlated into Atigaru Point 1, but it is difficult to trace horizon 0700 into this well from seismic data.

To the east of the Barrow area, the low-velocity shale that is characteristic of the top of unit Ka-1b is very thin. Thus, no prominent acoustic interface exists near the top of the unit. The horizon 0700 reflection found at Iko Bay 1 and Tulageak 1 originates in the basal part of unit Ka-2.

Younger Neocomian-earliest Aptian rocks may occur above Ka-1b in the southern one-third of the Reserve. Two observations suggest this possibility. One observation is that the 0700-0720 couplet (seismic maps 34, 35, 39, 40, 45) becomes less distinct in the southern foothills area where several strong reflectors within probable Torok-Fortress Mountain rocks downlap from the south onto horizon 0700. Secondly, the Ka-1b unit at Lisburne 1, identified on logs, is several thousand feet below the top of AWA foraminiferal zones F-12/13; the Ka-1b top is at 6,070 ft (1,850 m), whereas the zone F-12/13 top is at 2,220 ft (677 m) (figs. 5, 65).

Several seismic events of limited areal extent in the Ka-2 and Ka-3 parastratigraphic units were mapped, but could not be used to define these units over the entire Reserve. These horizons include horizon 0650 (seismic maps 46, 47), the clinoforms, and the top of the Torok. Horizon 0650, which was penetrated only at Awuna 1, is within unit Ka-2.

The clinoforms (seismic maps 48, 49), as well as shallow Cretaceous reflectors, are within units Ka-2 and Ka-3. The clinoforms mapped were selected on the basis of reflection

strength and areal extent to illustrate the orientation and change in dip across the NPRA. No attempt was made to correlate these reflectors with well data.

The top of the Torok is not a true seismic horizon, but is a boundary based on stacking velocity data. (See "Velocity Studies" for a complete discussion of the top of the Torok clinothem horizon.) For seismic-stratigraphic correlation, horizon 0500 was continued down the slope and into the basin (fondothem) until it merged with horizon 0700 ("basal Torok" unconformity). Horizon 0500 (seismic maps 50, 51) distinguishes differences in bedding characteristics within the formation. For example, below horizon 0500 in unit Ka-2, clinoform beds dip at a relatively lower angle and include fewer high-amplitude, high-continuity reflectors than the beds in the Ka-3 unit that overlies the horizon. This difference is shown in figures 11, 12, and 66.

The base of unit Ka-3 is near horizon 0500 and its top is near horizon 0400 (mid-Cenomanian unconformity). Horizon 0400 nearly corresponds to the lithologic contact between the Nanushuk and Colville Groups. The seismic character of unit Ka-3 is different from that of the underlying Ka-2 unit. In unit Ka-3 (figs. 10-12), clinoforms dip more steeply; a greater number of high-amplitude, high-continuity reflectors are included; several upward shifts in the shelf-slope break are evident; and several areas of hummocky bedding are associated with the shelf-slope upward shifts. Steeply dipping clinoforms become obvious between Topagoruk 1 and Ikpikpuk 1 (fig. 12). This steepening may be related to the breaching of a major barrier (the Meade Arch) or to a change in sediment supply. In general, unit Ka-3 probably represents a slower rate of sedimentation than does unit Ka-2.

Unit Kb (Late Cretaceous)

Unit Kb, which is restricted to the northeastern part of the Reserve, includes nearly all of the Late Cretaceous rocks in the NPRA (fig. 67). The base of unit Kb is near horizon 0400 (seismic maps 50, 51); the upper boundary of the unit cannot be identified on seismic records because of muting of the shallow data. Horizon 0400 correlates closely with the mid-Cenomian unconformity, although the correlation is not exact.

Horizon 0400 is present in 11 of the 13 NPRA wells that penetrated the mid-Cenomanian unconformity. The 11 wells are Atigaru Point 1, Cape Halkett 1, J. W. Dalton 1, Drew Point 1, West Fish Creek 1, W. T. Foran 1, South Harrison Bay 1, Inigok 1, North Inigok 1, North Kalikpik 1, and East

Teshekpuk 1. The unconformity is too shallow at East Simpson 1 and East Simpson 2 to map seismically. At Cape Halkett 1, horizon 0400 is about 300 ft (91 m) below the unconformity. A major discrepancy exists at Seabee 1 where horizon 0400 is present at about 1,200 ft (365 m), yet unit Ka-3 is on the surface.

Units T and Q (Tertiary and Quaternary)

Units T and Q were not studied extensively. The T unit coincides with the Sagavanirktok Formation or other Tertiary rocks and is restricted to the coastal area of the northeastern NPRA. The Q unit consists of the marine Gubik Formation, rocks questionably assigned to the Gubik, or any glacial, alluvial, or colluvial deposits of Pleistocene age.

Units T and Q, which are shallow, generally cannot be identified on logs or on seismic sections. The T unit coincides approximately to AWA foraminiferal zones F-2, F-3, and F-4; dinoflagellate zonules P-M11 and P-M12; and spore-pollen zonule, P-T10. The Q unit corresponds to AWA foraminiferal zone F-1. (See parastratigraphic, foraminiferal, and palynologic correlation charts in figures 5, 65, and 68).

LITHOSTRATIGRAPHIC UNITS

This section of the report describes lithostratigraphic units that occur in the NPRA. The oldest unit identified in this study is the "Argillite" unit. The younger units studied, listed from oldest to youngest, were the lower(?)-Middle Devonian unit; Endicott, Lisburne, and Sadlerochit Groups; Shublik Formation; Sag River Sandstone; Kingak Formation; "Pebble Shale" unit; Torok Formation and Nanushuk Group; Colville Group; and Sagavanirktok and Gubik Formations.

"Argillite" Unit

The "Argillite" unit derives its name from the dark metasedimentary basement rock in the Barrow High and Prudhoe Bay area. At the South Barrow and Prudhoe Bay fields, the "Argillite" is composed of steeply dipping phyllite and quartzite layers. Other lithologies previously assigned to the "Argillite" include granite at East Teshekpuk 1 (Bird and others, 1978), siltstone at W. T. Foran 1, and coal at Atigaru Point 1 (seismic maps 1, 2).

The term "Argillite," although commonly used, is not particularly suitable, but is the best of several alternatives. Other names for this unit include Neruokpuk

Formation, pre-Devonian, pre-Mississippian, Franklinian sequence, "Economic basement," and "Acoustic basement."

The term "Neruokpuk" is no longer used by the U. S. Geological Survey in defining rocks of the Barrow Arch, because of uncertainties existing in the correlation of these rocks with the type Neruokpuk Formation of the northeastern Brooks Range (Brosge and Reiser, 1972). Pre-Devonian is not an accurate name for this unit because some Devonian rocks are included in the basement (for example, the Early(?)-Middle Devonian rocks at Topagoruk 1). Likewise, the term "pre-Mississippian" is not appropriate because the horizon includes Mississippian rocks at Inigok 1, as shown in figure 19. (See also figure 15, parastratigraphic cross section D-D', between Oumalik 1 and Lisburne 1.) Use of the term "Acoustic basement" in place of "Argillite" suggests that the two are the same, but the only locations where the "Acoustic basement" can be proved to coincide with the top of the "Argillite" is on the Barrow High and in Prudhoe Bay Field.

Lower(?)-Middle Devonian Unit

An unnamed rock unit of presumed Early(?) to Middle Devonian age was drilled at Topagoruk 1, between 10,031 ft (3,058 m) and total depth at 10,503 ft (3,201 m), as shown in figure 9. The Devonian rocks, which are separated from the overlying beds by an angular unconformity, dip 35° to 60° and are composed of chert conglomerate and shale that contains some carbonaceous partings with plant fragments (Collins, 1958, p. 271, 313). Similar rocks were found above the "Argillite" at South Meade 1 between 9,537 and 9,892 ft (2,906 and 3,015 m). The carbonaceous partings are thicker at South Meade 1, but no age has been established yet for these rocks.

Endicott Group

The Endicott Group is a time-transgressive basal clastic unit that overlies the basement in the northeastern NPRA (seismic maps 3, 4; figs. 29-32). In northern Alaska, rocks of the Endicott Group range from low-grade Late Devonian metasedimentary rocks to slightly altered clastics of Late Mississippian (middle-Meramecian to Chesterian) and Pennsylvanian age. The older quartzites, slates, and pebble conglomerates (chert and quartz) are Devonian and Mississippian.

Traditionally, all clastic rocks below the Lisburne carbonates are placed in the Endicott Group. However, in this report, clastic rocks of Late Mississippian (post-middle Meramecian) and Pennsylvanian age are considered equivalents of the Lisburne and not included in the Endicott Group. Late

Mississippian clastics are probably facies of the Alapah Limestone, and Pennsylvanian clastics are probably equivalent to parts of the Wahoo Limestone. Both of these limestones are in the Lisburne Group. Guldenzopf and others (1980) called all post-middle Meramecian clastic strata below the Lisburne carbonates "Endicott" to distinguish the younger clastics from the older clastics, but this nomenclature is discontinued, because it is confusing.

In this report, the Endicott Group is not subdivided. Generally, the Endicott Group in the NPRA is subdivided into two formations: the Kekiktuk Conglomerate and the Kayak(?) Shale. However, these subdivisions are not used here because of difficulty in identification and correlation with the type sections of these formations. Originally, the Endicott Group was proposed as a lithologically distinctive lithostratigraphic unit for surface field mapping (Tailleur and others, 1967, p. 1350). The type area is in the Endicott Mountains of the central Brooks Range. Several lithologically related clastic formations that range from Late Devonian to Early Mississippian were combined to make up the Endicott Group.

In previous Tetra Tech reports that describe the subsurface of the NPRA, the basement rocks initially were called the Neruokpuk Formation and later the "Argillite"; coarse clastic rocks overlying the basement rocks were referred to as the Kekiktuk Conglomerate, and finer clastics overlying the Kekiktuk and underlying the Lisburne carbonates were called the Kayak or Kayak(?) Shale. These subdivisions of the Endicott Group are not used in this report because of uncertain stratigraphic relationships between the widely separated exposures of the Endicott. At Inigok 1, for example, nearly 2,000 ft (610 m) of coarse clastics identified earlier as Kekiktuk contain no beds of quartz and chert conglomerate, although conglomerate beds originally were considered to be typical of the unit (Brosge and others, 1962, p. 2195). The Kekiktuk at Inigok 1 is five times thicker than the described surface sections in the type area or elsewhere; however, these strata fit the extended description "... deposited in a paralic environment" given by Tailleur and others (1967, p. 1355). The Endicott Group at Inigok 1 is Late Mississippian (early to middle Meramecian).

The lithostratigraphic top of the Endicott Group, and of younger clastic rocks, occurs in successively younger strata to the north of Inigok 1. At Inigok 1, the top of the Endicott Group is the top of the M-1 parastratigraphic unit (figs. 18, 19, 33). At Ikpikpuk 1, the top of the clastics is within unit M-2a, whereas at East Teshekpuk 1 and West Fish Creek 1, the top is questionably within unit M-2b (figs.

10, 11, 38, 39). At J. W. Dalton 1, the top of the clastics is within unit P-1 (figs. 30, 31).

The inferred distribution of the Endicott Group is shown in cross sections F-F' and H-H' (figs. 21, 22, 25, 26). In cross section F-F', the Endicott Group onlaps the Umiat Platform to the south-southeast. To the north-northeast, the Endicott is unconformably overlain by the Alapah Limestone. Near its base, the Alapah may have a basal clastic member (for example, at Ikpikpuk 1). Cross section H-H' indicates that the Endicott Group is truncated and overlain by the Alapah Limestone. The Endicott is not known to occur west of the Meade Arch, although bedded reflectors from the Oumalik High (near Oumalik 1) and from the deepest part of the Meade Basin may be from rocks of the Endicott Group.

Lisburne Group

The Lisburne Group is a time-transgressive rock unit consisting mainly of carbonates (seismic maps 6, 7; fig. 4). The group includes Early to Late Mississippian rocks in the DeLong Mountains of the western Brooks Range (Sable and Dutro, 1961), Endicott Mountains of the central Brooks Range (Bowsher and Dutro, 1957), and the Lisburne type locality around Cape Lisburne (Campbell, 1965; 1967; Armstrong and others, 1971). In the northeastern Brooks Range and Prudhoe Bay Field, Lisburne carbonates are Late Mississippian to Middle Pennsylvanian (Armstrong and others, 1970; Armstrong and Mamet, 1974). Alaskan terminology was extended to carbonates in the British Mountains of the northern Yukon Territory (Mamet and Mason, 1970); these carbonates, as well as equivalent carbonates in the Richardson and Ogilvie Mountains farther south, are Late Mississippian to Early Permian (Bamber and Waterhouse, 1971). In the NPRA, the Lisburne is Late Mississippian to Early Permian.

The Lisburne Group is subdivided into three main formations in the central and eastern Brooks Range. In ascending order, these formations are Wachsmuth Limestone, Alapah Limestone (Bowsher and Dutro, 1957, p. 6), and Wahoo Limestone (Brosge and others, 1962, p. 2190-2192). To date, the Wachsmuth Limestone has not been identified in the NPRA subsurface (fig. 4).

The Lisburne is underlain by transgressive basal clastic rocks correlated with the Endicott Group in the NPRA, Prudhoe Bay Field, and northeastern Brooks Range (Armstrong, 1974; Armstrong and Bird, 1976). In these areas, some of the basal clastics are time-equivalents of the Lisburne carbonates. The uppermost several tens of feet of the Endicott Group

consist of interbedded shales and thin carbonates (Bowsher and Dutro, 1957, p. 6, 15; Brosge and others, 1962, p. 2186).

Lisburne Clastics

The Lisburne clastics comprise the Itkilyariak rocks that unconformably overlie the Endicott Group (figs. 9, 10). The Itkilyariak Formation, named by Mull and Mangus (1972), is a transitional clastic unit at the base of the Alapah Limestone in the far eastern Brooks Range. The Itkilyariak consists of red and maroon sandstone, conglomerate, and limestone interbedded with shales. Rocks that have similar lithologies and occupy a similar stratigraphic position were penetrated in the Prudhoe Bay Field and in the NPRA. At Prudhoe Bay State 1, the Late Mississippian Itkilyariak that overlies the Kekiktuk Conglomerate (Armstrong and Mamet, 1974) is 1,620 ft (493 m) thick. At Ikpikpuk 1, more than 1,279 ft (390 m) of Late Mississippian interbedded reddish sandstones, shales, and limestone lie above rocks correlated with the Endicott Group.

Clastics of the same type underlie the Wahoo Limestone at J. W. Dalton 1 and W. T. Foran 1 (figs. 29, 30). Micropaleontologic analyses of these clastics indicate that the redbeds, sandstones, shales, and interbedded limestones are lateral equivalents of the lower part of the Pennsylvanian Wahoo carbonates at J. W. Dalton 1 (Anderson, Warren and Associates, 1979) and, by inference, at W. T. Foran 1. These Pennsylvanian basal clastics also were called "Itkilyariak," which would be an appropriate name if the Itkilyariak Formation were redefined formally as a basic lateral redbed equivalent of portions of the Lisburne Group. Such a redefinition would circumvent the difficulty created by the disparity in age between the formation at the type locality and in J. W. Dalton 1.

Alapah Limestone

The Alapah Limestone contains most of the Lisburne hydrocarbons discovered in the Prudhoe Bay Field. Commercial quantities of oil occur in the "Dolomite unit" of the Alapah at Prudhoe Bay State 1 and Mikkelsen Bay State 1. Efforts to trace the limits of the "Dolomite unit" in the NPRA were made, and preliminary results indicate that the "Dolomite unit" lies below 10,000 ft (3,048 m) in areas where it may be prospective.

The Alapah is Late Mississippian in all locations where it is recognized (fig. 36). It unconformably overlies the Wachsmuth Limestone in the central Brooks Range, and is either unconformably overlain by the Permian Siksikpuk

Formation, or was truncated by Holocene(?) erosion. In the central Brooks Range, the formation is 970 ft (296 m) thick and includes four units; in descending order, these units are shaly limestone, limestone, cherty limestone, and shale (Bowsher and Dutro, 1957, p. 6-7).

Northeastward from the Shainin Lake area, additional Alapah section was recognized and classified informally as an upper dolomitic member (Brosge and others, 1962, p. 2189-2190). In the western Romanzof Mountains, the Alapah is subdivided informally into a lower sandy limestone unit and an upper dark carbonate unit that is dolomitic throughout (Sable, 1977, p. 13-17). The stratigraphic relationship between the Alapah and the overlying Wahoo Limestone is questionable. Sable (1977, p. 17) considers the contact to be conformable, whereas Brosge and others (1962, p. 2190) reported the contact probably is disconformable. The Alapah contrasted to the overlying Wahoo shows:

- The Alapah is Late Mississippian; consists mainly of dark-gray, shaly limestone (mudstone, wackstone, and some packstone); and is dolomitic.

- The Wahoo is Pennsylvanian; consists mainly of light-gray, massive limestone (mainly grainstone and packstone); and is only slightly dolomitic (Armstrong and Mamet, 1974; Armstrong and Bird, 1976).

Therefore, the Alapah-Wahoo contact probably is disconformable. For example, the "Dolomite unit" immediately underlies the Pennsylvanian Wahoo Limestone over the Fish Creek Platform. However, the "Dolomite unit" is overlain by additional dark Mississippian rocks farther south at Ikpikpuk 1 and Inigok 1.

A similar relationship probably exists in the Prudhoe Bay Field and surrounding areas. For example, along the crest of the Colville High (Armstrong and Bird, 1976, fig. 1), the "Dolomite unit" directly underlies the Wahoo (figs. 25-28); this is well-shown at Union Kookpuk 1, Sinclair Colville 1, and Union Kalubik Creek 1. However, slightly down the flank of the Colville High, several hundreds of feet of additional Mississippian rocks overlie the "Dolomite unit" and underlie the Wahoo; this is shown best at Arco Itkillik River 1 and Prudhoe Bay State 1.

The Alapah probably is restricted to the east side of the Meade Arch-Oumalik High trend. No Mississippian carbonates were penetrated in the northwestern part of the Reserve. Seismic stratigraphy indicates that the overlying Wahoo Limestone oversteps the Alapah northward toward the Barrow

Arch, southward toward the Umiat Platform, and westward toward the Meade Arch and Oumalik High. Some Mississippian carbonates may be present in the deeper parts of the Meade Basin. The Alapah may be overlapped south of the Oumalik High, but the seismic-stratigraphic indications for overlap are ambiguous.

The inferred distribution of the Alapah Limestone is shown in cross sections E-E', F-F', and H-H' and the unit M-2 isopach and lithofacies map (figs. 18, 22, 26, 36). In cross sections E-E' and F-F', the Wahoo unconformably overlies the Alapah to the northwest and north-northwest. Additionally, in cross section E-E', the Alapah thins by onlap and truncation toward the Barrow High. A similar pattern is shown in cross section F-F' on the south flank of the Fish Creek Platform near East Teshekpuk 1. From the Fish Creek Platform, the Alapah thickens markedly into the Umiat Basin and thins because of onlap and truncation by the Wahoo onto the northwest flank of the Umiat High. On the east flank of the Oumalik High, the Wahoo unconformably overlies both the Alapah and the Endicott Group as shown on cross section H-H' (figs. 25, 26).

Wahoo Limestone

The Wahoo Limestone, named for exposures in the northeastern Brooks Range, extends throughout the eastern half of the Brooks Range where it is up to 1,367 ft (417 m) thick. The Wahoo is composed of light-gray limestones with relatively few shale partings. In the type area, it includes a coarse- to fine-grained gray limestone upper member. In outcrop, the light-colored Wahoo contrasts with the dark-gray Alapah below (Brosge and others, 1962, p. 2190-2192, 2196-2198). On electric logs, the Wahoo presents a "blockier" appearance than the Alapah, because the Wahoo contains fewer interbedded shales than the Alapah (fig. 43). Where present, the Wahoo overlies the Alapah Limestone in the Brooks Range, Prudhoe Bay Field, and eastern NPRA south of the Barrow Arch.

In the northeastern Brooks Range, the top of the Wahoo is truncated and overlain by the Sadlerochit Group. There, the Wahoo is mostly Pennsylvanian, but the upper part of the formation is probably Early Permian (Brosge and others, 1962, p. 2192).

The Wahoo extends westward into Prudhoe Bay Field, but its upper part is absent over the Fish Creek Platform and along the Arctic Coast (figs. 37-41). There, the Wahoo is unconformably overlain by the Sadlerochit Group and the "Pebble Shale."

The Wahoo Limestone is 369 ft (112 m) thick at J. W. Dalton 1, and together with the basal Lisburne clastics totals 879 ft (268 m) thick (figs. 29-32). At W. T. Foran 1, the Wahoo carbonates are 377 ft (115 m) thick, and the carbonates and clastics together are 565 ft (172 m) thick. The Wahoo thickens south of the Fish Creek Platform; the formation is 1,507 ft (459 m) thick at Inigok 1 and 1,667 ft (508 m) thick at Ikpikpuk 1. At Inigok 1, section is added at both the top and bottom of the formation. At the top, the added section consists of Late Pennsylvanian to Early Permian carbonates that are missing to the north, indicating truncation in that direction; at the base, the added section is considered to be a clastic equivalent of the Wahoo Limestone.

The Wahoo extends westward over the northwestern NPRA (figs. 9-12). Kugrua 1 bottomed at 12,588 ft (3,837 m) in Pennsylvanian Lisburne carbonates that are equivalent to the Wahoo. The massive carbonates are 1,053 ft (321 m) thick at Kugrua 1, and seismic information indicates that the Lisburne overlies the "Acoustic basement" at about 12,800 to 13,000 ft (3,900 to 3,962 m); the total Wahoo section probably is about 1,265 to 1,465 ft (386 to 447 m) thick. At Tunalik 1, before the well bottomed at 20,335 ft (6,198 m) in the Wahoo, 1,240 ft (378 m) of Wahoo-equivalent carbonates were penetrated. Total thickness of the Lisburne at Tunalik 1 was not estimated, but at least an additional 500 ft (152 m) of Pennsylvanian carbonates are expected to be below the total depth.

The Wahoo corresponds closely to the P parastratigraphic unit east of the Meade Arch-Oumalik High trend (figs. 13-16). West of this trend, the lithostratigraphy of unit P is not as well understood, although the Wahoo and unit P are assumed to be identical.

Lithostratigraphic cross sections B-B', D-D', F-F', and H-H' and the unit P-1 isopach and lithofacies map (figs. 10, 22, 26, 41) show the inferred distribution of the Wahoo Limestone. The Wahoo extends across the Fish Creek Platform in cross sections B-B', F-F', and H-H'. In cross section F-F', the Wahoo is truncated and probably subcrops below the "Pebble Shale" unit north of the Barrow Arch; near Seabee 1, the Wahoo extends across the Umiat Platform.

In cross section D-D', the Wahoo laps out onto the Meade Arch and is unconformably overlapped by the "Transition Zone." Cross sections B-B', D-D', and H-H' show that the Wahoo also laps out on the Oumalik High where it is unconformably overlapped by the "Transition Zone." West of the Meade Arch-Oumalik High, the Wahoo Limestone or laterally equivalent rocks lie directly on the basement. The Wahoo is either thin or absent on the Wainwright Arch and the Utukok High.

"Transition Zone"

The "Transition Zone," which overlies the massive Wahoo Limestone and underlies the Echooka Formation in the northwestern part of the NPRA (figs. 9-12, 42, 44), may be an important seal for hydrocarbons in the underlying Lisburne formations. The informal term "Transition Zone" is used for the unit because it is considered to be part of the Lisburne Group, yet is lithologically similar to the overlying Joe Creek Member of the Echooka Formation.

The "Transition Zone," known only in the subsurface of northern Alaska, is distinguished from the underlying Wahoo by the greater number of interbedded shales and thinner carbonates beds contained in the zone. At Tunalik 1, Ikpikpuk 1, and Inigok 1, the "Transition Zone" is overlain by the Joe Creek Member of the Echooka Formation, and at Kugrua 1, it is overlain by the Ikiakpaurak Member of the Echooka (figs. 10, 22). The Joe Creek consists of interbedded shales and carbonates, but the "Transition Zone" contains much more limestone and less shale. On electric logs, the top of the "Transition Zone," which is also the top of the Lisburne, is distinguished by marked deflections of the gamma-ray, spontaneous potential, resistivity, and sonic curves (fig. 44). The "Transition Zone" is Early Permian.

"Transition Zone" rocks are best developed west of the Meade Arch-Oumalik High trend (figs. 9-12). At Kugrua 1, the unit is 537 ft (109 m) thick; at Tunalik 1, it is 1,575 ft (480 m) thick, and contains 745 ft (227 m) of basalt. Seismic stratigraphy indicates that the "Transition Zone" becomes very thick in the Meade and Tunalik Basins.

Seismic stratigraphy also indicates that the "Transition Zone" disconformably overlies the Wahoo Limestone and overlaps it between the Wainwright and Meade Arches (figs. 10, 11). The Echooka Formation overlaps the "Transition Zone" in this area.

On the north and east sides of the Wainwright and Meade Arches, the "Transition Zone" unconformably overlaps the Wahoo. The Wahoo is either thin or absent on the Utukok High near the western boundary of the Reserve, against the Wainwright and Meade Arches, and across the Oumalik High. Rocks of the "Transition Zone" are probably the only Lisburne carbonates present in these areas.

"Transition Zone" rocks are thinner east of the Meade Arch-Oumalik High trend. At Inigok 1, the unit is 185 ft (56 m) thick and, at Ikpikpuk 1, it is 1,212 ft (370 m) thick (fig.

17-20). The "Transition Zone" does not overlap the Wahoo in the eastern part of the NPRA, but wedges out under the Echooka Formation. In turn, the overlapping "Kavik shale" unconformably overlies the Echooka.

The distribution of the "Transition Zone" south of the Oumalik High-Key River Arch trend is not known. An equivalent to the "Transition Zone" is known on the surface in the British Mountains of the northern Yukon. There, Early Permian interbedded carbonates and shales overlie the massive Pennsylvanian Wahoo Limestone (Bamber and Waterhouse, 1971).

Sadlerochit Group

In northern Alaska, two formations comprise the Sadlerochit Group: the Echooka Formation and the Ivishak Formation. The "Ivishak sandstone" member of the Sadlerochit Group is the main hydrocarbon reservoir in Prudhoe Bay Field (fig. 70).

Echooka Formation

In the NPRA, the Echooka Formation is subdivided into the lower Joe Creek Member and the upper Ikiakpaurak Member (seismic maps 9, 10; figs. 45, 46). The Joe Creek is a calcareous shale and argillaceous limestone unit consisting of interbedded shales and limestones near the base and shales in the upper part. The Joe Creek (figs. 9-12, 17-20) occurs in wells that penetrated deeper basinal sediments: Tunalik 1, Inigok 1, Ikpikpuk 1, and Topagoruk 1. The Ikiakpaurak Member that overlies the Joe Creek is mostly a clastic unit. The Ikiakpaurak consists of glauconitic sandstone, quartz and chert pebble conglomerate, and siltstone.

West of the Meade Arch, the Ikiakpaurak overlaps the Joe Creek and pinches out below the "Kavik shale." The Joe Creek, Ikiakpaurak, and Kavik lap out toward the north. East of the Meade Arch, the "Kavik shale" unconformably overlies the Ikiakpaurak. The Kavik lies directly on the Lisburne north of the Ikiakpaurak wedge-out.

The Echooka Formation is a relatively thin stratigraphic unit that does not exceed a thickness of 400 ft (122 m) in the NPRA, but the formation was deposited over a period of about 40 million years. Its average deposition rate is by far one of the slowest of all formations in the NPRA. Major unconformities occur at the top and bottom of the Echooka (fig. 44), and several unconformities may exist within the unit.

The Echooka was first proposed as the lower member of the Sadlerochit Formation by Keller and others (1961, p. 178).

Detterman and others (1975, p. 5-11) raised the Sadlerochit to group status and the Echooka to formation status, and subdivided the Echooka into the lower Joe Creek Member and upper Ikiakpaurak Member (fig. 4).

Ivishak Formation

In this report, the informal names "Kavik shale" and "Ivishak sandstone" are used to describe the subsurface Ivishak Formation in the NPRA (seismic maps 14-19; figs. 47, 48, 70). The Kavik Shale was first proposed as a lower shale member of the Ivishak Formation by Detterman and others (1975, p. 11-12), but Jones and Speers (1976, p. 32) later proposed that the Kavik be raised to formation rank in the Prudhoe Bay Field.

In surface outcrops in the northeastern Brooks Range, the Ivishak Formation is subdivided into three members which are, in ascending order, the Kavik Shale, Ledge Sandstone, and Fire Creek Siltstone (Detterman and others, 1975). The Kavik Shale and Ivishak Sandstone described by Jones and Speers (1976) correspond to the Kavik Shale and Ledge Sandstone, respectively, of the surface outcrops in the northeastern Brooks Range. Jones and Speers did not recognize the Fire Creek Siltstone in the subsurface at Prudhoe Bay; furthermore, rocks similar to the Fire Creek Siltstone were not identified in the northeastern NPRA subsurface.

The "Kavik shale" is a distinctive unit composed of shale and siltstone, and may be an important hydrocarbon source (fig. 47). No important reservoirs occur within this unit. Separating the Kavik unit from the overlying Ivishak unit facilitates mapping and correlating. In all Tetra Tech reports issued prior to 1979, the Kavik was included as a member of the Ivishak Formation, which distorted significantly all sand-shale ratios calculated for the Ivishak Formation. This distortion was particularly evident south of the Arctic Coast where the Kavik thickens. To calculate realistic ratios in later work, the "Ivishak sandstone" alone was used (fig. 70).

The "Ivishak sandstone" is the most important hydrocarbon reservoir in the Prudhoe Bay Field where it is composed of interbedded conglomerate, sandstone, and siltstone. At Prudhoe, the unit has up to 30 percent porosity; at W. T. Foran 1 and J. W. Dalton 1 (figs. 29-32), oil shows and porosities of 15 percent were encountered. Hydrocarbon accumulation in the "Ivishak sandstone" reservoir at Prudhoe mainly is due to truncation by the overlying impermeable "Pebble Shale" unit. The sand is interpreted to be a braided

stream-delta complex (Morgridge and Smith, 1972; Jones and Speers, 1976). In the northwestern NPRA, Tetra Tech in 1978 interpreted the "Ivishak sandstone" to be a strandplain offshore bar complex. The unit becomes siltier to the west; west of the Meade Arch, the sandstone content of the unit steadily decreases until, at Tunalik 1, the unit is almost all siltstone (fig. 48).

Shublik Formation

The Shublik Formation is one of the more widespread and easily identifiable units in northern Alaska (fig. 49). In the Arctic Coastal Plain, the Shublik is composed mainly of dark-gray, organic, calcareous siltstones and shales. On the Barrow High and in the area of the Meade and Wainwright Arches, the Shublik contains much glauconitic silty sandstone and shell hash. In the northwestern coastal area of the NPRA, the contact between the Shublik and the overlying Sag River Sandstone is gradational. In the extreme southern part of the NPRA and off the Reserve in the central Brooks Range, the Shublik is an organic black shale containing chert layers and nodules in outcrops (Tailleur, personal communication, 1979). The Shublik was originally named and described by Leffingwell (1919, p. 115).

Sag River Sandstone

The Sag River Sandstone overlies the Shublik Formation and underlies the Kingak Formation (seismic maps 20, 21; figs. 50, 71). The Sag River is traceable into Prudhoe Bay Field, and probably is equivalent to the Karen Creek Sandstone of the northeastern Brooks Range (Detterman and others, 1975, p. 16-18). In this report, definition of the Sag River Sandstone is restricted to the light-greenish-gray glauconitic orthoquartzite that was described originally by Fackler (1970).

At Inigok 1 and Tunalik 1, the Sag River Sandstone laterally grades into partly calcareous siltstones, shales, and silty sandstones; on the Barrow High, these rocks also are glauconitic. The Sag River Sandstone grades into shale toward the Barrow Arch (figs. 14, 18, 30) and south of lat 70°20' N (figs. 10, 22, 71). The limit of the sandstone is drawn at the 1-to-8 sand-shale ratio contour line (fig. 50).

For practical mapping, the top of the Sag River Sandstone was used in computing Sag River interval (unit TR-3b) thicknesses and sand-shale ratios shown in figure 50. The "Sag River siltstone" of Jones and Speers (1976) was not included in calculations (although it was in previous years), because the irregular thickness and distribution would have introduced

statistical distortions. The calculated sand-shale ratios and isopach values indicate that the Sag River Sandstone consists of several isolated barlike accumulations (fig. 71).

Kingak Formation

In this report, all strata overlying the Sag River Sandstone or the Shublik Formation, and underlying the "Pebble Shale" and its included sandstones and siltstones, are considered to be part of the Kingak Formation (figs. 54, 55, 72). Defined in this manner, the age of the Kingak ranges from Early Jurassic (Sinemurian) to Early Cretaceous (Hauterivian).

The Kingak, described most recently by Detterman and others (1975, p. 18-20), was named by Leffingwell (1919, p. 119) for Kingak Cliff in the northeastern Brooks Range. The thickest completely exposed surface section of the formation is about 1,200 ft (366 m) thick, but the thickness of composite sections is estimated to total about 3,000 ft (914 m). Fossils ranging from Early to Late Jurassic (Tithonian) were recovered from outcrops in the type area, but fossils ranging through most of the Middle Jurassic (Callovian) are probably absent. Imlay and Detterman (1973, p. 16-19) suggested that this fossil gap, dated as latest Bathonian or "late Bajocian to possible early Bathonian...," may be the Late Callovian unconformity or an older one. These workers and Detterman and others (1975, p. 19) indicated that numerous unconformities may occur within the Kingak.

Seismic stratigraphy and paleontology also suggest that numerous regional and local unconformities occur within the Kingak (see "Jurassic Study"). The pattern of seismic reflectors suggests low-angle foreset beds that downlap onto the unconformity surfaces. The age of the foreset beds becomes progressively younger to the south-southeast, indicating progradation. The source of the sediments probably was northwest of the Reserve.

In the NPRA subsurface, the widespread mid-Jurassic unconformity is recognizable on electric logs and seismic sections, and may represent the fossil gap described by Imlay and Detterman (1973). Because of this unconformity, Tetra Tech subdivided the Kingak informally into the "Lower Kingak" and "Upper Kingak" in 1979. The "Lower Kingak" (fig. 54) consists of Early-Middle(?) Jurassic shales, siltstones, and sandstones that underlie the mid-Jurassic unconformity. The "Upper Kingak" (fig. 55) includes Late Jurassic shales, siltstones, and sandstones that overlie the mid-Jurassic unconformity. The "Upper Kingak" probably includes some Neocomian rocks, especially in the western NPRA.

In the northern Yukon, the Kingak Formation is subdivided into several lithostratigraphic units. Poulton (in press), proposing that the Kingak be raised to group status, recognizes four formations: the Early Jurassic Manuel Creek and Aimstrom Creek Formations, and the Middle Jurassic Richardson Mountains and Aklavik River Formations. This group is unconformably overlain by the Late Jurassic Husky Formation or Porcupine River Formation. These units correspond to the "Lower Kingak" described in this report.

In the Mackenzie Delta subsurface, Dixon (1981) recognized six "depositional-complexes" bound by major hiatal surfaces in the Upper Jurassic-Lower Cretaceous rocks. The first three of these "depositional-complexes" include all of the Husky Formation and the newly described "Parsons Group," which comprises the "Bluff Sandstone," "Blue-Gray Shale," and Kamik Formation. These units probably are equivalent to the "Upper Kingak" described here.

In the NPRA, the Kingak contains a number of prospective sandstone bodies. Existence of the sandstone is not obvious from outcrop studies in the northeastern Brooks Range where the Kingak consists "primarily of shale" (Detterman, and others, 1975, p. 19).

"Lower Kingak" Unit

In the "Lower Kingak," the best known sandstone is the "Barrow sandstone," which includes the "lower Barrow gas sand" and "upper Barrow gas sand," and is the producing gas zone in the South Barrow gas field. At South Meade 1, a thin silty sandstone occurs at the same horizon. No other prospective sandstone bodies are yet identified in the "Lower Kingak" (seismic maps 25-27).

The "Barrow sandstone" is an argillaceous sandstone in the Barrow area (figs. 73, 74). This unit is not a sheet sandstone, but a series of isolated sandstone bodies that are barlike in map view (see "Jurassic Study"). These sandstones climb toward the north, indicating that the "Lower Kingak" was deposited during a transgressive cycle.

"Upper Kingak" Unit

In the western NPRA, the "Upper Kingak" contains several sandstone bodies associated with the crest or the flank of the Meade and Wainwright Arches. Specifically, these sandstones include the:

- "Simpson sandstone, which is at the base of the "Upper Kingak" in the northwestern NPRA (seismic maps

28-30; figs. 75, 76). This unit was referred to as the "Kugrua" sandstone in Tetra Tech reports prepared prior to 1980, and was one of the objectives at Kugrua 1, South Meade 1, Peard 1, Walakpa 1, and Kuyanak 1. The unit is a barlike sandstone body restricted to the Meade Arch-Wainwright Arch area in the northwestern NPRA. The "Simpson sandstone" trends east-northeast and is about 100 mi (161 km) long and 30 mi (48 km) wide with a maximum thickness of about 200 ft (61 m).

- "Peard sandstone," which is a thin silty sandstone less than 100 ft (30 m) thick (fig. 77). The informally named "Peard sandstone" is present within the "Upper Kingak" at both Peard 1 and Kugrua 1. The unit may thicken toward the "Pebble Shale" truncation to the north, below the Chukchi Sea.

- Two unnamed silty and argillaceous sandstones in Tunalik 1 that had shows of gas. The deeper sandstone at 12,510 to 12,605 ft (3,814 to 3,842 m) contains high-pressure gas that caused drilling problems; attempts to test this sandstone were unsuccessful. The shallower sandstone at 10,900 to 11,650 ft (3,323 to 3,552 m) had a gas show on the mud log (fig. 60). Seismic-stratigraphic studies suggest that these sandstones and several nearby similar anomalies are submarine fans. The deeper sandstone appears to be an elliptical body about 10 mi (16 km) long, and the upper sandstone is truncated northeast of Tunalik 1 near the village of Wainwright where it possibly forms a hydrocarbon trap (see "Tunalik Study").

- "Walakpa sandstone," which is a gas-bearing sandstone that occurs at the top of the "Upper Kingak" (fig. 78). The "Walakpa sandstone" may be the basal part of the "Pebble Shale" unit rather than the Kingak Formation, and probably correlates with a sandstone body about 150 ft (46 m) thick at Kuyanak 1. If the sandstone body in Kuyanak correlates with the gas-bearing "Walakpa sandstone," the extent of the Walakpa reservoir may be very large.

In the northeastern NPRA, all of the wells drilled indicate that the "Upper Kingak" is composed mainly of shale and siltstone. A large seismic anomaly, the "Kealok anomaly," is identified on the south flank of the Fish Creek Platform. This anomaly seems to be an offshore bar-type deposit or longshore island (figs. 79, 80). Seismic profiles of the anomaly show a flat base and convex top, and the map view of

the entire anomalous complex resembles the present-day sand islands off the Texas Gulf Coast, with relatively straight basinward (seaward) "strand lines" facing toward the south and northward (lagoonward) projecting lobes, interrupted by "passes." The main part of the anomaly is about 40 mi (60 km) long, 15 mi (24 km) wide at its maximum width (on the largest shoreward lobe), and an estimated 240 ft (73 m) thick at its maximum. An isolated, smaller "island" is shoreward to the southwest and near West Fish Creek 1.

The "Kealok anomaly" was first tested at North Inigok 1 in 1981, with a good gas kick and slight flow of gas in a drill-stem test of the "Kealok" zone. North Inigok 1 was drilled on the up-dip part of a northern lobe and may have penetrated a back-bar facies. It is possible that sandstones occur in the main part of the bar, basinward to the south. At North Inigok 1, the anomaly is siltstone to very fine-grained sandstone. West Fish Creek 1, to the northeast of the anomaly, tested a small amount of gas from a sandy siltstone in the same seismic-stratigraphic interval, but the seismic anomaly does not extend to West Fish Creek 1.

"Pebble Shale" Unit

The "Pebble Shale" unit consists of fissile and carbonaceous shale, and several thin sand bodies that may have reservoir potential. The unit is the cap rock in the Prudhoe Bay Field and is considered to be the principle source for hydrocarbons in the "Ivishak sandstone" (Morgridge and Smith, 1972).

The "Pebble Shale" unit is recognized over most of the North Slope in wells and by seismic data (seismic maps 39, 40, 45; figs. 80-84), although the unit loses its identity to the south toward the Brooks Range (figs. 13-16) and is absent over the Fish Creek Platform (figs. 38, 39, 61). The "Gamma Ray Shale" zone near the top of the "Pebble Shale" is one of the most distinctive log markers on the North Slope (fig. 60). In the NPRA, the top of the "Gamma Ray Shale" is used as the top of the "Pebble Shale" unit. In the northeast Brooks Range, the "Pebble Shale" unit is present on the surface as an informal member of the Kongakut Formation (Detterman and others, 1975, p. 21-25); the Kongakut includes the "Clay Shale," Kemik Sandstone, "Pebble Shale," and "Siltstone" members. In the NPRA, the "Pebble Shale" sandstone in the basal part of the "Pebble Shale" unit may be equivalent, though not continuous, with the Kemik Sandstone. The "Clay Shale" formerly was identified in the NPRA subsurface as part of the "Pebble Shale" unit; however, the rocks identified as "Clay Shale" now are believed to be part of the underlying Kingak Formation. The "Siltstone" member is not recognized in the subsurface in the NPRA.

Workers disagree on the stratigraphic positions and nomenclature of sandstones below the "Gamma Ray Shale" zone. According to most workers, the Kuparuk River Formation is conformable with the underlying Kingak Formation (which is Jurassic at Prudhoe Bay), underlies the Lower Cretaceous unconformity, and is not part of the "Pebble Shale" unit. Thinner sandstones that perhaps fill channels in the unconformity surface are named the Put River Sandstone (Jamison and others, 1980), which is probably equivalent to the surface Kemik Sandstone. Other workers believe that the hydrocarbon-bearing Kuparuk River Formation in the Prudhoe Bay area is part of the "Pebble Shale" unit, which lies unconformably on Permo-Triassic and Jurassic rocks.

In this report, the term basal "Pebble Shale" unconformity (seismic maps 34, 35) is used instead of Lower Cretaceous unconformity, because Cretaceous rocks were encountered below the "Pebble Shale" unconformity in the western NPRA at Tunalik 1. These Cretaceous rocks are included in the Kingak Formation, as they lie below the unconformity.

Several sandstone bodies are associated with the lower "Pebble Shale" in the northern NPRA, especially on the flanks of the Barrow High. These sandstones are collectively referred to as the "Pebble Shale" sandstone in this report, even though the individual sandstone bodies are not continuous (fig. 62). As at Prudhoe Bay, those sandstones that are below the basal "Pebble Shale" unconformity are classified here as part of the Kingak Formation; only those sandstones above the unconformity are part of the basal "Pebble Shale" unit. In earlier Tetra Tech reports, the "Pebble Shale" sandstone in the NPRA was referred to as Kuparuk River Sandstone; this nomenclature was discontinued after 1979, because the basal "Pebble Shale" sandstone is above, not below, the basal "Pebble Shale" unconformity. In this report, only the "Walakpa gas sandstone" is named for a well (Walakpa 1), as its stratigraphic position is still questionable.

The "Walakpa gas sandstone" (fig. 78) probably correlates with the basal "Pebble Shale" sandstone. A factor supporting such a correlation is that new section is added below, rather than above, the sandstone at Walakpa 2, which is a down-dip, step-out well; additionally, biostratigraphic analysis indicates that Neocomian instead of Oxfordian rocks lie immediately above the sandstone. According to Guldenzopf and others (1980), this gas-producing sandstone (unnamed) was incorrectly correlated with the "Kealok anomaly" within the "Upper Kingak." This previously unnamed sandstone is called the "Walakpa sandstone" in this report and is described above

in "Kingak Formation." The "Walakpa gas sandstone" probably correlates with the "Walakpa sandstone" in Kuyanak 1, but the correlation is only tentative.

Torok Formation and Nanushuk Group

The Torok Formation and overlying Nanushuk Group (seismic maps 46, 47, 52; figs. 85, 86) are prograding, time-transgressive lithostratigraphic units, as shown on lithostratigraphic and compressed seismic sections. The subdivisions of each group are lithofacies units that are also time-transgressive. Within the Torok, well log correlations were tied into seismic horizons by Andrews and Pratt (1978); these correlations were expanded by Molenaar (written communication, 1979). For this report, all Torok-Nanushuk lithologic boundaries are taken from Molenaar (written communication, 1979), except for a boundary at Ikpikpuk 1 that was selected higher in the section.

The Torok Formation is mainly shale with interbedded argillaceous siltstones and sandstones (figs. 86, 87). Originally, the Torok included all rocks lying between the underlying Okpikruak Formation and overlying Nanushuk Group (Gryc and others, 1951, p. 160); the formation later was restricted to the upper shaly part of the unit. The lower interbedded sequence of conglomerate, sandstone, siltstone, and shale was placed in the Fortress Mountain Formation by Patton (1956, p. 222). According to Molenaar, the Fortress Mountain Formation is probably a clastic facies of the Torok; consequently, the term "Fortress Mountain" is not used in this report. Rocks that were grouped in the Fortress Mountain Formation in earlier Tetra Tech reports now are considered to be part of the "basal Torok."

The age of the Torok ranges from Neocomian(?) or Aptian to Early Cenomanian, and Torok and Nanushuk rocks prograde from the west toward the east. South of the Carbon trend in the south-central part of the NPRA, the "basal Torok" may be as old as Neocomian (for example, at Lisburne 1). Toward the northeast, the Torok is progressively younger until it becomes practically "all Albian at Cape Halkett 1 and Arco Itkillik River 1" (Mickey, personal communication, 1979).

The Torok clinoform beds dip at a relatively low angle west of the Meade Arch-Oumalik High trend, but dips are steeper east of the trend. Numerous high-amplitude, continuous reflectors are in the Torok-Nanushuk (figs. 10, 12). Some "hummocky" reflectors from the "basal Torok" fondoform beds and "sigmoid-oblique" seismic patterns at the undaform-clinoform juncture are associated with several of the strong reflectors. The difference in depositional pattern may be

related to several variables, including basin configuration, rate of sedimentation, rate of subsidence, and wave energy.

For subsurface mapping purposes, Molenaar (written communication, 1979) described two major facies units for the Nanushuk; one of these units was dominantly marine and the other dominantly nonmarine. These terms are used in this report because the stratigraphy and formal lithostratigraphic nomenclature of the Nanushuk Group is complex (Andrews and Pratt, 1976).

Nanushuk marine beds prograde from west to east, and, in turn, Nanushuk nonmarine beds prograde from west to east over the marine beds (seismic maps 50-52). The two major source areas for the Nanushuk nonmarine beds were the Corwin Delta in the western NPRA and the Umiat Delta in the southeastern corner of the NPRA, as far east as the Sagavanirktok River (Huffman and Ahlbrandt, 1979).

Nanushuk nonmarine rocks, recognized in the subsurface from lithologic, gamma-ray, sonic, and density logs, are characterized by the presence of numerous coal beds. Intertonguing of facies is common between the Torok undathem facies and Nanushuk marine facies, and between the Nanushuk marine and nonmarine facies, especially east of the Meade Arch. The tongues indicate rapid lateral shifts in the position of the shoreline during deposition of the Torok-Nanushuk sequence.

Relatively more sandstone is found in the Nanushuk east of the Meade Arch. Percent sand contours by Bird and Andrews (1979) indicate that the best Nanushuk reservoir conditions are in the "Umiat-Simpson Fairway," a zone about 20 mi (32 km) or more wide trending through the Umiat and Simpson areas (Payne, written communication, 1978).

Colville Group, Sagavanirktok Formation, and Gubik Formation

The Late Cretaceous Colville Group, together with the overlying Tertiary Sagavanirktok Formation and the Quaternary Gubik Formation were not studied in detail. These units are restricted to the northeastern NPRA and lie at or near the surface. Oil and gas occur in the Colville Group at Umiat and shows have been reported in Tertiary rocks, but these rocks are not considered prime hydrocarbon targets in the Reserve.

The Colville Group consists of the marine Seabee Formation and Schrader Bluff Formation in the northeastern NPRA; the nonmarine Prince Creek Formation occurs farther south.

Seismic-stratigraphic studies (Molenaar, written communication, 1979) indicate that the Seabee downlaps on the Nanushuk. The Colville and Nanushuk contact is at the mid-Cenomanian unconformity, which is distinct on logs and seismic sections and well-defined by fossils.

TECTONIC FRAMEWORK

The NPRA is subdivided tectonically into three major east-trending elements that make up the Alaskan North Slope. These elements are the Barrow Arch, Colville Trough, and Brooks Range Orogen, and correspond generally to the Coastal Plain, Foothills, and Brooks Range physiographic provinces, respectively (Carter and others, p. 22, 1977). Somewhat in this manner, physiographic terms are used in part in this report: the Arctic Coastal Plain, Foothills Fold Belt, and Brooks Range Orogen.

ARCTIC COASTAL PLAIN

Cretaceous rocks in the Arctic Coastal Plain are relatively flat-lying and essentially without structure. The configuration of Paleozoic rocks at depth either controls or modifies the expression of the post-Paleozoic sediments in this region. A combination of seismic interpretation and seismic stratigraphy define the Paleozoic tectonic elements, as shown in figure 8. Convergence of seismic horizons 1100 (seismic maps 9, 10), 1300 (seismic maps 6, 7), and 1400 (seismic maps 3, 4) with horizon 1500, the "Acoustic basement" (seismic maps 5, 8, 11-13), defines the margins of the Paleozoic basins (figs. 9-20).

The main Paleozoic tectonic elements recognized beneath the Arctic Coastal Plain and much of the Foothills Fold Belt are identified in figure 8. These elements are the Barrow, Meade, and Wainwright Arches; Colville, Ikpikpuk, Kokalik, Meade, Tunalik, Umiat, and Utukok Basins; Barrow, Oumalik, and Utukok Highs; and Fish Creek and Umiat Platforms.

Minor flexures between basins include the Ivisauruk Saddle between the Tunalik and Meade Basins, and the Inigok Saddle between the Ikpikpuk and Umiat Basins. Several minor anticlines bounded by high-angle faults are present in the Paleozoic rocks in the Ikpikpuk River and Umiat Quadrangles (figs. 25-28; seismic map 1); the most prominent structure of this type is the Key River Arch. Additionally, a high-angle fault system that may be displaced for a total of several thousand feet exists on the eastern margin of the Meade Basin. South of the Carbon trend, the complex structure of the Cretaceous rocks obscures the Paleozoic tectonics.

FOOTHILLS FOLD BELT

In the Foothills Fold Belt, Cretaceous rocks are progressively more deformed toward the south. Several shallow, detached, shale-filled folds occur in the northern foothills, as shown in figures 26 and 28. The prominent anticlines from west to east are the Kaolak, Meade, Shaningarok, Oumalik, Koluktak, Titaluk, Wolf Creek, and Umiat anticlines. These folds originate above the "Pebble Shale" unit. It is probable that the structure of the older rocks is different from that of the Cretaceous rocks (figs. 13-16).

In the southern foothills, several detached, shale-filled folds are associated with thrust faults that originate from below the "Pebble Shale" level. The southern Foothills Fold Belt is bisected by the Carbon trend, a zone of deep-seated anticlines along thrust faults. The Carbon and Awuna anticlines are the two largest structures along the Carbon trend. Six large surface anticlines occur south of the Carbon trend: Norseman, Snowbank, Archimedes, Blizzard, Driftwood, and Brady. It is not known if these anticlines have closure at depth.

BROOKS RANGE OROGEN

The Brooks Range Orogen is a region where older rocks are thrust over the Cretaceous. Near the northern boundary of the Brooks Range Orogen, Permo-Triassic and Mississippian rocks are at or near the surface (Tailleur and others, 1966). Mississippian carbonates are near or on the surface in the middle part of the region, and Devonian rocks are at the surface at the southern boundary.

The Brooks Range Orogen is so complexly faulted that few seismic horizons can be traced with certainty more than a few miles (figs. 88-92). Consequently, interpretation of the structure of the region was based on shallow, intermediate, and deep form-line maps (figs. 93-95). Seismic events traced at these three levels from one side of a fault to another were fair to poor; it is not possible to determine if the seismic events are from the same stratigraphic level.

The most commonly cited age for the major thrusting of the Brooks Range is Early Cretaceous. However, it is likely that some of the identifiable thrust sheets in the Brooks Range are the result of compression that occurred in post-Cretaceous time. The main evidence for post-Cretaceous thrusting is the deformation of the Late Cretaceous Colville Group near Umiat (figs. 19, 20, 23, 24).

The great thickness of the Torok-Nanushuk sequence to the south indicates that uplift occurred in the vicinity of the Brooks Range during Early Cretaceous time. Paleotransport and facies analysis of the Nanushuk Group indicates two source areas: the DeLong Mountains, or submarine Herald Arch, and the Endicott Mountains (Huffman and Ahlbrandt, 1979).

GEOLOGIC HISTORY

The geologic history of the NPRA is shown in historical cross sections B-B', E-E', and G-G' (figs. 96-98) that parallel three of the correlation cross sections (figs. 9, 17, 37) in this report. The historical cross sections show development of the main tectonic and stratigraphic elements of the Arctic Coastal Plain in the NPRA. Eight datums, corresponding to the tops of parastratigraphic units M-1, M-2b, P-2 or PR-2, TR-3b, J-1, Ka-1b, and Ka-3, and sea level, show the depositional history. These parastratigraphic units, identified in figure 4, are practical time-rock-stratigraphic units that are ideal for showing geologic history. Some of the more important potential reservoir sandstones (for example, the "Barrow sandstone" and Sag River Sandstone) are shown in a stippled pattern in figures 96 through 98.

Each successive historical section shows the development of positive tectonic areas and basins in geologic time. Periods of relative stability, uplift, or subsidence are inferred from the sections. The vertical scale was exaggerated 74 times in figures 96 and 97, and about 20 times in figure 98.

DATUM M-1

Datum M-1 corresponds to the top of unit M-1. Deposition of M-1 took place during Early Mississippian (late Kinderhookian) time in a northwest-trending trough in the northeastern part of the NPRA. Deposition was restricted to the northeast by the Barrow Arch, to the west by the Oumalik High, and to the south by the Umiat Platform (figs. 8, 35). The historical sections indicate that the Fish Creek Platform area was uplifted during Late Mississippian (middle to late Meramecian) time, late in the deposition of unit M-1 or early in the deposition of unit M-2. Initial growth of the Ikpikpuk Basin probably occurred in Early Mississippian (late Osagian to early Meramecian) time.

DATUM M-2

Datum M-2 corresponds to the top of unit M-2. Unit M-2 was deposited on the eastern side of the NPRA during Late Mississippian (late Meramecian) time (fig. 36). Tectonic highs existed to the northwest (Barrow Arch), west (Meade Arch and Oumalik High), and south (Umiat Platform).

Uplift of the Fish Creek Platform resulted in truncation of unit M-1 and overlapping by unit M-2 at East Teshekpuk 1, North Kalikpik 1, South Harrison Bay 1, and West Fish Creek 1. Although unit M-2 overlapped the Fish Creek Platform, the type of sediments deposited still were influenced by the Fish Creek Platform. Uplift of the Barrow Arch took place late in the deposition of unit M-1 or early in the deposition of unit M-2. Additionally, seismic stratigraphy indicates that the Meade Basin may have begun to develop west of the Oumalik High during late Mississippian time.

DATUM P-2

Historical reconstruction of datum P-2 shows lowering of tectonic highs (Meade Arch and Oumalik High), which resulted in deposition of Pennsylvanian and Early Permian rocks (unit P-1) across the NPRA into the northwest. Deposition was limited by the Barrow High and Meade Arch in the north (figs. 41, 42). Datum P-2 is used as the "Latest Paleozoic" event in figures 97 and 98.

During Late Mississippian (late Chesterian) or Early Pennsylvanian (Morrowan) time, tectonic emergence of the Wainwright and Meade Arches controlled the limits of P-1 and P-2 deposition (fig. 96); further lowering of the Barrow Arch resulted in deposition of unit P-1 north of the Fish Creek Platform. At the same time, the trough-like trend of the Ikpikpuk Basin was extended in the direction of the Umiat Basin. Overlap of the Umiat Platform by unit P-1 may have occurred in Late Mississippian time (fig. 97).

Additionally, growth of the Tunalik Basin probably began while the Meade Basin continued to grow. Deposition of unit P-2 was influenced basically by the same tectonic features that influenced unit P-1 deposition during Early Permian (late Wolfcampian) time.

The absence of unit P-2 in the northeastern NPRA is probably due to a combination of nondeposition caused by tectonic uplift of the Barrow Arch and truncation caused by uplift of the Fish Creek Platform in Early Permian (middle Leonardian) time.

DATUM PR-2

Datum PR-2 corresponds to the top of unit PR-2, which was deposited in Late Permian time. Unit PR-1, deposited in the north-central part of the NPRA during Early Permian (middle

Leonardian) time, lapped onto the Meade Arch to the north and Wainwright Arch to the west, and was limited to the northeast by the Fish Creek Platform. In all parts of the NPRA, unit PR-1 thickened to the south, with the thickest known section occurring in the Meade and Umiat Basins.

Unit PR-2 was deposited higher on the flanks of tectonic positive areas such as the Barrow, Meade, and Wainwright Arches in Early Permian (late Leonardian) time. These tectonic highs influenced the type of PR-2 sediments that were deposited (fig. 46). Unit PR-2 lapped onto the Meade Arch to the north, Wainwright Arch to the west, and Barrow Arch to the northeast. Sands were deposited on the flanks of all the tectonic highs; the thickest accumulations encountered to date are at Peard 1 and Kugrua 1. To the south, unit PR-2 possibly was limited by the Oumalik High. The thickest section of unit PR-2 in this region was found in Ikpikpuk 1. Datum PR-2 is used in place of datum P-2 as the "Latest Paleozoic" event in figure 96.

DATUM TR-3b

Widespread deposition of units over the tectonic highs took place in Early to Late Triassic time (fig. 96). However, these highs continued to influence the type of sedimentation around their edges, as shown by marked thinning of Triassic deposits where they lap over the tectonic highs. Datum TR-3b corresponds to the top of unit TR-3b, the youngest Triassic unit.

Unit TR-1, the oldest Triassic unit, was deposited throughout the NPRA in Early Triassic (Scythian) time, lapping onto the Meade Arch in the north and possibly the Barrow Arch to the northeast (fig. 47). The unit thickened to the south, with the greatest thickening in the Tunalik Basin.

Unit TR-2 was deposited over the Meade Arch toward the Barrow High during Middle Triassic (Anisian-Landinian) time (fig. 48). The unit was restricted to the northeast by the Barrow Arch, thickened toward the south in the Umiat and Tunalik Basins (fig. 97), and thinned toward the north. The tectonically positive areas were areas of sand deposition on the periphery of the Meade Arch in an east-west trend.

Unit TR-3a, which is Middle to Late Triassic, varies in thickness from more than 500 ft (152 m) to less than 200 ft (61 m) (fig. 49). The "thicks" and "thins" generally are related to the previously existing tectonic elements. However, some of the "thicks" do not correspond directly with the basins. For example, in the central part of the Reserve,

unit TR-3a thickens in a northern basin-like feature between the east flank of the Meade Arch and the Ikpikpuk Basin, and possibly extends north to the Barrow Arch (fig. 97). In the western half of the Reserve, the unit is thickest in the Tunalik Basin and thins northward toward the Barrow High. Unit Tr-3a thins and onlaps the Barrow High northwest of Dease Inlet and also thins on the flanks of the Meade Arch. Uplift or tectonic oscillation of the Fish Creek Platform at the end of early Triassic (Spathian) time influenced deposition of unit TR-3a.

Unit TR-3b was deposited in the northern half of the NPRA during Late Triassic time (figs. 50, 98). The tectonic highs that influenced deposition of unit TR-3b were the Barrow High on the north and Barrow Arch on the northeast. The Sag River Sandstone deposited on the south flank of these highs grades into siltstone toward the south.

Three distinct areas of good sand development are present in unit TR-3b: an area southeast of the Barrow High, on the northeastern flank of the Meade Arch between South Meade 1, North Simpson 1, and Drew Point 1; an area on the northeastern flank of the Wainwright Arch in the vicinity of Peard 1 and Kugrua 1; and an area on the south flank of the Barrow Arch from Cape Halkett 1 through the Prudhoe Bay area. An especially good sand area is associated with the Fish Creek Platform around West Fish Creek 1. A separation between the Barrow High and Barrow Arch is indicated by the thickening of unit TR-3b to the northeast in the vicinity of Dease Inlet near Tulageak 1 and West Dease 1.

DATUM J-1

Datum J-1 corresponds to the top of unit J-1. Unit J-1, which is Early to Middle Jurassic (Sinemurian to Callovian) in age, is thickest in the northern half of the Reserve (seismic maps 25-27; fig. 54). During this interval of geologic time, sea level was relatively higher over all of the NPRA, and all of the tectonic highs in the northern part of the NPRA were blanketed by marine shale, siltstone, and some sandstones. The J-1 unit transgressed from east to west in a series of pulsations over the Fish Creek Platform, caused by the lowering of the Fish Creek Platform in Early Jurassic time and/or the relative rise in sea level (see "Jurassic Study"). Transgression is indicated by a series of sand bodies ("Barrow sandstone") that were deposited on the shelf on a post-Triassic erosional surface (seismic maps 25-27; fig. 54). The sands are stacked above one another and were shifted from the southeast to the northwest during the deposition of unit J-1 (figs. 99, 100).

Unit J-1 onlaps the Barrow High to the north, Barrow Arch to the northeast, and Wainwright Arch to the northwest. The exact deposition limit of unit J-1 cannot be determined, because the unit is truncated by the basal "Pebble Shale" unconformity and overlain by unit Ka-1b over the tectonic highs. Areas of sand development during the deposition of unit J-1 are on the east flank of the Meade Arch, and on the Barrow High, Dease Inlet area, and Fish Creek Platform (figs. 54, 73). The greatest sand thicknesses seem to be on the Fish Creek Platform and the east flank of the Meade Arch.

Unit J-1 thins because of downlap toward the south, as shown at Inigok 1 in figure 97. The Ikpikpuk and Umiat Basins received little sediment during Early to Middle Jurassic time.

DATUM Ka-1b

Datum Ka-1b corresponds to the top of unit Ka-1b, deposited after units J and Ka-1a. At the end of the unit J-1 depositional cycle, a long period of nondeposition or erosion prevailed throughout the northern NPRA. Widespread transgression resulted in renewed sedimentation in Late Jurassic (Oxfordian) time (seismic maps 28-30; fig. 57). The mid-Jurassic unconformity (seismic maps 25-27), which is at the top of unit J-1, is the most prominent of several unconformities that occur near J-1.

Unit J-3a was deposited throughout the northern half of the Reserve, and extended to the southern edges of the present Oumalik and Utukok Highs (fig. 56). The unit is thickest on the eastern side of the NPRA from the Colville Trough to the Umiat Basin, and thins uniformly to the south and west.

Unit J-3aI, containing the "Simpson sandstone" deposited early in Oxfordian time, was limited on the northwest by the Wainwright Arch, the north by the Barrow High, and the northeast by the Barrow Arch. The unit onlaps the Barrow High to the north, and thickens toward the northeastern side of the NPRA, between the Ikpikpuk and Umiat Basins on the south and Fish Creek Platform on the north. Unit J-3aI is thickest near North Inigok 1 where 320 ft (98 m) of the unit was drilled. On the western side of the Reserve, unit J-3aI thickens to the north from the flanks of the Meade and Wainwright Arches (fig. 57). The unit thins toward the southern edges of the Oumalik and Utukok Highs. Within unit J-3aI, the "Simpson sandstone" is a clastic facies consisting of sands and silts that were deposited in an east-northeast trend south of the Barrow High. The sandstone extends from

the Wainwright Arch to the vicinity of South Simpson 1 and is best developed near Kugrua 1 (fig. 57).

The depositional trend of unit J-3b is similar to that of unit J-3a (fig. 58). Unit J-3b, deposited throughout the northern half of the NPRA during Late Jurassic (Oxfordian-Kimmeridgian) time, thins over the Wainwright and Meade Arches, Oumalik High, and Fish Creek and Umiat Platforms. The unit thickens in the Ikpikpuk and Umiat Basins and probably also thickens in the Tunalik Basin. The unit is thickest at Ikpikpuk 1 where it is 850 ft (259 m) thick. The depositional cycle of unit J-3b was ended by a possible short-term hiatus during early Neocomian time.

Unit J-3c (fig. 59), deposited during early Neocomian (Berriasian-Valanginian) time, possibly onlaps the Barrow High to the north and Barrow Arch to the northeast. If so, the sediments were removed by the basal "Pebble Shale" unconformity and overlain by unit Ka-1b ("Pebble Shale"). To the west, unit J-3c onlaps the Meade and Wainwright Arches, and probably downlaps onto older rocks to the south. The unit thickens toward the southeast in the Ikpikpuk and Umiat Basins. At Seabee 1, its thickness of 2,271 ft (692 m) is questionable because log correlation is difficult and there is insufficient paleontologic data. As shown in figure 97, the J-3c unit, may include rocks belonging to unit J-3b or unit Ka-1a. Near the end of the J-3c depositional cycle, sedimentation was interrupted or slowed by a major uplift to the north and northeast. Rocks of Jurassic and Triassic age were eroded in Valanginian time (figs, 96, 97); at the same time, the Tunalik Basin subsided.

Unit Ka-1a was deposited south of the Wainwright and Meade Arches in Neocomian time (figs. 55, 60). Tunalik 1 was the only well in which the unit was recognized, and the thickest known section of the unit is at Tunalik 1 (fig. 8, 60). Unit Ka-1a also may be present at Seabee 1 and Inigok 1, and thin erosional remnants of the unit may occur at West Fish Creek 1, South Harrison Bay 1, South Meade 1, South Simpson 1, Walakpa 1, Walakpa 2, and Kuyanak 1.

Following the Ka-1a depositional cycle, the Barrow High-Barrow Arch trend continued to rise and the basal "Pebble Shale" unconformity truncated unit Ka-1a in late Neocomian time. A rapid rise in relative sea level and anoxic bottom conditions occurred. Unit Ka-1b, composed mainly of the "Pebble Shale," was deposited when the sea transgressed completely over the tectonic highs in the northern NPRA (fig. 61); basal "Pebble Shale" sandstones are associated with these tectonic highs. On the west flank of the Meade Arch, the basal sandstones were deposited in a northeast trend,

indicating influence by the Barrow Arch farther to the north. To the south, the sandstones were associated with the northern flank of the Umiat Platform. Several thin sandstone beds were deposited around the Barrow High; one of these beds produced oil in South Barrow 20.

The upper part of unit Ka-1b consists of the "Gamma Ray Shale" zone of the "Pebble Shale" unit (seismic maps 39, 40, 45; fig. 60). Prominent positive gamma-ray log deflections suggest that the unit may contain a series of unconformities. The largest deflection at the top of Ka-1b is the "basal Torok" unconformity; the tentative age of this unconformity is latest Neocomian.

DATUM Ka-3

Rapid subsidence began over most of the NPRA in early Aptian time and continued until middle Cenomanian time, which corresponds with datum Ka-3. The maximum subsidence was to the south in the Colville Geosyncline (figs. 96-98), and probably was associated with uplift far to the south (not the present thrust structures of the Brooks Range). The source of the sediment probably was to the south and west. A series of time-transgressive deposits prograded toward the northeast.

Unit Ka-2 was deposited from the west-southwest to east-northeast of the NPRA in early Aptian time; its base is the "basal Torok" unconformity. The lower angled and less well defined clinoforms of unit Ka-2, as compared to those of unit Ka-3, occur mostly west of the Meade Arch-Oumalik High trend. This pattern may indicate a more rapid rate of sedimentation, or a greater rate of subsidence and lower wave energy. Sediment accumulation was thickest to the southwest (fig. 96).

Unit Ka-3, which comprises the rest of the time-transgressive Torok-Nanushuk sequence, was deposited in late Aptian to early Cenomanian time. East of the Meade Arch-Oumalik High trend, the Torok clinoform beds of unit Ka-3, as seen on seismic sections, are relatively steeper and more variable than those in the underlying Ka-2 unit (figs. 31, 32).

The early Aptian depositional patterns of the Torok-Nanushuk sequence (seismic map 52) are thought to be controlled by subsidence of the Colville Trough and the silling effect of the Barrow High and Barrow Arch (Molenaar, written communication, 1979). The silling effect of these tectonic highs to the north would account for the relatively lower marine energy indicated by the lower angled Ka-2 clinoforms

in the western part of the Reserve. Although units Ka-2 and Ka-3 overlapped the tectonic highs, the highs were responsible for local variations in sedimentary transport directions. This was shown on the Fish Creek Platform and the flanks of the Wainwright and Meade Arches by Andrews and Pratt (plates IV, V, and VI, 1978).

In late Aptian to early Albian time, the Colville Geosyncline was filled with sediments that overlapped the tectonic highs to the north (Barrow High and Barrow Arch) and northeast (Fish Creek Platform), as shown in figure 96. During this time, more open marine conditions may have prevailed, with an increase in wave energy, resulting in the shoreface sands being deposited along the Umiat-Inigok-Simpson trend.

Initially, a basinal flysch-like facies deposited in deep water filled the Colville Geosyncline; these deposits are called the Torok fondothem or the "basal Torok," and were overlain by the slope deposits of the Torok clinothem. Flat-lying shelf shales of the Torok undathem facies or flat-lying sandstones and shales of the Nanushuk marine facies were deposited on top of the Torok clinothem when the Colville Geosyncline was nearly filled. The Nanushuk marine beds prograde from west to east, and Nanushuk nonmarine beds prograde from west to east over the Nanushuk marine beds. Source areas for the Nanushuk nonmarine were the Corwin Delta (early to middle Albian) in the western NPRA, and the Umiat Delta (probably middle Albian to Cenomanian) in the southeastern corner of the Reserve, as far east as the Sagavanirktok River. The Umiat Delta is younger than the Corwin Delta (Huffman and Ahlbrandt, 1979), and its sandstones are richer in quartz (Molenaar, written communication, 1979). As the basin filled, the ancient shore line advanced to the northeast.

Because the Torok-Nanushuk sequence is time-transgressive, the rocks in the sequence are younger toward the east. Intertonguing of facies is common between the Torok undathem and Nanushuk marine facies, and between the Nanushuk marine and nonmarine facies; the intertonguing is especially common east of the Meade Arch.

DATUM SEA LEVEL

The youngest datum used to show geologic history in the NPRA corresponds to sea level. A brief hiatus, represented by the mid-Cenomanian unconformity, ended the depositional cycle of unit Ka-3. The Colville Trough and Umiat Basin subsided in Late Cretaceous time, causing westward transgression in the eastern NPRA. Unit Kb was deposited in this area in early

Cenomanian time (figs. 67, 97). Late Cretaceous rocks are also known from outcrops in the Utukok River Quadrangle in the southwestern part of the Reserve. A worldwide rise in sea level may have contributed to the transgression.

During middle Cenomanian time following the transgression, unit Kb deposits prograded toward the east, similar to those of the Torok-Nanushuk sequence (Andrews and Bird, 1978). Deposition of unit Kb was restricted to the northeastern part of the NPRA, possibly because the source area at that time was the Umiat Delta (fig. 98). The depositional cycle of unit Kb was completed by late Senonian time.

VELOCITY STUDIES

The velocity studies focused on delineating velocity anomalies, explaining the possible exploration significance of these anomalies, and constructing the regional velocity fields needed for accurate calculation of isopach and depth values from seismic data. All of the available NPRA velocity data, including seismically derived and well velocity survey data, were used in the velocity studies.

On the basis of interval velocity characteristics, the sediments of the Arctic Coastal Plain and northern Foothills Fold Belt are divided into five groups (terminology from Mitchum and others, 1977):

- Group 1 consists of interbedded sandstones, siltstones, and shales in the Colville and Nanushuk Groups and Torok undathem. Interval velocity and average velocity usually increase with depth within group 1. On stacking velocity analyses, group 1 often displays a nearly linear increase in stacking velocity versus time.

- Group 2 is the predominantly shale Torok clinothem and "basal Torok." Group 2 increases in average velocity and interval velocity with depth, however, the rate of increase usually is less than that found within the overlying group 1. Group 2 frequently has an apparently hyberbolic increase in stacking velocity with time, asymptotically approaching a maximum value; occasionally, rapid increases in interval velocity or nearly constant interval velocity occur within this group.

- Group 3 consists of the "Pebble Shale" unit and Kingak Formation. The shales in group 3 have a much lower interval velocity than the overlying "basal Torok" sediments; sandstones and siltstones within the "Pebble Shale" and Kingak have much faster interval velocities than the encasing shales. Regionally, however, the high-velocity sandstones and siltstones comprise probably less than 15 percent of these formations. Average velocity and stacking velocity through group 3 generally remain constant or decrease with time or depth.

- Group 4 is Triassic section composed mostly of clastics and some dirty limestones. Interval velocity of these sediments is much higher than in the overlying Kingak shales. Average velocity and stacking velocity increase with depth throughout this unit.

- Group 5 is Paleozoic section that generally consists of a thick, very high-velocity carbonate sequence. Interval velocity appears to be relatively constant through the massive carbonates in most places. Average and stacking velocity increase downward through the section.

Considering the large area of the NPRA, the overall interval velocity characteristics are remarkably consistent across the Arctic Coastal Plain and northern Foothills Fold Belt, as illustrated by velocity displays from Tunalik 1 and Inigok 1 (figs. 101, 102; from seismic velocity survey and log calibration reports produced by Birdwell Division for each well). These two wells, both deeper than 20,000 ft (6,100 m), are the deepest wells on the North Slope and are located about 200 mi (322 km) apart near the western and eastern boundaries of the NPRA, respectively. Figures 101 and 102 display the calibrated sonic log for Tunalik 1 and Inigok 1, respectively, in addition to the time-depth, interval velocity, and average velocity functions derived from check-shot survey data. The five major velocity groups correlate between the two wells using any of the four curves, especially the interval velocity function.

Lower velocity Paleozoic clastics, penetrated only at Inigok 1, seem to be restricted to the deep basins (Umiat, Meade, and Utukok Basins). The lower interval velocity of this zone is sometimes evident on stacking velocity analyses, but it is not feasible to study interval velocities of these sediments using stacking velocity data, because of the large depth-to-spread length and depth-to-thickness ratios. Therefore, these restricted clastic Paleozoic sediments are lumped with the overlying Paleozoic carbonate rocks into group 5 for this velocity study.

Primary seismic reflectors, generated at the base of groups 2 through 5, were correlated regionally as horizons 0700, 1000, 1100, and 1500 (fig. 4). These seismic events correlate closely with the tops of the "Pebble Shale" unit, Sag River Sandstone, Lisburne Group, and "Argillite," respectively. The top of the Torok clinothem is a time-transgressive, gradational boundary which does not generate a seismic reflection that can be correlated regionally. Therefore, the velocity studies of the post "Pebble Shale" section (groups 1 and 2) are less precise than those of groups 3, 4, and 5.

VELOCITY INTERPRETATIONS

A regional interval velocity map was made for each of the five major velocity groups. The map of average velocity to the Torok clinothem (seismic map 53) represents interval velocity between the surface and the Torok clinothem. Additionally, because of the imprecise identification of the Torok clinothem and the need for accurate calculation of depth for the top of the "Pebble Shale" geologic marker, seismic map 54 was prepared to show regional average velocity to horizon 0700.

Regional Average Velocity to Torok Clinothem

Seismic map 53 was constructed to identify areas of hydrocarbon accumulations within the Colville and Nanushuk Groups (group 1) by correlating structural highs with definite low-velocity anomalies. Unfortunately, seismic map 53 is relatively featureless, with broad low-gradient anomalies that are merely the result of the normal increase of velocity with depth. No definite correlations with structure can be made. This approach could be more successful if the shallow Cretaceous was a primary objective in seismic data acquisition.

The velocity gradient in seismic map 53 generally increases to the south with values ranging from 7,500 ft/s along the northeast coast of the NPRA to 11,000 ft/s in the south. Two low-velocity anomalies interrupt this general trend. One, with velocity values less than 8,000 ft/s, is in the northeast and includes North Inigok 1, West Fish Creek 1, South Harrison Bay 1, North Kalikpik 1, East Teshekpuk 1, and most of Teshekpuk Lake. The other low-velocity anomaly has velocity values of less than 8,500 ft/s, centers around Kugrua 1, and incorporates Peard 1 in the northwestern NPRA.

The Cretaceous in the northern NPRA has no major regional structural features, but there are four local structural anomalies in the area of the low-velocity anomaly in the northeastern NPRA. One of these is a structurally low anomaly around Ikpikpuk 1 and three are structurally high anomalies in a large southeastward trend from just south of Drew Point 1 to southeast of North Inigok 1. The deepest structural area, around Ikpikpuk 1, has a time of 0.900 s. The three high anomalies are centered at: T16N-R8W to T14N-R5W, with a time of 0.500 s; T12N-R7W, with a time of less than 0.600 s; and T10N-R2W extending southeastward to T9N-R1W, with a time of less than 0.700 s. To the east of these anomalies, the time of the Torok clinothem increases to about 1.000 s at the eastern boundary of the NPRA.

Two major regional structural features occur just south of lat 70°N. One of these features is a structural low extending to the east across the entire NPRA. Immediately south of this low trend is a high structural trend, which also extends eastward across the NPRA. The shallowest parts of this high trend are defined by five separate anomalies centered near T4N-R40W, near T4N-R36W, between T3N-R34W and T4N-R31W, between T4N-R27W and T4N-R19W, and near T1N-R10W. To the south of this high structural trend, time values increase to a maximum value of 1.100 s.

Regional Average Velocity to Horizon 0700

The average velocity to horizon 0700 (top of the "Pebble Shale") increases to the south from less than 8,000 ft/s at Barrow to 13,500 ft/s at the southern limit of mapping (seismic map 54; see also seismic maps 39, 40). A low-velocity anomaly is centered around the "Disturbed Zone" at Barrow. Average velocity also decreases to less than 8,000 ft/s northeast of this anomaly, toward the Beaufort Sea; this decrease is thought to be associated with a low-velocity trend along the Barrow Arch.

Several small anomalies that occur in the overall regional gradient are more apparent in the north, mainly because of better data quality. The most significant of these anomalies is the low average velocity on the Fish Creek Platform in the northeasternmost part of the NPRA. The contours in the Fish Creek area trend southeastward as opposed to the more normal east-west orientation apparent across most of the NPRA. Another significant anomaly is in the vicinity of the Meade Arch; the regional average velocity that occurs across the Arch is higher than first order. A third major anomaly is near Kugrua 1 where the regional average velocity is lower than first order; this anomaly extends from Peard Bay south to about lat 70° N.

Regional Interval Velocity between Torok Clinothem and Horizon 0700

Interval velocity increases generally to the south, from less than 9,500 ft/s at Barrow to more than 14,500 ft/s at the southern limit of mapping (seismic map 55). The gradient is interrupted by five prominent velocity anomalies: two low-velocity anomalies in the northern NPRA, one high-velocity anomaly in the west-central NPRA, and two high-velocity anomalies in the southwest. The high-velocity anomalies suggest the presence of greater sand development in those areas.

One of the two low-velocity anomalies in the north is centered just south of Cape Halkett, near T15N-R3W, with interval velocities less than 10,000 ft/s. The other low-velocity anomaly occurs from Peard Bay to Kugrua 1 with interval velocities of about 10,750 ft/s.

The high-velocity anomaly in the west-central part of the Reserve is centered near T10N-R20W along lat 70°10'N. This anomaly has velocities greater than 13,500 ft/s.

The two high-velocity anomalies in the southwestern part of the Reserve trend east-west along lat 69°40'N, and extend from about T3N-R20W on the western boundary of the NPRA to about T3N-R40W near the center of the Reserve. The centers of these anomalies are at T3N-R35W and T3N-R24W where interval velocities reach a maximum of over 14,500 ft/s.

Regional Interval Velocity between Horizons 1000 and 0700

The velocity study of the interval between horizons 1000 and 0700, which includes the "Pebble Shale" and Kingak Formation of group 3, produced one of the most significant results of the geophysical studies (seismic map 61). In this interval, a high-velocity anomaly exists in an area where the "Simpson sandstone" and "Walakpa sandstone" occur. The anomaly provides additional evidence of the presence and configuration of sands in the Kingak Formation (compare seismic map 56 with figure 75). Walakpa 1 and Walakpa 2 had flows of gas from tests in the "Walakpa sandstone" and South Simpson 1 had mud-log shows of gas in the "Simpson sandstone." The main part of the anomaly is between Peard 1, Kugrua 1, South Meade 1, Topogaruk 1, South Simpson 1, Kuyanak 1, Walakpa 1, and Walakpa 2, and has a maximum value of more than 13,000 ft/s. The axis of the anomaly trends across most of the NPRA, from the Chukchi Sea near the mouth of the Sinaburuk River (T16N-R23W), through the area of Ikpikpuk 1, East Teshekpuk 1, West Fish Creek 1, and North Inigok 1.

North and south of this major high-velocity trend are two lesser low-velocity trends. The northern low-velocity trend seems to nearly parallel the southern flank of the Barrow Arch, and extends from about T21N-R19W near the Chukchi Sea southwest of Barrow to about T21N-R14W where it turns east-southeastward to T14N-R1E on Harrison Bay. The minimum value along this northern low-velocity trend is less than 10,000 ft/s. Two major anomalies are located along the axis; one is centered south of the "Disturbed Zone" at Barrow, between South Barrow 3 and Iko Bay 1, and the other is centered offshore from Smith Bay, northwest of Drew Point 1. The northern low-velocity trend seems to be related to the

presence of the Kingak Formation. Farther to the north, the mapped interval consisting solely of the Cretaceous "Pebble Shale" unit, seems to have a higher interval velocity than the Jurassic shales.

The axis of the southern low-velocity trend meanders across the NPRA from the Chukchi Sea coast near Kasegaluk Lagoon in the Tunalik 1 area, east-southwestward through the Inigok 1 area to the eastern boundary of the Reserve. This southern trend nearly merges with the high-velocity trend to the north in the extreme eastern part of the NPRA, resulting in a broad area of almost constant interval velocity. The low-velocity anomaly apparent at the western end of the southern low-velocity trend probably is related to the presence of the geopressured and gas-charged Neocomian sands and Jurassic shales at Tunalik 1. Any interpretation of the second low-velocity anomaly observed on the southern trend, centered north of Oumalik 1, would be speculative.

To the south of the southern low-velocity trend, interval velocity increases at a nearly uniform rate to a maximum value of 16,000 ft/s at about lat 60°20'N. Data south of this parallel are erratic because of the great depth and poor data quality.

Regional Interval Velocity between Horizons 1100 and 1000

The rocks between horizons 1100 and 1000 are in the Ivishak Formation, Shublik Formation, and Sag River Sandstone of velocity group 4. Interval velocity for the predominantly clastic lithology increases from north to south, from a minimum value of 11,000 ft/s in the Barrow area and adjacent offshore regions, to 19,000 ft/s at the southern limit of usable data (seismic map 57). This gross regional trend is interrupted by four prominent anomalies trending east-southeastward across most of the NPRA.

The largest of these prominent anomalies is the northernmost high-velocity trend, with an axis extending from near Skull Cliff on the Chukchi Sea, through Ikpikpuk 1 and between Inigok 1 and North Inigok 1, to T6N-R2E at the eastern boundary of the Reserve. Maximum interval velocity along this trend is greater than 16,000 ft/s near the Chukchi Sea.

South of this high-velocity anomaly and approximately parallel to it is the most prominent low-velocity anomaly in this interval, extending from about T14N-R30W near Wainwright Inlet to T4N-R2E near the eastern boundary of the NPRA. A minor extension of this anomaly trends southwestward from the Wainwright Inlet area to the Tunalik 1 area. Two minima

along the axis of this anomaly are centered at T14N-R30W and T10N-R15W, with minimum velocities of less than 12,000 ft/s.

The second high-velocity trend, farther south, is much narrower than the more prominent high-velocity anomaly to the north. This trend extends from about T11N-R32W east of the Tunalik 1 area through the Oumalik 1-Koluktak 1 area to T3N-R2E at the eastern edge of the NPRA. The maximum value of this high-velocity anomaly is more than 15,000 ft/s. This trend has three maxima, centered near T10N-R28W, T7N-R16W, and T5N-R7W.

The southernmost anomaly in this interval is a low-velocity trend that has about the same orientation as the other three trends. However, this anomaly trends east-west and extends from about T10N-R36W near Tunalik 1 to T2N-R2E just north of Umiat at the eastern edge of the NPRA. The lowest interval velocity along this trend is less than 13,000 ft/s. One large minimum is present along the trend, extending from T6N-R30W to T4N-R16W about 90 mi (145 km). South of this anomaly, the interval velocity is interpreted to be increasing. Mapping was discontinued at the 19,000 ft/s contour because the data were erratic and of poor quality.

No reservoirs are known in this interval except in the vicinity of the Barrow Arch. Wells drilled in both the high- and low-velocity anomalies failed to show the presence of significant reservoirs, so it is not possible to relate the anomalies on seismic map 57 to potential exploration targets.

Regional Interval Velocity between Horizons 1500 and 1100

The interval velocity of the group 5 Paleozoic rocks between seismic horizons 1500 (the top of the "Argillite") and 1100 (the top of the Lisburne) generally increases from north to south from a minimum value of about 14,000 ft/s to over 24,000 ft/s (seismic map 58). This regional gradient is interrupted by several high- and low-velocity anomalies. In the Fish Creek area in the northeastern NPRA, there is a high-velocity anomaly with interval velocities greater than 20,000 ft/s. South of this high-velocity anomaly, a very large and broad low-interval velocity anomaly exists, which largely coincides with the Ikpikpuk and Umiat Basins. Interval velocities of less than 16,000 ft/s are present in the minima centered near T6N-R8W between Inigok 1 and Koluktak 1 and near T9N-R15W between Topagoruk 1 and Oumalik 1.

A second major low-velocity anomaly is present in the southwest quadrant of the NPRA, roughly coinciding with the Utukok Basin between Kaolok 1 and Oumalik 1. This latter

low-velocity anomaly, which is not as sharply defined and has minimum values of less than 18,000 ft/s, extends to the north in the vicinity of the Meade Basin south of Kugrua 1, near T9N-R26W where interval velocities are as low as 16,000 ft/s.

An isolated low-velocity anomaly occurs in the Wainwright Quadrangle near T12N-R31W, about midway between Tunalik 1 and Kugrua 1. Several relatively small high-velocity anomalies are present across the northwestern part of the NPRA east-southeast of Tunalik 1 near T8N-R33W, midway between Kugrua 1 and Oumalik 1 near T8N-R21W, and near T13N-R31W in the Wainwright-Kuk River area. Still smaller anomalies are near T14N-R26W, T11N-R24W, and T10N-R17W.

From an exploration standpoint, the most promising anomalies are those low-velocity regions to the north near the onlap termination of horizon 1100. Lower interval velocities within this portion of the geologic section were found at W. T. Foran 1 and J. W. Dalton 1 where a somewhat porous Lisburne section was penetrated. Untested areas of low interval velocity adjacent to this termination line occur near T17N-R9W in the southernmost part of Smith Bay, at T14N-R23W through T15N-R14W (from east of Kugrua 1 to east-northeast of Topagoruk 1), and in an area extending from T15N-R31W through T16N-R26W (from Wainwright Inlet to just north of Kugrua 1). The low-velocity trends that extend southwestward from T15N-R28W to T11N-R31W (from near Peard 1 and Kugrua 1 toward Tunalik 1) and from T14N-R23W toward the Meade Basin (T9N-R26W) southeast of Kugrua 1 also may have exploratory interest.

The low-velocity anomalies to the south probably are related to thick noncarbonate Paleozoic sediments such as those penetrated at Inigok 1 and Ikpikpuk 1. Alternatively, the low-velocities may be caused by porous carbonate rocks. Significant clastic and/or carbonate reservoirs may be present within the Paleozoic section south of lat 70° N., but the great depths of these rocks limit their potential. The high-velocity anomalies are most likely caused by thick, nonporous, very high-velocity carbonates such as those penetrated at West Fish Creek 1, East Teshekpuk 1, and Kugrua 1. The high-velocity anomalies, therefore, are not considered to have potential economic value.

WELL AND SEISMIC DATA

Two basic types of velocity information are available for the NPRA: check-shot well survey data and seismic stacking velocity data. Check-shot surveys of wells provided the data used to prepare calibrated sonic logs for all NPRA wells

drilled since 1974, except for certain development wells in the Barrow area.

In all recent NPRA check-shot surveys of wells, "first-break" times were used to calculate average velocity, with three exceptions. At South Simpson 1, West Fish Creek 1, and W. T. Foran 1, average velocity was calculated using maximum amplitude time, as the records for these wells were filtered because of noise. Subsequent studies indicated that the times used for average velocity calculations in these three wells lag "first-break" times by about 15 ms, 15 ms, and 20 ms, respectively; the average velocity data were adjusted accordingly.

Additionally, check-shot surveys are available for seven wells drilled as part of the Navy Pet-4 program to test pre-Cretaceous sediments; no sonic logs were run in these old wells, and no field records exist. The method used to calculate average velocity is unknown. Study of the check-shot data relative to the regional seismic grid suggests that most of the surveys used "first-break" time. However, Simpson 1 data are believed to lag "first-breaks" by 10 to 15 ms. These Navy wells were used only as secondary control, and Simpson 1 data were adjusted for the apparent lag.

Stacking velocity analyses were generated from seismic stacking velocity data after final statics at approximately 3-mi (5-km) intervals. About 13,000 line miles (21,000 km) of multi-fold seismic data were acquired for the U. S. Navy and the Survey on and adjacent to the NPRA between FY 1972 and FY 1980 (fig. 3). More than 3,100 of the seismic stacking velocity analyses were used in this study.

About half of the analyses are state-of-the-art Velscan analyses; most of the rest are the less precise Velpak type. The FY 1974 survey used a forerunner of the Velscan package, but displays from the forerunner are more difficult to interpret and yielded less reliable results than other packages. Additionally, some continuous velocity analyses were generated in the Cape Halkett area where many permafrost anomalies occur.

INTERPRETATION TECHNIQUES

Several interpretation techniques were used. These techniques, described below, included editing and interpreting stacking velocity analyses, reducing stacking velocity to average and interval velocity, and constructing basic and regional velocity maps.

For depth calculations, seismic data were correlated to sea level datum north of lat 69°25'N (seismic map 59). South of lat 69°25'N, a sloping datum was used from sea level to an elevation of 2,000 ft (610 m) at the southern boundary of the NPRA.

Editing of Stacking Velocity Analyses

The first step in interpretation was to analyze the suitability of each stacking velocity analysis for estimating root mean square (RMS) velocity. Following a review of seismic sections, analyses in areas of discordant dip, across short-wave shallow anomalies (permafrost anomalies), or across faults were disregarded. Data quality and consistency with adjacent analyses were the final editing parameters.

Interpretation of Analyses

Time, velocity, normal moveout (NMO), and dip were recorded for valid data points within one cycle of the selected mapped seismic horizons. The mapped horizons (top of the Torok clinothem; horizon 0700; horizon 1000, or horizon 1020 south of the termination of horizon 1000; horizon 1100; and horizon 1500) correspond closely with the major regional velocity interfaces at the top of the Torok clinothem, top of the "Pebble Shale," top of the Triassic, top of the Paleozoic, and the "Acoustic basement," respectively.

The top of the Torok clinothem is a time-transgressive, gradational boundary that does not generate a seismic response that can be mapped regionally. Therefore, the interpretation of the Torok velocity data was not based on a single seismic horizon. To define the Torok clinothem, other seismic characteristics were used: specifically, changes in interval velocity, amplitude, and dip. At many places, at least two of the three characteristics, or changes, were present, increasing the confidence in the Torok clinothem identification.

Changes in velocity, amplitude, and dip were observed between the Colville and Nanushuk Groups and the deeper Torok sediments in many places. The stacking velocity in the Colville and Nanushuk Groups displays a nearly linear increase of velocity with time in many locations. The top of the Torok clinothem is often a velocity "knee" where the stacking velocity continues to increase with time, but does so at a slower rate. A change in amplitude usually is observed between the high-amplitude Colville and Nanushuk Groups and the normally opaque Torok sediments. A change in dip occurs in some places, especially on east-west lines, between the undathem sediments of the Colville and Nanushuk

Groups and the clinothem sediments of the Torok. These criteria were used to identify the time and RMS velocity of the top of the Torok clinothem on stacking velocity analyses.

Reduction to Average and Interval Velocity

Because there is a bias (source undetermined) in the velocity data, the Dix equation is insufficient to reduce stacking velocity to average velocity. As an empirically derived correction is required to correct the data, it was deemed unnecessarily laborious to select all of the intermediate data points required to reduce the data using the Dix equation. Dip correction was unnecessary because the dip is generally small; dip correction normally alters NPRA data values by only a fraction of 1 percent.

Numerous attempts were made to derive an empirical factor, including analysis of bias versus time, depth, and velocity. Finally, a reduction factor of 0.94 was selected. By reducing stacking velocity by 6 percent, the seismically derived data corrected were within 2 percent of the average velocity that was derived from well survey data for virtually all NPRA wells. This maximum error of ±2 percent is within the estimated limit of accuracy of the seismic data.

Interval velocity values were calculated from the Dix equation. When the expected error of interval velocity measurements was considered, no other correction was necessary to tie the well information.

Construction of Basic and Regional Velocity Maps

The first maps made were basic velocity maps for both average velocity and interval velocity. Raw stacking velocity data were used to prepare the average velocity maps; interval velocity data were derived from the Dix equation. Basic maps prepared without regard for well data were used to identify and analyze anomalies. A minimum of two data points was required to define a velocity anomaly.

Regional velocity maps were based primarily on well data and secondarily on seismically derived data between wells and in areas void of well control. Seismically derived data were corrected as needed. The regional maps tie the well data very closely and exhibit the most significant seismically defined anomalies. These maps were used to calculate depth and isopach values. Well velocity data for the Torok clinothem were derived using time values from the Torok clinothem time map.

ACCURACY OF STACKING VELOCITY DATA

Stacking velocity can be determined rather precisely with a state-of-the-art package such as Velscan, which uses information from up to 23 adjacent common depth points. Unfortunately, stacking velocity is merely the velocity which best stacks the data; it does not necessarily relate to average velocity, RMS velocity, or any other measurable property of the sediments. Where the earth is composed of horizontally layered strata across the zone of investigation, and the interval velocity of each layer is greater than that of the overlying layer, stacking velocity closely approximates RMS velocity. The more the area of interest varies from the ideal model, the poorer is the approximation of RMS velocity from stacking velocity.

The less disturbed regions of the NPRA resemble the ideal model. The sediments, although not horizontal, are reasonably concordant. The stacking velocity for parallel dipping beds exceeds the stacking velocity for horizontal beds by the factor $1/\cos \emptyset$, where $\emptyset$ is the angle of dip. Therefore,

$$V_{RMS} = V_{stack} (\cos \emptyset).$$

This relationship usually is valid for subparallel layers, but is invalid for discordant beds. The relationship between stacking velocity and RMS velocity in areas of discordant dip cannot be predicted except by modeling. Dip over most of the NPRA where concordant bedding is prevalent is usually less than 5°; thus, the cosine correction is insignificant.

Velocity generally increases with depth on the NPRA with two major exceptions, the low-velocity "Pebble Shale" and Kingak group, and the shallow high-velocity permafrost layer. The precise effect of these velocity inversions on the stacking velocity-RMS velocity relationship is unknown. Analysis of these effects was beyond the scope of this study.

Rapid lateral velocity variations (short-wave anomalies) also are present on the NPRA, especially in the area of permafrost anomalies. As with discordant beds, modeling is required to predict the effect of rapid lateral velocity variation on the stacking velocity-RMS velocity relationship.

Assuming that the stacking velocity approximates RMS velocity (or a theoretical or empirical relationship can be demonstrated), the accuracy of the approximation must be assessed. Because stacking velocity is calculated from NMO and the precision with which NMO is measured is generally constant, the accuracy varies with the amount of NMO. Thus, accuracy

decreases with depth. A rule of thumb is that accurate velocity data can only be derived to a depth of 1.5 spread lengths. Most of the NPRA seismic data were acquired with a spread length of 8,000 to 10,000 ft (2,440 to 3,050 m). Therefore, accurate velocity information is available only to depths of 12,000 to 15,000 ft (3,660 to 4,575 m).

If the geology resembles the ideal model, and the spread length is appropriate for the depth, stacking velocity still will differ from RMS velocity. The differences can be divided into two components: systematic error (bias) and random error. Bias can be empirically corrected; random error determines the usefulness of the seismically derived velocity data. Random error, mainly a function of the signal-to-noise ratio, is estimated at about 2 percent for NPRA seismic velocity data.

Interval velocity is calculated from the estimate of RMS velocity using the Dix equation:

$$V_{int} = \left[\frac{(V_2^2 t_2 - V_1^2 t_1)}{(t_2 - t_1)} \right]^{1/2}$$

where V is the RMS velocity, t is the two-way travel time, and the subscripts 1 and 2 refer to the top and bottom of the interval of interest, respectively. The factors determining the error of interval velocity measurements are the error in RMS velocity estimation and the ratio of depth to interval thickness. The accuracy of each seismically derived interval velocity estimate must be assessed individually.

From FY 1972 through FY 1980, stacking velocity analyses using different processing packages and parameters on NPRA data were acquired using different field parameters. Over 15 different data sets can be identified. Stacking velocity is calculated from NMO, and the zero-offset time (t_0) is a parameter in the equation. As different deconvolution operators were used on the data sets, different t_0 values resulted. Yet, in spite of the numerous data sets, an unexpected result was that only one instance was observed where a noticeable difference in the calculated stacking velocity exists between data sets. The exception involved certain FY 1979 data acquired by crew 1182; velocity analyses were generated from the data prior to application of the deconvolution operator. This set was corrected by recalculating stacking velocity from NMO using adjusted t_0 times. Explanation of this unexpected consistency in stacking velocity is beyond the scope of this study.

For NPRA data, an analysis of the relationship between average velocity, as calculated from well check-shot surveys using "first-break" times, and stacking velocity reveals that stacking velocity exceeds average velocity by an average of 6 percent. Use of the Dix equation reduced stacking velocity by less than 2 percent in most cases. Therefore, a positive bias exists in the data, resulting in a consistent overestimation of average velocity from seismic data. Determining the source of this bias is beyond the scope of this study. Al-Chababi (1974, pp. 458-475) suggests that a positive bias should be expected in an area with a shallow high-velocity layer such as permafrost. Velocity mapping was terminated wherever the data was considered unreliable because of great depth, complex structure, or erratic values of adjacent analyses.

CORRECTION FOR SHORT-WAVE ANOMALIES

Accurate depth and isopach values cannot be calculated using regional velocity fields in the vicinity of short-wave velocity anomalies (fig. 103). Because of the divergence of stacking velocity from RMS velocity in the vicinity of short-wave anomalies, detailed stacking velocity analysis will not correct the time distortions induced by such velocity anomalies. The anomalies are best handled in the time domain prior to depth and isopach calculation. The procedure consists of adjusting reflection time values so that the anomalies appear to be similar to the normal regional values. Use of regional velocity fields then results in correct depth and isopach data, even in the vicinity of the anomalies.

Two types of short-wave velocity anomalies are present on the NPRA. The more common anomalies are the shallow-layer, "weathering-type" anomalies (generally permafrost related) affecting all reflectors (see "Short-Wave Permafrost Corrections"). Less common are the subsurface anomalies, resulting from rapid variations in the thickness of the "Pebble Shale" unit and velocity variations in the "basal Torok." The unique seismic characteristics of both types of anomalies allow the anomalies to be identified easily; therefore, they were corrected with confidence.

The shallow velocity anomalies often are associated with lakes and streams. Under bodies of water, the high-velocity permafrost is abnormally thin, resulting in a "sag" or "pull-down" throughout the seismic section. The amount of "pull-down" was estimated at each shotpoint, and this amount of time was subtracted from all horizons prior to calculation of depths.

Subsurface anomalies are restricted to the Fish Creek area in the northeastern NPRA. Local absence of the low-velocity "Gamma Ray Shale" and other "Pebble Shale" and "basal Torok" sediments results in the "pull-up" of the underlying pre-Cretaceous seismic reflectors (fig. 104). The amount of "pull-up" was estimated, and this amount of time was added to the travel time for each pre-Cretaceous reflector prior to calculation of isopach and depth values.

To avoid over-correction of depth values, the average velocity measured in a well drilled within a permafrost anomaly must be adjusted. The adjusted average velocity was used to generate regional average velocity maps.

SURFACE VELOCITY MAPPING

In mapping surface velocity across the NPRA, numerous methods were tried. A surface velocity map (seismic map 60) was necessary for shallow control so that average velocity values could be interpolated for the shallow Cretaceous reflectors within the Colville and Nanushuk Groups. The interpolated average velocities subsequently were used for depth calculations. Attempts to map surface velocity using uphole time and shothole depth from both seismic data and well velocity surveys were unsuccessful. These studies demonstrated the rapidly fluctuating velocity of the first 100 ft of section in a permafrost area. Although a map of the erratic surface velocity may be interesting for some studies, it is not useful for interpolating velocities for depth calculations; therefore, these studies were suspended. The most useful method was to map the interval velocity of the first 500 ft (152 m) of the section, as determined from the well check-shot surveys. These data were contoured to make a regional surface velocity map.

Regionally, the surface velocity increases from north to south. This overall regional trend is interrupted by three prominent anomalies. A high-velocity trend extends southward from the Barrow area through South Meade 1 to Oumalik 1, the southernmost control point in the central NPRA. Another high-velocity region is in the area between Cape Halkett and Drew Point centered just south of J. W. Dalton 1 where a surface velocity of more than 9,000 ft/s was observed. South of the latter high-velocity region is a low-velocity zone extending from North Kalikpik 1 southwestward to Koluktak 1. These three anomalies interrupt the otherwise east-southeastward trend of the regional contours. A constant surface velocity of 11,000 ft/s was used south of a line extending from Seabee 1 to Oumalik 1 and Tunalik 1.

DEPTH AND ISOPACH CALCULATIONS

A main objective of the velocity study was to calculate accurate depth and isopach values for all of the interpreted seismic horizons in the NPRA north of the Brooks Range Orogen. These values were calculated by computer. The regional velocity fields previously described were input into the computer by building polynomial surfaces. Time values were input as raw section time, and necessary corrections were applied through computer programming. A "layer cake" method using interval velocities was used to calculate depth and isopach values for the pre-Cretaceous section, and an average velocity function was used for the shallower sediments.

After manual construction of the regional velocity fields, the fields were approximated with polynomial surfaces. To build these surfaces, a distribution of points was picked, and location coordinates (X, Y) and velocity values (Z) for the points were input into the computer. As well coverage is not evenly distributed throughout the NPRA, well velocity data was supplemented with seismically defined velocity data to facilitate adequate definition of all significant velocity trends and anomalies. The polynomial surfaces calculated by the computer approximate a mapped surface by creating a polynomial equation based on powers and cross-products of the X-Y coordinates and solving for the coefficients of that equation. The coefficients enable the computer to calculate velocity values for any given set of the X-Y coordinates.

These polynomial surfaces tied all well data and incorporated all major seismically defined anomalies on the regional velocity maps within allowable error. Allowable error was established as ±10 percent for surface velocity. At wells, the allowable error was reduced to ±5 percent for average velocity to the Torok clinothem and for all interval velocity fields, but remained ±10 percent at seismically defined interval velocity anomalies. Tolerance for the average velocity to horizon 0700, the critical seismic marker, was restricted to ±2 percent at wells and ±5 percent at seismically defined anomalies. A margin of ±100 ms was used for the Torok clinothem time map (seismic maps 48, 49).

The complexity of a surface is reflected in the complexity of the polynomial equation used to define it. The more complex the polynomial, the more coefficients are needed to describe it. The highest order polynomial surface used was an 8th order surface. A surface of this complexity is defined by a set of 45 coefficients. Generally, only one surface was built for the entire NPRA for each regional map. However, because of the complexity and required accuracy of certain

fields, it was not always possible to produce a satisfactory fit using only one surface. In such cases, the NPRA was partitioned, multiple surfaces were created, and adjoining surfaces were tied properly. Coefficients used for each area are tabulated in the seismic data base.

Before calculating depth and isopach values, raw reflection times required correction for a number of reasons. Some corrections applied only to certain horizons. For example, to facilitate seismic interpretation, horizon 0700 was mapped as the trough above a strong peak generated by the top of the "Pebble Shale"; therefore, a time value of 15 ms (about one-half cycle) was added to horizon 0700 to make a better tie with well data. Other corrections were applied to all horizons at a given shotpoint and thus affected only depth values. A third type of correction was applied to entire seismic lines.

The static correction for permafrost anomalies was a correction made for abnormally thin or low-velocity permafrost. Areas covered with only a thin layer of permafrost show a sag on the seismic section (fig. 105). This sag was estimated at appropriate shotpoints and a time value (negative) was added to raw section time to compensate for these short-wave velocity anomalies.

Another velocity-related correction, the horizon static correction, was applied only in a small area of the northeastern NPRA where "Pebble Shale" and "basal Torok" erosional remnants are present. Between these remnants, the "Pebble Shale" and "basal Torok" were replaced by higher velocity material, causing "pull-up" of the pre-Cretaceous seismic horizons (fig. 104). To compensate for this short-wave anomaly, horizon statics were estimated at pertinent shotpoints and added to horizon times for the pre-Cretaceous horizons.

Bulk static correction was applied to entire seismic lines, rather than individual shotpoints. This correction compensated for the difference between section time and two-way check-shot survey time. It also compensated for the effects caused by annual changes in acquisition instrumentation and processing parameters.

Two procedures were necessary to calculate depth values because of the differing nature of the Cretaceous and pre-Cretaceous sediments. Horizon 0700, a prominent seismic marker across the entire NPRA, was incorporated into both procedures and therefore marks the division. The depth to horizon 0700 was calculated using an average velocity and adjusted time. This method was used across all of the NPRA,

except for the Fish Creek area in the northeast where horizon 0700 is truncated and it was necessary to substitute horizon 0720 values.

Depth and isopach values for the pre-Cretaceous part of the geologic section were calculated using the "layer cake" method. Isopach values were calculated at shotpoint locations using isochrons, derived from adjusted time values, and the appropriate interval velocity value was calculated from the polynomial surfaces. Depth values for the deeper horizons were determined by the summation of isopach values and the horizon 0700 depth value.

An interpolation process was used to calculate depth values in the part of the geologic section that is younger than horizon 0700. Seismic horizons in this shallow section tend to be regionally discontinuous; therefore, the layering method used for the deeper horizons is not suitable, and a procedure based on average velocity was used. A time-average velocity function was made at each shotpoint incorporating data from the surface velocity, Torok clinothem time and average velocity, and horizon 0700 time and average velocity. Depth calculations for horizons between the surface and horizon 0700 used average velocity values interpolated from this time-average velocity function.

All final depth and isopach maps for this report were contoured by computer, using data picked by geophysicists and transferred from seismic sections to the computerized seismic data base. A depth or isopach surface was constructed in a number of steps. First, the depth of isopach values was calculated for a specific horizon or interval. Second, the average distance (d_{avg}) between data points was calculated using the formula:

$$d_{avg} = \left[\frac{(X_{max} - X_{min})(Y_{max} - Y_{min})}{n} \right]^{\frac{1}{2}}$$

where X and Y values are the maximum and minimum X and Y values for the area being mapped, and n is the number of data points in the area. Third, a grid was constructed with a spacing of one-half the average distance between data points. Fourth, an eight-sector search routine was used to sample data points, and a weighted least-squares fit defined the value of the grid point. Finally, the path of the contours was determined by interpolating across the individual grid squares. The contoured maps were edited manually, but only a small number of changes were required.

SHORT-WAVE PERMAFROST CORRECTIONS

Permafrost anomalies can cause distortions in seismic interpretations, especially in areas where the subsurface relief and regional gradient are slight. Therefore, a study was conducted to determine the net effect and correction for permafrost on seismic time sections (seismic map 61). The study was confined to that part of the NPRA north of lat 70°N. South of lat 70°N, only a few permafrost anomalies seem to exist, and none of these are of sufficient magnitude to distort structural interpretation.

The NPRA regions affected the most by permafrost variations are the northeast half of the Teshekpuk and Harrison Bay Quadrangles, and the East Barrow and West Barrow Quadrangles. Shoreline areas, both nearshore and short distances offshore, are especially affected.

Velocity anomalies caused by variations of the frozen zone as related to seismic data can be divided into three categories: long-wave, high-frequency, and short-wave anomalies. The long-wave anomaly is a gradient velocity and is handled as such with a regional velocity field. High-frequency anomalies are weathering problems and quite limited in areal extent. High-frequency anomalies extending a shorter distance than a seismic cable length normally are compensated for by automatic static programs, which generally are applied during processing to seismic data obtained in areas of erratic weathering. Some high-frequency anomalies are of such a magnitude that an automatic static program is not effective in their attenuation. If this is the case, the anomaly is termed a short-wave anomaly.

Various approaches based on stacking velocity analysis have been suggested for correcting short-wave permafrost anomalies. This type of approach is not feasible, however, because of the anomalous nature of stacking velocity information in an area where short-wave permafrost variations persist (for example, the northeastern coastal plain of the NPRA).

Stacking velocity data are useless for accurate determination of structure in an area with high-frequency permafrost variations, as shown in figure 106. Stacking velocity can fluctuate rapidly over areas of geologic change, whereas RMS velocity varies smoothly with geologic change; this phenomenon is best illustrated by a simplified model of a permafrost variation similar to the type present in the NPRA. Figure 106 shows the effect of permafrost variation on the reflection time and stacking velocity for horizontal marker beds at depths of 5,000 ft (1,563 m) and 12,000 ft (3,658 m).

Two techniques are used to compensate for short-wave anomalies. One of these techniques involves manual editing of field data to make the necessary adjustments prior to final processing; however, this specialized processing technique was not used on the NPRA data. With the second technique, compensation is made during interpretation. The latter technique, although not absolutely correct, probably is within the normal limits of error for most of the permafrost anomalies in the NPRA.

Making adjustments during interpretation entailed a detailed inspection and study of seismic lines, and the application of correction times to the seismic sections wherever permafrost anomalies appeared. The correction times, determined at each shotpoint location, were subtracted from all horizon times prior to calculating depths. In this study, all seismic sections were reviewed for reflection continuity. No local "pull-ups" were observed, which suggests that isolated, high-velocity conditions did not exist in the NPRA.

Where sags or depressions appeared in the upper sediments, and the time differential remained constant downward through the section, it was assumed that lower velocity material, or thinner high-velocity material in the upper surface, caused an excessive delay time in the returned seismic signal. Such time sags frequently are associated with open lakes or active river systems. Often, however, such sags appear on seismic sections that have no apparent abnormal surface conditions. Old buried river channels, buried lakes, active underground water systems, or areas near pingos are examples of local zones with thinner permafrost or lower velocity material. Permafrost time sags are consistent throughout the vertical section (fig. 105). Real structure rarely appears constant with time. Where there is recent folding, the normal increase in velocity with depth results in a decrease in the apparent size of a syncline with increasing time. Where subsidence is contemporaneous with deposition, the syncline usually increases in apparent magnitude with time. Thus, it is unlikely that careful application of this compensation technique would eliminate real structure.

Wherever local sags appear on the seismic section for relatively short distances laterally, and the horizons display normal regional dip on either side, the correction time factor applied to restore lateral continuity across the sag probably is valid. Determination of realistic correction values is more conjectural where the seismic lines cross large bodies of water, extend outward from a shoreline, or run parallel to a shore line. Extending the interpretation to three dimensions reduces the uncertainty.

In the region around Admiralty Bay and Dease Inlet, application of the procedure described above for nearsurface correction is practically impossible. A submarine canyon cuts into flat-lying, shallow sediments in this region, replacing them with fill (fig. 81). Thus, no criteria exist for making corrections in such an area.

Where the lines on land extend seaward and the nearsurface reflections retain their continuity, a sudden increase in vertical time generally appears on the section. Farther offshore, the permafrost correction must be reduced from maximum effect to zero. The exact point where this transition occurs is very difficult, if not impossible, to determine. This problem was dealt with by establishing a velocity field between the onshore and offshore data and prorating the permafrost effect from maximum effect nearshore to zero time delay on marine data. The absence of structure on the depth maps trending along the shoreline suggests that this approach was reasonably successful.

PHASE AND POLARITY CHARACTERISTICS OF NPRA SEISMIC DATA

An understanding of phase and polarity characteristics of NPRA seismic data is necessary for proper identification of mapped reflections and detailed stratigraphic interpretation. An attempt was made to deduce these characteristics for the 13,000 mi (21,000 km) of NPRA seismic data. Most of the NPRA seismic data approximate zero phase. A positive reflection coefficient generates a trough on time-variant deconvolution (TVD) data displayed "normal" and wavelet deconvolution, or designature deconvolution (DESIG), data displayed "reverse." TVD final stack sections lag check-shot survey "first-break" times by about 0.050 s; bulk static for the data is about 0.020 s.

DATA ACQUISITION

Field data acquired in the FY 1974, FY 1975, and FY 1976 seismic programs have similar phase and polarity characteristics, as the field parameters and recording equipment were essentially the same for all three surveys. The DFS-III recording instruments (with 8/36-124 filter settings) used in these programs were designed for minimum phase response (fig. 107). Proper recording polarity for the DFS-III is SEG standard.

The FY 1977 detail and reconnaissance programs were conducted using DFS-IV and DFS-V recording instruments, respectively; all other field parameters were essentially similar to those used in the FY 1976 survey. DFS-IV and DFS-V recording instruments (with 8/36-124 and 8/18-128 filter settings, respectively) have minimum phase responses similar to the DFS-III (fig. 107) and proper recording polarity is SEG standard. Therefore, the FY 1977 field data have very nearly the same phase and polarity as data acquired from FY 1974 through FY 1976.

In FY 1978 and subsequent years, all crews used DFS-V recording instruments, generally with the 8/18-128 filter. The FY 1978 data, excluding data acquired by crew 1182, were recorded in the same manner as the FY 1977 reconnaissance data and share the same field phase and polarity characteristics. The FY 1978 field data shot by crew 1182 were recorded with non-SEG standard polarity, and therefore have opposite polarity relative to most NPRA seismic data. The

data acquired using a "mud gun" as an energy source are of lower quality and frequency than the data acquired using dynamite, but visual inspection of line intersections indicate the phase and polarity characteristics of these data are similar.

FY 1979 data acquired by crew 1182 prior to 15 February 1980 also were recorded with non-SEG standard polarity. Early in FY 1979, crew 1182 used an out-128 filter setting instead of the usual 8/18-128 setting, but figure 107 indicates that use of the out-128 filter resulted in no significant change in phase. Aside from polarity differences in the early shooting, FY 1979 field data acquired by crew 1182 are similar in phase and polarity to FY 1974 through FY 1977 data. In the foothills, FY 1979 data was acquired using both dynamite and Vibroseis as energy sources; filter settings for Vibroseis data were 8/18-90.

Shooting parameters in FY 1980 were similar to those used in previous years. All crews used dynamite, and recorded with SEG standard polarity. Thus, these field data also have phase and polarity characteristics similar to data acquired from FY 1974 through FY 1977.

DATA PROCESSING

Data processing parameters used for most of the FY 1974 through FY 1980 data were similar. The most significant difference was the use of two different deconvolution operators: TVD and DESIG. The FY 1974 through FY 1978 data, excluding FY 1978 data acquired by crew 1182, were processed with TVD; subsequent data acquired, as well as FY 1978 data acquired by crew 1182, were processed with DESIG.

Figure 108 illustrates the effects of various deconvolution operators on a wavelet resulting from minimum phase correlation of Vibroseis data obtained from a test impulse. As previously illustrated in figure 107, the DFS-III and DFS-IV recording instruments with an 8/36-124 filter and the DFS-V instrument with an 8/18-128 notch-out filter produce nearly minimum phase responses, as does the Vibroseis minimum phase correlation ("A" in fig. 108). Therefore, the information presented in figure 108 is directly applicable to the data acquired using dynamite as the energy source.

A nearly minimum phase wavelet similar to the one displayed under "A" in figure 108 would result from a positive reflection coefficient if SEG standard recording polarity is used. The NPRA seismic data processed with TVD had 5 to 10 percent white noise added, thus "E" in the figure is the

appropriate display of the output after TVD. The resulting complex wavelet most closely approximates zero phase, and a positive reflection coefficient produces a trough. The output after DESIG ("B" in the figure) is virtually zero phase, with a positive reflection coefficient producing a peak; the maximum amplitude of DESIG output occurs at an earlier time than TVD output. The relative phase angle between DESIG and TVD output is about 180°, nearly equivalent to reversing the polarity.

The above observations are consistent with the analysis of line ties between data processed with DESIG versus TVD, which indicates that DESIG data are about 0.030 s shallower, similar in phase, and opposite in polarity. Thus, DESIG data must be displayed "reverse" in order to match TVD data, and a 0.030 s correction is required. Because early FY 1979 and all FY 1978 data shot by crew 1182 were recorded with non-SEG standard polarity, the "normal" display matches TVD data.

Numerous synthetic seismograms were prepared by Tetra Tech, Petroleum Information Corporation, Schlumberger Well Services, and GeoQuest Exploration, Inc. Generally, a reasonable match to the seismic data was achieved. Study of these synthetics confirmed final stack sections that were processed with TVD approximate zero phase, with a positive reflection coefficient producing a trough. Assuming these phase and polarity characteristics, the final stack section maximum amplitude time is delayed relative to two-way check-shot survey "first-break" times by about 0.050 s. DESIG-processed final stack sections seem to lag "first-break" check-shot times by about 0.020 s.

A velocity filter was applied to certain data during processing. This procedure could result in different phase and polarity characteristics, but visual inspection of line intersections suggests that the processing step did not induce appreciable changes. FY 1979 foothills data, acquired using either dynamite (with 8/18-128 filter) or Vibroseis (with 8/18-90 filter), were processed in a variety of ways. DESIG was applied to certain data; on other lines, no deconvolution operator was used. As a result, a variety of phase, polarity, and lag characteristics is expected, and much additional study is required before stratigraphic interpret-ation can be attempted in this structurally complex region.

All FY 1979 and FY 1980 foothills data are displayed on final stack sections with "normal" polarity. Because DESIG processing of lines results in polarity opposite to that of most of the NPRA seismic data, these data were interpreted as though they were processed with TVD. That is, a bulk static

of 0.050 s was required to tie two-way, check-shot, "first-break" data to provide an acceptable tie to the other foothills data for structural interpretation. Consideration of the opposite polarity and 0.020 s bulk static is necessary if detailed stratigraphic interpretation of these DESIG data is attempted.

OTHER SURVEYS

In 1977, marine data were recorded with DFS-IV instruments using 8-62 filter settings. Air guns were the energy source and the data were processed using a DESIG operator; final stack display polarity is "normal." No synthetic seismograms or check-shot information directly tie these seismic sections. A rigorous study of the phase and polarity characteristics of these data was not done, but study of line intersections with FY 1978 data indicates that these sections approximate zero phase. For structural and stratigraphic interpretation, it is assumed that an increase in acoustic impedence will result in a trough on these data, and a bulk static of 0.070 s is required to tie two-way, check-shot, "first-break" data.

Acquisition and processing parameters differed significantly for the FY 1972 through FY 1975 Barrow surveys and the FY 1978 and FY 1979 "high resolution" surveys, both relative to the reconnaissance surveys and to each other. Additionally, all data except the FY 1979 data were reprocessed using DESIG. Further study is required before definitive statements can be made regarding the phase and polarity characteristics of these numerous data sets.

A few FY 1972 through FY 1975 Barrow lines were used to infill the reconnaissance grid. For this purpose, the reprocessed lines (displayed "reverse") were used. These lines appear similar to FY 1978 and FY 1979 regional lines in phase, polarity, and bulk static.

For the Barrow detail interpretation (scale 1:36,000) all data were assumed to be zero phase (seismic maps 62-71). FY 1978 and FY 1979 "high-resolution" lines, and DESIG reprocessed lines, were assumed to require no bulk static. FY 1972 through FY 1975 Barrow lines (not reprocessed) were assumed to require a 0.020 s bulk static.

JURASSIC STUDY

A study of Jurassic rocks in the NPRA focused on determining the stratigraphy, distribution, and depositional environment of sandstones, and locating unconformities in the Jurassic-Neocomian Kingak Formation. Detailed correlations are presented to describe Kingak Formation subdivisions. The work was based on well logs, lithologic logs, core descriptions, and micropaleontology. A geophysical study of the Jurassic "Simpson sandstone" is included.

GEOLOGIC SUBDIVISION AND CORRELATION

The main parastratigraphic divisions of the Kingak Formation are shown in regional correlation cross sections (figs. 109, 110). These divisions are units J-1 which is subdivided into units J-1a, J-1b, and J-1c; J-3 which is subdivided into units J-3a, J-3b, and J-3c; and Ka-1a. Further subdivision of these units for more detailed study is discussed below.

Unit J-1 is the "Lower Kingak"; units J-3 and Ka-1a comprise the "Upper Kingak." A Triassic-Jurassic unconformity separates the Kingak from the underlying TR-3b unit that consists of the Sag River Sandstone and its equivalents. The mid-Jurassic unconformity separates the "Lower Kingak" from the "Upper Kingak." Where unit Ka-1b overlies the Kingak (for example, at Kugrua 1 and Peard 1), the basal "Pebble Shale" unconformity separates the two Kingak units. Where unit Ka-2 or Ka-3 overlies the Kingak (for example, at Sinclair Colville 1 and Arco Itkillik River 1), the "basal Torok" unconformity separates the units. Unit Ka-1b coincides with the "Pebble Shale" unit, which locally includes basal sandstones; units Ka-2 and Ka-3 above the "basal Torok" unconformity make up the lower part of the Torok Formation.

Five detailed correlation cross sections were prepared for the Jurassic part of the Kingak: figures 111 and 112 show unit J-1, or the "Lower Kingak," and figures 113 through 115 show unit J-3a. Units J-3b and J-3c were not correlated in detail; unit Ka-1a is discussed in "Tunalik Study." Figure 54 is an isopach and lithofacies map of unit J-1.

"Lower Kingak" Unit

The "Lower Kingak" unit is underlain by Triassic rocks and overlain by Upper Jurassic rocks. Unit J-1a, which is above

the Triassic-Jurassic unconformity, extends up to the Jurassic "spike" shown on resistivity and sonic logs. Unit J-1a, composed mainly of siltstone and shale, consists of four smaller units, described below in ascending order:

- The oldest unit, J-1a(1), is composed of siltstone and shale, and apparently occupies depressions on the eroded Triassic surface. For example, the unit is present at South Meade 1, Ikpikpuk 1, and Walakpa 1, but is absent on highs at Kugrua 1, East Teshekpuk 1, and South Simpson 1. At Peard 1, the entire J-1a unit is absent because of onlap on the Wainwright Arch.

- The second unit, J-1a(2), is composed of siltstone, shale, and barlike sandstone bodies. These lenticular sandstones collectively make up the "Barrow sandstone." This unit directly overlies the Triassic section at South Simpson 1, Kugrua 1, East Teshekpuk 1, and Atigaru Point 1, but is absent at Tunalik 1.

- The third unit, J-1a(3), is composed of siltstone, shale, and interbedded barlike sandstones. At Tunalik 1, this unit lies directly on the Triassic section.

- The uppermost unit, J-1a(4), also is composed of siltstone and shale and contains interbedded barlike sandstones.

The "Barrow sandstone" bodies in unit J-1a probably were deposited on slopes of irregular relief during a marine transgression, as indicated by the distribution of the individual sandstone lenses. The first occurrence of the isolated barlike sandstone bodies that comprise the "Barrow sandstone" is in unit J-1a(2) south and east of the Barrow High. To the north on the Barrow High, the sandstone bodies are found at higher stratigraphic levels in the higher J-1a subunits. The pattern is especially evident in figure 112 between South Simpson 1 and Walakpa 1.

The J-1b parastratigraphic unit is located between the Jurassic "spike" and the Lower Jurassic "shoulder," a distinctive log marker coinciding with deflections on nearly all log curves from northwestern NPRA wells. This marker was used in regional correlations in this and earlier Tetra Tech reports. Unit J-1b, which is conformable with the underlying J-1a unit, is subdivided further into two units that mainly consist of shale: J-1b(1) and J-1b(2). At South Barrow 17, unit J-1b is truncated by the J-1b/J-1c unconformity, as

shown at the top of the unit in figure 112. At Tunalik 1 and Inigok 1, unit J-1b is absent because of truncation by the mid-Jurassic unconformity (figs. 111, 112).

Unit J-1c is characterized on logs by low resistivity and high sonic interval transit time. The base and top of the unit are picked at sharp breaks in these curves; the base is at the Lower Jurassic "shoulder" and the top is at the mid-Jurassic unconformity. J-1c is subdivided further into two units: a lower unit, J-1c(1), composed of shale and an upper unit, J-1c(2), composed of shale with interbedded silty shale and siltstone. The mid-Jurassic unconformity truncates unit J-1c, as demonstrated by the thinning or absence of J-1c in several wells. For example, unit J-1c(2) is thin at Walakpa 1 and South Harrison Bay 1 (fig. 114) and absent at Peard 1 (fig. 113); additionally, unit J-1c is absent at Tunalik 1 (fig. 113), West Fish Creek 1, and Inigok 1 (fig. 114).

"Upper Kingak" Unit

Parastratigraphic units J-3 and Ka-1a (fig. 55) comprise the "Upper Kingak." Only the J-3a (fig. 56) subunit of unit J-3 was correlated in detail for this study; no detailed study was made of units J-3b and J-3c (figs. 58, 59), but a general subdivision of these units is shown in figures 109 and 110. Fossils indicate that unit J-3c is Neocomian (earliest Cretaceous), and the unconformity between the Jurassic and Neocomian sections was traced and named the lower Neocomian unconformity.

Unit J-3a, which lies immediately above the mid-Jurassic unconformity, has two distinct parastratigraphic subdivisions: units J-3aI and J-3aII. The lower unit, J-3aI, contains the "Simpson sandstone" or equivalents (figs. 57, 75); the bottom and top of this unit were picked at sharp breaks on resistivity and sonic log curves.

J-3aI is divided further into five subunits: J-3aI(1), J-3aI(2), J-3aI(3), J-3aI(4), and J-3aI(5). The oldest of these subunits, J-3aI(1), is composed of sandstone, siltstone, and shale. At Kugrua 1, subunits J-3aI(2) and J-3aI(3) consist mainly of sandstone (fig. 113). Subunits J-3aI(4) and J-3aI(5) are the sandiest parts of J-3aI, as shown in figure 113 between Kugrua 1 and Ikpikpuk 1.

A local unconformity was identified in unit J-3aI at South Harrison Bay 1 where the upper part of J-3aI(5) lies directly on J-3aI(3) (fig. 114). At South Simpson 1, the upper part of J-3aI is truncated by the basal "Pebble Shale" unconformity, as shown in 114. Unit J-3aI and part of the underlying J-1 unit are truncated farther north at East Simpson 1, J. W.

Dalton 1, Cape Halkett 1, and W. T. Foran 1, although this is not shown in figures 109 through 115. An unconformity probably occurs at the top of unit J-3aI, as indicated by the detailed correlation of the overlying J-3aII unit, which probably onlaps J-3aI from the south to north.

The bottom of unit J-3aII was picked at the break on resistivity and sonic log curves above the unconformity at the top of the "Simpson sandstone" or its equivalent. The upper boundary was picked on a prominent 10 to 25 ft (3 to 8 m) "spike" that is recognized as a marker bed west of the Meade Arch. At Inigok 1 and West Fish Creek 1 east of the Meade Arch, this marker was truncated, and the top of J-3aII is defined conditionally.

As shown in figure 113, J-3aII is divided into six subunits, which are labeled sequentially from J-3aII(1), the oldest subunit, through J-3aII(6), the youngest subunit. The lowermost and uppermost parts of unit J-3aII consist of shale and sandstone, whereas the middle subunits are predominantly shale.

Unit J-3aII(1) is recognized only in Tunalik 1 and Kugrua 1. In all other wells, J-3aII(2) overlaps the older rocks of J-3aI, except at South Harrison Bay 1 where J-3aII(3) overlaps J-3aI (fig. 114).

The uppermost subunit, J-3aII(6), is an easily recognizable log interval characterized by high resistivity and low sonic transit time. This subunit is traced eastward from Tunalik 1 to South Meade 1. At Ikpikpuk 1, the unit is not well defined, but is very likely represented. In the northeastern part of the Reserve at Inigok 1 and West Fish Creek 1, unit J-3aII(6) is truncated by an unconformity, as shown in figures 109 and 110 from Inigok 1 to South Harrison Bay 1. The unconformity is about 150 ft (48 m) above unit J-3a at Ikpikpuk 1, and is traced along the boundary between J-3a and J-3b west of the Meade Arch at South Meade 1 and Tunalik 1.

DEPOSITIONAL ENVIRONMENT

The Kingak Shale, which was deposited in several environments, is exceedingly complex. The Kingak members and markers are bound by depositional events such as transgressive, regressive, or stable stages of a depositional cycle. Depositional patterns based on lithologic subdivision-probably represent the first pulse in a widespread part of the sedimentary cycle. The sedimentary cycle seems to begin with a transgressive stage and finish with a hiatus.

In the northern NPRA, shelf deposits prevailed during Jurassic time, and several depositional cycles are known. After a short Triassic-Jurassic hiatus, which did not flatten relief, Early Jurassic sedimentation began with rapid subsidence and transgression. The lows were submerged quickly and deposition of muds and silts took place in the basins with an irregular relief. (See J-1a(1) in figures 99 and 100.)

The Early Jurassic sandstone bodies are characterized as linear and strand bars. Configuration of the bars is shown in a facies map of the early Jurassic basin (fig. 116); the dominant sediment types also are shown. The association of bars and clay sediments creates possible hydrocarbon environments because of the natural combination of traps and source material.

Unit J-1b contains two depositional patterns; the lower pattern indicates a stable sedimentation stage (dominance of clay) and the upper shows a regressive stage (silt-clay sedimentation). At the end of J-1b time, a short time break in sedimentation occurred. After this break, sedimentation resumed and, in J-1c time, clays and silts accumulated; the time break is expressed as a local unconformity between units J-1b and J-1c.

At the end of J-1c time, a hiatus that occurred throughout the region completed the Early Jurassic depositional cycle. During the hiatus, which parallels the mid-Jurassic unconformity, the Lower Jurassic rocks were exposed and eroded.

Sedimentation in the region resumed only in the Late Jurassic epoch. Erosion flattened the relief and the first impulses of Late Jurassic transgression submerged the region; sand-silt deposition prevailed on the inner shelf of the basin. The outer shelf, located in the South Meade-Ikpikpuk area, was characterized by the dominance of clay.

This reconstruction is based on an analysis of the depositional pattern at the base of unit J-3aI; depositional patterns could not be identified in the rest of the unit because of its complexity. In J-3aI time (after the transgression), sedimentation probably did not have distinct depositional centers. In the central part of the basin (the Kugrua-South Meade area), shallow-water shelf sand and silt-sand deposits prevailed. Along the flanks of the basin, clastics and clays were deposited in deeper water. Based on the greater sand content and their interbedding with and replacement by finer clastics and clays, it was concluded that the complex represented by the "Simpson sandstone" is a

subaqueous delta with the lower part deposited as offshore bars.

At the end of J-3aI time, a short-term break in sedimentation took place, which is expressed as a local unconformity between units J-3aI and J-3aII. Study of the depositional environment of the latest occurrences of Jurassic geologic history was not completed.

RESOLUTION OF THE SEISMIC DATA

Stratigraphic interpretation of Jurassic rocks in the NPRA was based largely on analysis of the amplitude and polarity of reflections, and the lateral variation of these characteristics. Variations in amplitude often are attributable to a change in the physical properties of sediments, manifested as a change in the interval velocity and/or density.

Any other phenomena affecting amplitude must also be considered, for example, data quality, acquisition and processing parameters, tuning, and interference from other beds. Differences in data quality affect the entire section and generally can be identified; the interpretation is not affected unless resolution is seriously impaired. In the study area, acquisition parameters were relatively constant and did not present a major problem. Two processing procedures that can affect amplitude are time-variant filtering and time-variant scaling; time-variant filtering was restricted to bandpass filtering over the normal range of signal, and time-variant scaling used relatively long gates. These procedures did not affect relative amplitude adversely; however, the final stack sections are not true amplitude sections. Tuning and interference, which are geometric phenomena that affect amplitude significantly, were difficult to distinguish from amplitude variations resulting mainly from velocity and/or density variation.

Tuning is the constructive interference from the upper and lower boundaries of a bed having opposite reflection coefficients at the respective boundaries. Tuning thickness (the thickness at which maximum constructive interference occurs) is 1/4 wavelength and depends on the predominant frequency of the seismic data and velocity of the bed. Tuning effects decrease with additional thickness up to about 1/2 wavelength; tuning is not a factor of amplitude at greater thicknesses. Amplitude decreases with thickness below 1/4 wavelength until the limit of resolution of the seismic data is reached. The observed isochron does not decrease below 1/4 wavelength. Amplitude was used to

estimate bed thickness where it was less than tuning thickness.

The limit of resolution ranges from a theoretical 1/12 wavelength up to a practical limit of 1/2 wavelength for noisy data. The practical limit of resolution for the FY 1972 through FY 1980 seismic data on the northern part of the coastal plain is estimated to be 1/8 wavelength. The predominant frequency of this coastal plain seismic data is about 30 Hz for the Jurassic section; the frequency increases to the north where the Jurassic is present at shallower depths. For example, the "Simpson sandstone" has an interval velocity of about 13,000 ft/s; therefore, its tuning thickness is about 110 ft (34 m). Tuning effects are present for thicknesses less than 200 ft (61 m); the minimum detectable bed thickness is about 55 ft (17 m).

Interference results from the presence of nearby acoustic interfaces. Interference can be either constructive or destructive, and is subject to the same resolution limitations as tuning.

SEISMIC-STRATIGRAPHIC INTERPRETATION OF THE "SIMPSON SANDSTONE"

Stratigraphic interpretation of the seismic data, together with isopach mapping and velocity analysis, can be integrated into a geologic model, consistent with well data for the "Simpson sandstone." A postulated permeability barrier (based on changes in seismic character) lies along the northern flank of a high interval velocity trend in an area regionally high at the time of deposition. The coincidence of the velocity trend and the thickest part of the "Simpson sandstone" suggests the geologic model described below. Additionally, the "Kealok anomaly" may contain a sand body within the Late Jurassic "Upper Kingak."

The "Simpson sandstone" seems to be an elongated sand body (possibly a barrier island or delta bar complex) trending east-northeast (seismic map 56; fig. 75). The westward limit of the sand body is not yet defined; eastward, it is truncated by the basal "Pebble Shale" unconformity. The axis of the sand body probably is very near line 56-75 and 56-76. Kugrua 1 penetrated the "Simpson sandstone" near its axis; the northern flank was penetrated at Peard 1, and the southern flank at South Meade 1, Topagoruk 1, and South Simpson 1. A different depositional environment (possibly a lagoonal facies) was penetrated at Kuyanak 1, Walakpa 1, Walakpa 2, and South Barrow 3. All other wells that encountered unit J-3aI probably penetrated fine-grained

offshore sediments. A structural-stratigraphic trapping mechanism possibly exists, because of a permeability barrier to the northwest, truncation to the northeast, and south regional dip. Seismic-stratigraphic interpretation suggests that character change "f" (identified later in "Reprocessing and Color Displays") may represent the permeability barrier; however, a failure to find "Simpson sandstone" at Kuyanak 1 demonstrates the difficulty in extrapolating from a well or interpolating between widely spaced wells.

The Jurassic sandstone, first penetrated at Topagoruk 1, was tentatively named "Simpson sandstone" by Bird (written communication, 1979). The unit was encountered at South Simpson 1, Kugrua 1, South Meade 1, and Peard 1 where it is in unit J-3aI. Unit J-3aI also was penetrated at South Barrow 3, East Teshekpuk 1, South Harrison Bay 1, West Fish Creek 1, Inigok 1, Ikpikpuk 1, Tunalik 1, Walakpa 1, Walakpa 2, and Kuyanak 1 where it consists of siltstone and/or shale. The velocity in unit J-3aI generally is significantly faster than in overlying sediments, and the unit is much more than 1/8 wavelength thick. Thus, the approximate top of J-3aI generates a seismic reflection that is mappable over a large part of the Arctic Coastal Plain.

Correlation of Well and Seismic Data

Most of the NPRA wells that penetrated unit J-3aI are tied by pre-FY 1978 seismic data. As stated previously in "Short-Wave Permafrost Corrections," these data approximate zero phase and lag check-shot survey "first-break" time by about 0.050 s. The polarity of the data is deduced from processing and display parameters. The polarity of the pre-FY 1978 final stack sections ("normal" display polarity) is such that a positive reflection coefficient produces a trough.

Well and seismic data correlations of unit J-3aI are described below for nine NPRA wells:

- Kugrua 1. A sharp increase in interval velocity very nearly coincides with top of the "Simpson sandstone" at 8,680 ft (2,646 m). Velocity throughout unit J-3aI is fairly uniform. The gamma-ray log for the interval from 8,722 to 8,867 ft (2,659 to 2,703 m) indicates that 145 ft (44 m) of the 218-ft (66-m) thick unit is mostly sandstone (fig. 75). Reflections are generated by both the top (trough) and bottom (peak) of the unit; these events occur on line 121-76, shotpoint 164.5, at 1.739 s and 1.770 s, respectively. Tuning effects are negligible.

- South Meade 1. Interval velocity of the "Simpson sandstone" unit at South Meade 1 from 7,852 to 8,056 ft (2,394 to 2,456 m) is not as uniform as at Kugrua 1. Velocity at the top of the unit is essentially the same as that of overlying sediments; from 7,870 to 7,885 ft (2,399 to 2,404 m), the unit has a low velocity, which may indicate porous rocks. This low-velocity interval is too thin to detect with the frequency of the present data. The high interval velocity generally characteristic of the "Simpson sandstone" begins at 7,970 ft (2,430 m); this interface generates the trough found on line 52-75, shotpoint 100.5, at 1.528 s. Below this interface, the rock velocities slowly grade back to values more characteristic of the Kingak Shale. However, a small decrease in velocity near the base of the unit contributes to the first peak of a doublet at 1.545 s. Some tuning effects probably are present. Accurate thickness determinations are not possible at South Meade 1 because of the gradational velocity below the "Simpson sandstone."

- Peard 1. Interval velocity of the "Simpson sandstone" unit at Peard 1 from 7,817 to 7,991 ft (2,383 to 2,436 m) is only slightly higher than that of the overlying siltstone. Porous sandstone near the top of the unit is 35 ft (11 m) thick and has low interval velocity. The acoustic interface at the base of this porous zone near 7,870 ft (2,399 m) generates the trough on line 122-76, shotpoint 344, at 1.570 s. A sharp decrease in interval velocity at the base of the "Simpson sandstone" unit, combined with some tuning effects from the underlying J-1b unit, generates the peak at 1.582 s.

- South Simpson 1. At South Simpson 1, the upper portion of the "Simpson sandstone" perhaps was truncated at the basal "Pebble Shale" unconformity. The interval velocity of the "Simpson sandstone" from 6,520 to 6,703 ft (1,988 to 2,044 m) is significantly faster than that of most of the overlying "Pebble Shale." An acoustic interface just above the top of the "Simpson sandstone" generates a trough on line DS3-76, shotpoint 27.5, at 1.400 s. The velocity below unit J-3aI grades gradually to shale velocities. Several thin porous zones had gas shows. The porous zones near the base of the unit, combined with tuning effects, produce the peak at 1.420 s.

- Topagoruk 1. No sonic log was run at Topagoruk 1. Inspection of the spontaneous potential and

resistivity logs suggests that reflections are present from near the top and bottom of unit J-3aI at 7,748 ft (2,362 m) and 7,918 ft (2,414 m), respectively. Check-shot survey data indicate that the base of J-3aI on line 40X-75, shotpoint 70, is the peak at 1.565 s, and the top is the trough at 1.540 s.

- Walakpa 1. At Walakpa 1, unit J-3aI consists mainly of siltstone and has little or no permeability. The velocity in the siltstone is much faster than in the shales, so reflections are generated from the top of the unit at 2,313 ft (705 m) and the bottom at 2,543 ft (775 m); these reflections are identified as the trough at 0.510 s and the peak at 0.570 s, respectively, by projecting well data to line 618N-79, shotpoint 23. (Note: Line 618N-79 was recorded with non-SEG standard polarity and processed using the DESIG deconvolution operator; therefore, the "normal" polarity display is the same as for pre-FY 1978 data, and section time lags check-shot survey "first-break" time by about 0.020 s.)

- Walakpa 2. The J-3aI section penetrated at Walakpa 2 extended from 2,962 to 3,230 ft (903 to 985 m) and is similar to that encountered in Walakpa 1. The unit is mainly siltstone and has little porosity. Interval velocity is uniform (about 12,000 ft/s), and is faster than the overlying and underlying sediments. Reflections are generated by both the top and bottom of the unit at 0.670 s and 0.720 s, respectively, on line B5-78 at shotpoint 308. Minor interference probably is present at the upper interface. The interference at the lower boundary is caused by the proximity of unit J-1b. At Walakpa 2, the interference is constructive, resulting in a much higher amplitude event from the base of the unit, even though the magnitude of the reflection coefficient is similar at both the top and bottom of the unit.

- Kuyanak 1. Unit J-3aI from 5,376 to 5,656 ft (1,639 to 1,724 m) at Kuyanak 1 is mostly siltstone, and has little porosity. The unit has a uniform interval velocity of about 12,500 ft/s, which is faster than the velocity of the Kingak shales, but is similar to other Kingak siltstones. Siltstones immediately overlying unit J-3aI at about 5,265 ft (1,605 m) have similar velocity and generate a trough on line 601-79, shotpoint 299, at 1.110 s. The top of unit J-3aI did not generate a primary reflection at

Kuyanak 1, and a decrease in velocity occurs near the base. Constructive interference from unit J-1b is equally responsible for the peak on line 601-79, shotpoint 299, at 1.170 s.

- At South Barrow 3, East Teshekpuk 1, South Harrison Bay 1, West Fish Creek 1, Inigok 1, and Tunalik 1, unit J-3aI consists mainly of shale and/or siltstone with an interval velocity not much different from that of the overlying Kingak sediments. Only weak, if any, reflections are generated by the top of J-3aI at these wells; the base of unit J-3aI (top of unit J-1) generally is a major acoustic interface producing a peak on the NPRA seismic data. This trough is mapped as horizon 0900.

The structure of the "Simpson sandstone" is mapped easily where high interval velocity occurs at or near the top of the unit. In areas where unit J-3aI contains siltstone or shale mapping is increasingly difficult. A reasonable representation of structure at the top of J-3aI is shown by horizon 0900 (seismic map 25). Regionally, south dip is evident, showing gentle expression of the Meade Arch. A few minor structural closures were mapped; the largest of these is at South Simpson 1 where a show of gas was tested in the "Simpson sandstone." At South Simpson 1 and to the northeast, unit J-3aI is truncated by the basal "Pebble Shale" unconformity (see "Jurassic Study").

In the vicinity of Peard Bay, the "Simpson sandstone" appears to onlap unit J-1. Lapout occurs along a line trending east-northeast into the Chukchi Sea. No potential traps were delineated along this lapout.

Standard Seismic Data Interpretation

Within unit J-3aI, several changes in seismic character (such as amplitude, event shape, and frequency) were noted and correlated between seismic lines. The single most prominent character change, which trends east-northeast subparallel to line 601-79, consists of the apparent termination of the trough identified as the top of J-3aI at Topagoruk 1, South Simpson 1, Kugrua 1, South Meade 1, and Peard 1. This character change is very obvious on line 612-79 near shotpoint 25 (fig. 84), line 136-76 near shotpoint 123, line 614-79 near shotpoint 71, line 616-79 near shotpoint 82, and line 618-79 near shotpoint 139. The change also can be located on line 55-76 near shotpoint 150 (westward, the trend projects offshore), line 65-76 near shotpoint 280, and line 52-75 near shotpoint 27. This seismic character change is difficult to identify on other lines in the area (lines

54-75, 51-75, and 622-79) because of poor data quality, and on line B23-78 because of the proximity of the basal "Pebble Shale" unconformity. The change is not present on lines east of line B23-78, because unit J-3aI is truncated south of this trend. Possible implications of this character change are discussed later.

Farther south, another potentially significant seismic character change, which occurs at the reflector near the base of unit J-3aI, suggests thickening of the sand body and/or the presence of an acoustic interface (with a positive reflection coefficient) within the unit. The change can be detected on most of the north-south seismic lines between lines 610-79 and 49-75 and is approximated by the 1.450 s contour on the horizon 0900 maps (seismic maps 25, 26). West of line 610-79, this character change cannot be identified with confidence; however, complex changes in the character of unit J-3aI occur to the west along this trend. Poorer data quality and a large seismic grid prevent identification of this change east of line 49-75.

A third character change occurs on north-south lines in the vicinity of lines 30-76 and 30X-75. On lines 602-79 to 47-75, this character change consists of a gradual decrease in amplitude to the level of background noise, and probably indicates a change in facies from sandstone to mainly shale lithology.

Many minor character changes also are identified just above or within the "Simpson sandstone" unit, probably caused by interference and/or tuning effects. Some can only be correlated over short distances, and their significance is unknown.

Several different interpretations of the significance of the primary character change (about parallel to line 601-79) are possible, including tuning and/or interference, lithologic change, or gas-water contact. the presence of a facies boundary or tuning/interference are more plausible explanations for the character change, because the change does not parallel structure contours. A lithologic change occurs between South Meade 1 and Walakpa 1. Tuning and/or interference is prominent at Kuyanak 1, which is in the vicinity.

Reprocessing and Color Displays

Numerous seismic lines relevant to seismic-stratigraphic interpretation of the "Simpson sandstone" were reprocessed: lines B5-78, B22-78, B23-78, 52-76, 601-79, 614-79, 616-79, 618-79, 618N-79, and 622-79. A set of "pulse compression" seismic sections that approximate zero pnase were made; these

sections were confirmed with the synthetic seismogram for South Meade 1 and also by comparison with normally processed data that were demonstrated to approximate zero phase. The polarity of most of the "pulse compression" sections results in a positive reflection coefficient that produces a trough; lines B22-78 and B23-78 are displayed in an opposite manner.

In addition to the "pulse compression" sections, color displays were generated with wiggle trace backgrounds for four seismic attributes: reflection strength, instantaneous frequency, instantaneous phase, and instantaneous velocity. The reflection strength, instantaneous frequency, and instantaneous phase attributes were derived by complex trace analysis.

The instantaneous velocity display is a form of trace inversion. Low-frequency variations were calculated from stacking velocity analyses; high-frequency velocity variations were calculated from reflection coefficients estimated from amplitude data. Density variations were ignored, as they cannot be separated from velocity variations, but are generally of less magnitude. Tuning and interference, as previously discussed, affect instantaneous velocity calculations because of their effect on amplitude.

Of the four color displays, instantaneous velocity is the most useful for interpreting the "Simpson sandstone" because of the high interval velocity that generally is associated with the unit. Instantaneous phase is a useful display; the major character changes are highlighted by the color presentation. However, the changes also can be observed readily on the black and white "pulse compression" sections or on the wiggle trace background of the color displays. Reflection strength and instantaneous frequency are primarily hydrocarbon indicator (HCI) displays, and, in this case, were inconclusive.

Many of the same or similar character changes seen on the normally processed data are identified on reprocessed sections. It is easier to correlate these character changes between lines, because fewer lines are involved and the processing is more consistent. Eight character changes associated with unit J-3aI were identified and labeled "a" through "h". An additional character change, which is seismically related to the overlying sediments and probably is the result of interference and tuning, is labeled a'. The approximate shotpoint locations of these character changes are as follows:

Line number	Character change								
	a	a'	b	c	d	e	f	g	h
614-79	8	27	33	36	57	70	73	?	110
616-79	208	186	167	149	139	128	115	96?	47
52-75	107	96?	77	69	57	?	31	-	-
618-79	1?	21	50	76	89	?	132	179	209
622-79	-	-	-	217	167	153	147	109	-
601-79	-	-	-	-	-	-	-	168?	-
B24-78	-	-	-	-	-	-	-	68?	60
B23-78	-	-	-	-	-	-	-	100	-

Some of these character changes, especially a', d, and f, subparallel time contours. The rest do not appear to relate to structure.

Possible Geologic Significance of Character Changes

A facies change within unit J-3aI between South Meade 1 and the Walakpa 2-Kuyanak 1 area results in a permeability barrier (fig. 57). Depending on the orientation of this barrier, various potential traps may exist. One of the more optimistic interpretations is to assume that the character change seen on the seismic data in the vicinity of line 601-79 represents the permeability barrier and that the character change near the 1.450 s contour represents a hydrocarbon-water contact (seismic maps 28, 29). Other dimensions of closure may be truncation by the basal "Pebble Shale" unconformity to the northeast and regional dip to the south. In the west, pinchout of the "Simpson sandstone" may contribute to the trapping mechanism; such a trap would cover about 850 sq mi (2,200 sq km).

The multiple character changes on the reprocessed data allow formulation of more complex interpretations. Character type "a" probably indicates a "Simpson sandstone" section similar to that encountered at South Meade 1. Character types "b" and "c" may indicate some thickening of the sandstone and/or a greater velocity contrast at the base of unit J-3aI. Type "d" suggests that a substantial thickness of porous sandstone may be present, whereas "e" may be related to a gas-water or gas-oil contact. Type "f" may represent the permeability barrier.

Many alternative interpretations are possible, each suggesting different prospects. Character change "g" originally was interpreted to be a permeability barrier, resulting in a postulated trap covering up to 180 sq mi (466 sq km). This possibility was tested at Kuyanak 1 where siltstone was penetrated.

Isopach Mapping

Information about the depositional environment of the "Simpson sandstone" can be inferred from the isopach map between horizons 0900 and 0850 (seismic map 30). The interval thickens south-southeasterly into the Ikpikpuk and Meade basins, centered at T8N-R10W and T8N-R27W, respectively. The two basins are separated by the north-trending Meade Arch.

The interpreted position of the "Simpson sandstone" is across the north end of the Meade Arch south of Walakpa 2 and Kuyanak 1 and north of South Meade 1 (fig. 75). The sand body appears to be oriented east-northeasterly, parallel to the strike of the isopach map. Thus, the sandstone seems to be located in a favorable area, based on paleogeographic analysis. The "Simpson sandstone" was deposited on a paleohigh in a shallow marine environment, suggesting possible development of porous sand.

Velocity Mapping

As part of an overall review of stacking velocity data, a map of the interval velocity between horizons 1000 and 0700 (seismic map 56) was prepared over the area of known "Simpson sandstone" occurrence. The parastratigraphic units (J-1, J-3, and Ka-1) included in the isopach interval on the map are mainly shale with relatively low velocity. Also present within this section are several high-velocity members, notably sands within the "Pebble Shale," "Simpson sandstone," and J-3aI and J-1b siltstones. Because of the general increase in velocity with grain size observed throughout the section, high interval velocity anomalies probably indicate high sand-shale ratios. For a discussion of these anomalies, see "Regional Interval Velocity between Horizons 1000 and 0700" in "Velocity Studies."

"Kealok Anomaly"

The "Kealok anomaly," postulated as a possible sand body within the Late Jurassic "Upper Kingak" (see "Upper Kingak" in "NPRA Stratigraphy"), is decribed as a thickening on a seismic unit within the upper part of parastratigraphic unit

J-3b (figs. 79, 80). More specifically, this anomaly is recognized where a single reflector divides or splits into two separate events attaining a maximum separation of 40+ ms; the separate events later return to a single event (fig. 80). The "Kealok anomaly" first was observed at the south end of line 21-74 in the Harrison Bay Quadrangle and subsequently was identified on several adjoining lines, with line 30-74 generally the southern limit of the feature. This elongated anomaly is oriented northwesterly with the eastern limit near the southeast corner of the Harrison Bay Quadrangle and the western limit terminating about 12 to 15 mi (19 to 24 km) southeast of Ikpikpuk 1. Subsea depths to the top of the feature are estimated to vary from 8,200 ft (2,500 m) at the northwest end to below 9,000 ft (2,744 m) in the extreme southeast. The horizon 0850 depth map (seismic map 29) of the Harrison Bay and Teshekpuk Quadrangles gives the computed depth estimates of this feature.

The limits of the anomaly were not outlined accurately because of the wide spacing of the seismic lines. A smaller, thinner isolated anomaly was outlined with its center located about 10 mi (16 km) west of Fish Creek 1. Subsea depth to the smaller anomaly at shotpoint 72 on line 11-74 is estimated to be 7,500 ft (2,287 m).

TUNALIK STUDY

At Tunalik 1, a methane gas show was noted in a Neocomian sandstone between 12,510 and 12,605 ft (3,813 and 3,842 m). The maximum gas show was encountered between 12,459 and 12,557 ft (3,798 and 3,827 m). An integrated geophysical/geological study was undertaken to identify the extent of the Neocomian sandstone that contains gas in Tunalik 1 and to identify similar potential reservoirs near Tunalik 1. The sandstone is very fine-grained, slightly argillaceous and well-cemented, and interbedded with thin shale layers; porosities in the sandstone are about 12 percent.

The sandstone is interpreted as lying immediately above seismic horizon 0800 (seismic maps 31, 32; fig. 117). A weak reflection corresponding to the interval containing the sandstone can be traced over an area of about 150 sq mi (384 sq km). This lens of gas sandstone has a maximum thickness of about 86 ft (26 m).

Regional dip is to the southwest. Hydrocarbons may have migrated through the Kingak Formation from a large part of the southwestern Arctic Coastal Plain (figs. 118, 119) and be trapped in stratigraphically controlled sandstone reservoirs. The northwestern trapping mechanism of the sandstone is not defined seismically because of the lack of seismic data. Data from Tunalik 1 indicate that the sandstone is sealed by the overlying shale, either because of pinchout of the sandstone below a local unconformity, or because of a lateral facies change from sandstone to shale.

Preliminary study of interval velocity data derived from stacking velocity analysis suggests that a low-velocity anomaly coincides somewhat with the interpreted limits of the Neocomian sandstone. Interval velocity values of 9,000 to 10,000 ft/sec versus a normal value of about 11,000 ft/sec suggest that a gas accumulation may be present.

PALEOENVIRONMENTAL STUDIES

This section of the report describes two paleoenvironmental studies conducted in the NPRA. One of these studies compared regional paleoenvironmental NPRA data with global sea-level cycles. The second was a lithofacies study of the Torok Formation and Nanushuk Group.

To improve chronostratigraphic correlation and prediction of the distribution of depositional facies throughout the Reserve, regional paleoenvironmental sequences of NPRA wells were compared with the global sea-level cycles outlined by Vail and others (1977 p. 83-97). This comparison matches regional chronostratigraphic sequences to parastratigraphic units and seismic horizons inferred from seismic profiles. Subsequent matching of these elements with the regional geology provided better interpretations of the distribution of depositional facies.

Micropaleontologic records from NPRA wells reveal several hiatuses of regional extent that correspond to times of worldwide sea-level lowstands. Use of these hiatuses and major regressive sequences found in NPRA wells permits more accurate determination of time-stratigraphic positions of the regional unconformities.

A comparison chart of paleoenvironmental sequences of selected NPRA wells and global cycles during Devonian to Tertiary time is shown in figure 120. The geologic time scale is given in millions of years. The chart shows first-order as well as second- and third-order global cycles outlined by Vail and others (1977, p. 83-97). The first-order cycle and the Devonian through Late Jurassic parts of the second- and third-order cycles are expanded horizontally to show more clearly the paleoenvironmental sequences of the NPRA and the global sea-level curves. Additionally, the chart shows the standard geologic eras, periods, and epochs; AWA formainiferal zones; and NPRA parastratigraphy. Paleoenvironmental sequences for six selected NPRA wells are presented, and the average sedimentation rates for the main parastratigraphic units are shown.

The depositional environments represented in the selected NPRA wells range from nonmarine to open marine equivalent to modern continental slope and basin. Most of the Middle Triassic through Early Cretaceous rocks were deposited in marine shelf and slope environments; rocks of Mississippian

through Early Triassic age, as well as rocks of Late Cretaceous age, are mainly nonmarine to marginal marine deposits. The interpretation of paleoenvironmental sequences is based mainly on micropaleontologic analysis by Anderson, Warren and Associates, Inc., (1974-1979).

The paleoenvironmental sequences represented in the selected NPRA wells were correlated with the second-order cycle of the global sea-level chart. Several major falling cycles shown on the chart (Vail and others, 1977, p. 85) coincide with the breaks found in paleoenvironmental sequences in NPRA wells. These breaks probably represent major regressions of the sea. After correlating the major falling cycles, each marked sequence was tied with units and seismic horizons. The comparison showed that:

- The NPRA paleoenvironmental curves and first-order global curve are very similar, although some differences are obvious between the paleoenvironmental curves and second- and third-order cycles. In the Reserve, the maximum transgression occurred during Late Cretaceous time, and maximum regression took place in Early Permian through Middle Triassic time.

- Generally, the five major depositional cycles in the NPRA match the Vail curves (fig. 120).

  - In the NPRA wells, paleoenvironmental curves generally begin with inner-shelf and middle-shelf deposition in Pennsylvanian time followed by nonmarine conditions during Early Permian (middle Leonardian) time. This cycle correlates with the supercycle of Vail and others (1977a). Supercycle P is not recognized in the paleoenvironmental curves because the AWA foraminiferal zones are not sufficiently detailed to subdivide the interval.

  - The paleoenvironmental curves indicate a hiatus (nondeposition or erosion) during Middle Triassic (Anisian(?)) time. Rocks of Middle to Late Triassic age probably were deposited on the outer to inner shelf. This cycle correlates with supercycle TR of the global sea-level chart.

  - Most of the rocks of Jurassic (Sinemurian-Oxfordian) age were deposited on the outer to middle shelf. Open marine (upper to lower slope) deposition prevailed during Late Jurassic and Early Cretaceous (Kimmeridgian(?) to Valanginian) time. This cycle correlates with supercycle J of

the global sea-level chart.

- Upper-slope to middle-shelf deposition occurred in Early Cretaceous (Hauterivian to Barremian) time followed by nonmarine to marginal marine conditions in Late Cretaceous (Middle Cenomanian) time. This cycle correlates with supercycle Ka of the global chart.

- Most regional unconformities and abrupt changes of depositional regimes found in NPRA wells coincide with the major global lowstands. The major regressive sequences and unconformities that correspond to periods of major global sea-level falling cycles shown in figure 120 are Middle Leonardian, Hettangian to Sinemurian, earliest Neocomian, Valanginian, and Middle Cenomanian. These sea-level drops and hiatuses, recognizable and traceable throughout the Reserve, correlate with seismic horizons and parastratigraphic unit tops (horizon 1100(?) and unit PR-1(?), horizon 1000 and unit TR-3b, unit J-3b, horizon 0800 and unit J-3c, and horizon 0400 and unit Ka-3). The mid-Jurassic, "basal Torok," and mid-Aptian unconformities are not recognized on the chart.

- The main discrepancies between the global and NPRA data occur in the Triassic interval. In the Triassic, the global curve indicates a relative stillstand of sea-level, but NPRA paleoenvironmental curves show that an overall transgression occurred during Triassic time. This discrepancy may exist because local subsidence occurred in the NPRA at a greater rate than global sea-level fall, producing gradual transgression. Middle to Late Triassic sequences (units TR-2 and TR-3) in the NPRA show a dominant and widespread marine transgression over all the Reserve. In parastratigraphic cross section B-B' (fig. 11), unit TR-2 shows onlap against the Meade and Wainwright Arches; this transgressive pattern of unit TR-2 continues through latest Triassic time. Unit TR-3 overlaps against these two paleogeographic highs, as shown in parastratigraphic cross section D-D' (fig. 15).

Figure 120 also shows extremely wide variations in the sedimentation rate of parastratigraphic units in the Reserve. Estimates of sedimentation rate were obtained by plotting the thickness of parastratigraphic units against a geochronologic time scale for the Devonian through Quaternary periods. The sedimentation rate, expressed in terms of feet per millions

of years (ft/MY), is calculated by dividing the maximum present thickness in feet of a given parastratigraphic unit by duration of deposition (in millions of years). The sedimentation rate values were not adjusted for differences in the degree of compaction with depth. Regardless of the generalized nature of these values, the relative changes in sedimentation rate were useful in interpreting the tectonic and depositional history of the Reserve.

Gilluly (1949) indicated that the probability of finding the section showing the maximum thickness decreases with the age of the deposit. Therefore, estimates of the maximum thicknesses of younger units probably are more correct than those of older units. Figure 120 shows that the highest sedimentation rates (4,000 to 5,000 ft/MY) occurred during Aptian through Middle Cenomanian time. The lowest rates (100 to 250 ft/MY) prevailed during Early to Late Permian (middle Wolfcampian to Ochoan), Early Triassic to Early Jurassic (Smithian to Sinemurian), and Middle Jurassic (Bajocian to Callovian) time.

Different sedimentation rates for the same parastratigraphic unit are recognized in units P-2, J-3aII, Ka-2, and Ka-3. The marked differences in rates suggest local subsidence. Rona (1973, p. 2851) suggests that higher sedimentation rates can be correlated with marine transgression or with reversal between regression and transgression. The lower rate of sediment accumulation correlates with marine regression or with reversal between transgression and regression.

Preliminary results of a facies study of parastratigraphic units Ka-2 and Ka-3 are shown in figure 87. The study includes only the Torok Formation, which unconformably overlies unit Ka-1, and the marine facies of the Nanushuk Group, which overlies the Torok. Correlations between wells are of time-transgressive lithofacies, not time-rock units. An unconformity at the base of units Ka-2 and Ka-3, the "basal Torok" unconformity, is traced over the region. A boundary between marine and nonmarine deposits of the Nanushuk is placed at the bottom of a series of coal beds.

The Early Cretaceous (Torok-Nanushuk) depositional cycle began after a hiatus at the end of unit Ka-1 deposition. Units Ka-2 and Ka-3 were deposited in a series of depositional pulses that do not seem to be marked by major hiatuses. Each pulse started with a transgression, followed by a stage of stable sedimentation at the end of the deposition of the Torok Formation. Completion of the depositional cycle is marked by regression and deposition of the nonmarine Nanushuk lithofacies.

As shown in figure 87 the generalized lithologic subdivisions were correlated with their lithofacies equivalents. It was assumed that changes in lithofacies from predominantly sand and silt-sand to clay reflected sedimentation from the shelf to basin. The concentration of the clay (basin) facies was timed to the transgressive and stable stage of sedimentation. It is well known that the facies of basin clay generally contain abnormally high quantities of the primary dispersed hydrocarbons. To predict migration and accumulation of oil and gas, the hydrocarbon sources must be known.

GEOCHEMICAL STUDY

To provide an overview of geochemical conditions in the NPRA, a geochemical study was conducted with emphasis on indicators of thermal maturation, source rock potential, and potential hydrocarbon types. The study was based on geochemical data from 26 key NPRA wells. Results of the investigation are shown in a parastratigraphic framework in eight cross sections (fig. 121-128). Only broad conclusions can be drawn from these results. Listed below are the geochemical indices used in the assessment of hydrocarbon potential in the NPRA:

- Gross source rock potential, expressed as total organic carbon (TOC). Source rock potential is divided into three categories: poor, with less than 1 percent TOC; fair, with 1 to 2 percent TOC; and good, with more than 2 percent TOC.

- Estimates of thermal maturation, such as vitrinite reflectance (R_o), gas wetness, thermal alteration index (TAI), and thermal evolution analysis (TEA-FID).

- Visual kerogen analyses, hydrogen-to-carbon (H/C) ratio determinations, TEA-FID, and PHC/OC indicators, used as the basis for hydrocarbon types. PHC/OC indicators, derived from TEA-FID pyrolysis techniques, show the percentage of pyrolytic hydrocarbon yield per organic carbon content and facilitate determination of the oil-prone or gas-prone nature of the sediments.

The geochemical data suggest that NPRA stratigraphy is generally more gas-prone than oil-prone. Units with the best potential for generating hydrocarbons are those that combine good source rock potential with thermal maturity and favorable kerogen composition. The most promising hydrocarbon generators are unit Ka-1b and the mature sections of units Ka-2 and Ka-3. Source potential within units Ka-2 and Ka-3 is mainly fair, but because of their considerable thickness, these units may represent good hydrocarbon sources. Unit Ka-1b is thinner, but it contains the "Pebble Shale" unit with continuously good source rock potential. The top of the oil-generation zone frequently is either in the lower part of unit Ka-3, or in unit Ka-2. Overall, the units with the best hydrocarbon-generating potential in ascending stratigraphic order, are units M-2a, P-2, TR-3a,

J-3, Ka-1b, Ka-2, and Ka-3. An assessment of the hydrocarbon-generating potential of the parastratigraphic units follows.

UNIT D

Unit D, the Devonian section, has poor source rock potential and is thermally post-mature.

UNIT M

The entire Mississippian section is confined to the eastern part of the Reserve in the Ikpikpuk and Umiat Basins and Fish Creek Platform area. Unit M-1, the lower unit of this section, has poor source rock potential, except at Inigok 1 where the potential ranges from fair to good. Herbaceous, woody, and inertinite kerogens are dominant in this unit; the TOC from coals is high, but amorphous kerogen is mostly absent. PHC/OC indicators also are largely absent. Unit M-1, which is thermally post-mature, lies below the 1.2 percent vitrinite reflectance boundary.

Unit M-2a is found in only three of the wells studied: Lisburne 1 and Inigok 1 where source rock potential is poor and Ikpikpuk 1 where source rock potential ranges from poor to fair. This unit contains 20 to 30 percent amorphous kerogen, indicating an oil-prone source. PHC/OC values indicate both oil- and gas-prone sources within the unit. As in the older units, unit M-2a is thermally post-mature.

Unit M-2b also has poor source rock potential (TOC is less than 1 percent), but contains significant amounts of amorphous kerogen at Atigaru Point 1, Lisburne 1, and Inigok 1. These occurrences of amorphous kerogen are matched by PHC/OC indicators of oil-prone sources, although PHC/OC values also show the presence of gas-prone sources. Unit M-2b is thermally post-mature.

UNIT P

Source rock potential for unit P-1 is poor. At Ikpikpuk 1 and Inigok 1, the unit is thermally post-mature; elsewhere, unit P-1 is within the mature, or oil-generation zone, as delineated by vitrinite reflectance and gas wetness values (figs. 121, 122, 124). At all of the key wells except Ikpikpuk 1, the kerogen in unit P-1 is mainly amorphous; however, the unit also contains significant quantities of herbaceous and woody kerogens. PHC/OC values indicate a

completely oil-prone source at Atigaru Point 1, but mainly gas-prone sources elsewhere.

Unit P-2 is present only at Tunalik 1, Kugrua 1, Ikpikpuk 1, and Inigok 1 where its source rock potential is poor. The unit is post-mature in all of these wells. At Kugrua 1, unit P-2 contains as much as 50 percent amorphous kerogen, and PHC/OC values indicate an oil-prone source. In the other wells, woody and inertinite kerogens are predominant, and PHC/OC values indicate largely gas-prone sources.

UNIT PR

Unit PR-1 is present at Inigok 1, Ikpikpuk 1, and Topagoruk 1 where its source rock potential is poor. The unit also occurs at Tunalik 1 where it has fair source rock potential (TOC of 1 to 2 percent). Visual kerogen analyses and PHC/OC source data are sporadic and unreliable for this interval. The unit is post-mature in these wells, except at Topagoruk 1 where it rises into the lower section of the mature oil-generation zone.

Source rock potential for unit PR-2 is good at Lisburne 1 and fair at Atigaru Point 1. Otherwise, the unit has poor source rock potential. South Simpson 1 is the only well that contains a significant amount of oil-prone amorphous kerogen; elsewhere, woody and inertinite kerogens are dominant. Unit PR-2 reaches post-maturity at Ikpikpuk 1, Kugrua 1, Tunalik 1, and Inigok 1, but elsewhere lies within the mature zone.

UNIT TR

Unit TR-1 has good source rock potential at Lisburne 1 and fair potential at South Harrison Bay 1; elsewhere, its source rock potential is poor. The unit is post-mature at Inigok 1 and Ikpikpuk 1, but in other wells is in a mature section near the bottom of the oil-generation zone. At J. W. Dalton 1, unit TR-1 contains 25 to 30 percent amorphous kerogen, and PHC/OC values also indicate oil-prone source potential. At W. T. Foran 1, amorphous kerogen content is slightly higher, but only one PHC/OC source is indicated and it is gas prone. Elsewhere, herbaceous and woody kerogens dominate the visual analyses with significant amounts of inertinite (non-source organic material) in many wells.

Source rock potential in Unit TR-2 is poor in most places, but is fair at Tunalik 1, J. W. Dalton 1, W. T. Foran 1, and South Harrison Bay 1. The unit is thermally mature, and in most places lies in the lower section of the oil-generation

zone. Unit TR-2 reaches post-maturity at South Meade 1, Kugrua 1, Tunalik 1, and Inigok 1. East of the Meade Arch, unit TR-2 contains a high percentage of amorphous kerogen (fig. 126); herbaceous kerogen is abundant throughout the unit. At J. W. Dalton 1 and Atigaru Point 1, PHC/OC indications of oil-prone sources coincide well with high amorphous kerogen content. At Kugrua 1, PHC/OC indicators of oil-prone sources are associated with a sharp increase in amorphous kerogen content, even though PHC/OC values indicate that the unit also contains abundant gas-prone sources.

Source rock potential for unit TR-3a is mainly poor (as reflected by TOC percentages), but localized intervals of fair source rock potential occur at South Harrison Bay 1, Atigaru Point 1, J. W. Dalton 1, East Simpson 2, and Tunalik 1. Source rock potential is good at W. T. Foran 1, Lisburne 1, and Inigok 1. Unit TR-3a is thermally mature in most wells where it is identified. The unit reaches post-maturity in Kugrua 1, Tunalik 1, and Inigok 1 where it lies below the 1.2 percent vitrinite reflectance boundary. Unit TR-3a often contains more than 30 percent amorphous kerogen, indicating an oil-prone tendency. PHC/OC values which indicate oil-prone sources in unit TR-3a at Atigaru Point 1, East Simpson 1, Drew Point 1, W. T. Foran 1, South Barrow 3, and South Simpson 1, generally show that the unit has more gas-prone sources than oil-prone sources.

Unit TR-3b mainly has poor source rock potential. The unit has good source potential in South Barrow 13 and South Harrison Bay 1, and fair source potential in Tunalik 1, Kugrua 1, and Inigok 1. Unit TR-3b lies in the lower part of the thermally mature zone, except at Tunalik 1, Kugrua 1, and Inigok 1 where it is in the post-mature zone. The unit contains at least 30 percent amorphous kerogen at South Barrow 17, East Simpson 1, East Simpson 2, Atigaru Point 1, and South Harrison Bay 1. Where PHC/OC values are present, they indicate mainly gas-prone sources.

UNIT J

Unit J-1a has poor source rock potential in most wells, but fair-to-good potential at Tunalik 1, East Simpson 2, West Dease 1, Atigaru Point 1, and South Harrison Bay 1. Unit J-1a lies within the thermally mature zone, but becomes post-mature at Tunalik 1 and Kugrua 1. At South Barrow 17, Walakpa 1, Atigaru Point 1, and South Harrison Bay 1, visual kerogen analyses show high amorphous kerogen content (figs. 125, 127); in other wells, significant quantities of herbaceous and woody kerogens are present. Inertinite content often exceeds 30 percent. PHC/OC values indicate

gas-prone and oil-prone sources for this unit; the oil-prone sources coincide with the high amorphous kerogen contents.

Source rock potential for unit J-1b is poor to fair. The unit has poor source rock potential at Peard 1, South Barrow 3, South Barrow 13, Simpson 1, South Simpson 1, South Meade 1 and Topagoruk 1; elsewhere, source rock potential is fair. Unit J-1b is in the lower part of the thermally mature zone. In the Barrow area and as far south as South Simpson 1, as much as 30 percent amorphous kerogen was observed in sample analyses. High herbaceous and woody kerogen contents dominate in the rest of the wells. PHC/OC indicators in the Barrow area wells show more gas-prone sources, although the high amorphous kerogen content found in this area indicates the source material is more oil prone.

TOC percentages indicate that source rock potential in unit J-1c is mainly fair; it is poor at South Barrow 3, Peard 1, and Topagoruk 1, and good at Kugrua 1. Unit J-1c is in the mature zone. Visual kerogen analyses show that the unit contains only very small amounts of amorphous kerogen; herbaceous and woody types dominate, indicating a probable tendency towards gas rather than oil generation. PHC/OC indicators are rare in unit J-1c, indicating non-source or a lack of samples for PHC/OC determinations.

Unit J-3a has fair source potential, except at South Harrison Bay 1 where the unit contains a thick section with poor source rock potential, and Ikpikpuk 1 where many layers have good potential. The unit contains amorphous kerogen, but herbaceous and woody types are most abundant. At Ikpikpuk 1, PHC/OC values indicate oil-prone sources within unit J-3a.

Source potential also is fair for unit J-3b. The unit, which contains thin layers of good source rock potential (TOC is more than 2.0 percent), is thermally mature throughout its extent and post-mature at Tunalik 1 and Seabee 1. Herbaceous and woody kerogens dominate the visual analyses; amorphous kerogen is present in significant quantities only at Kugrua 1, Ikpikpuk 1, and Inigok 1. PHC/OC oil sources coincide with amorphous kerogen accumulations in the lower part of the unit at Ikpikpuk 1 and Inigok 1.

Unit J-3c has fair to good source rock potential, except at South Meade 1 where it is poor. The unit is mainly thermally mature at Lisburne 1 and Seabee 1, but post-mature at Tunalik 1, Seabee 1, and Oumalik 1. Visual kerogen analyses show that herbaceous and woody types are most abundant, but many wells have an amorphous kerogen content of 20 to 30 percent and more. Where PHC/OC source indicators are present, gas-prone rather than oil-prone sources are indicated.

UNIT Ka

Unit Ka-1a is present only at Tunalik 1 where it has fair source rock potential and is thermally post-mature. It contains roughly equal amounts of herbaceous, woody, and inertinite kerogens. Amorphous kerogen content and PHC/OC indicators are negligible. PHC/OC values are too low to indicate either oil or gas sources.

Unit Ka-1b underlies units Ka-2 and Ka-3 and has the best source rock potential observed; however, the potential is only fair at Atigaru Point 1, South Barrow 13, East Simpson 1, South Simpson 1, and Seabee 1. South Barrow 13 did not penetrate a mature section. South Barrow 17 penetrated a zone several hundred feet thick in the bottom of the well where gas wetness exceeds 50 percent and vitrinite reflectance values are in the submature range. In other wells, unit Ka-1b is consistently thermally mature, except at Tunalik 1, Seabee 1, and Oumalik 1 where the unit is post-mature. The TOC content of unit Ka-1b is nearly always more than 2 percent. Visual kerogen analyses indicate that this unit is an oil-prone interval; its amorphous kerogen content is high, reaching 30 percent in many places.

Units Ka-2 and Ka-3 contain many thick sections that could provide an abundance of organic material. In most wells penetrating these units, the TOC content is more than 1 percent, and oil and gas shows were encountered during drilling. The Nanushuk Group is contained within units Ka-2 and Ka-3. Magoon and Claypool (1978) found that oil in the Nanushuk Group at Umiat 11 migrated from deeper strata, because it was found in a thermally immature zone. Oil shows in the mature intervals of South Simpson 1, Peard 1, W. T. Foran 1, and other wells could indicate localized hydrocarbon generation. The top of the oil-generation zone often is in units Ka-2 and Ka-3, indicating a potential for hydrocarbon generation.

Source potential within unit Ka-2 is largely fair, except at Lisburne 1 and Walakpa 1 where it is poor. Most of unit Ka-2 is thermally immature, except in the Barrow wells where it is mature; at Seabee 1, the unit is post-mature. Visual kerogen analyses are dominated by herbaceous types. In the Simpson wells and South Meade 1, the amorphous kerogen content increases to up to 40 percent, indicating an increase in oil-prone source intervals. PHC/OC values strongly indicate gas-prone organic matter, except at South Meade 1 where PHC/OC values show that oil-prone sources are as abundant as gas-prone sources. The oil-prone sources mainly coincide with intervals containing large amounts of amorphous kerogen.

Source rock potential in unit Ka-3 is mostly fair except at W. T. Foran 1, Cape Halkett 1, and Topagoruk 1 where it is poor. Good source potential was noted at Tunalik 1, Peard 1, South Meade 1, and Ikpikpuk 1, although high TOC content is associated with coaly intervals. Unit Ka-3 reaches maturity in its lower parts, as shown by at least one maturity indicator at eight wells: South Meade 1, South Simpson 1, Simpson 1, J. W. Dalton 1, Atigaru Point 1, North Kalikpik 1, South Harrison Bay 1, and Inigok 1. The lower two-thirds of the unit is thermally mature at Seabee 1. Herbaceous kerogen is dominant in visual analyses; however, significant amounts of amorphous kerogen are present in many wells in the northern part of the Reserve, as shown on cross section A-A' (fig. 125). This may indicate a stronger tendency towards oil-prone sources, but nearly all PHC/OC indicators show gas-prone sources.

UNIT Kb

Source rock potential in unit Kb is poor at J. W. Dalton 1, W. T. Foran 1, and Cape Halkett 1; elsewhere, it ranges from poor to good, with large sections of fair potential at Atigaru Point 1 and Drew Point 1. Intervals of good source potential at Atigaru Point 1, East Simpson 1, and East Simpson 2, are related to coaly layers. Unit Kb is thermally immature. Herbaceous and woody kerogens dominate, indicating gas-prone organic matter.

UNIT T

Source rock potential within unit T is poor. TOC values denoting good source potential at J. W. Dalton 1 are largely attributed to organic layers and peat. The Tertiary section is thermally immature. Herbaceous and woody kerogens dominate visual kerogen records, indicating gas-prone rather than oil-prone source potential.

INTERPRETATION SUMMARY

In this report, the three main tectonic subdivisions in the NPRA are the Arctic Coastal Plain, Foothills Fold Belt, and Brooks Range Orogen, as shown in figures 8 and 29. The exploration possibilities in these regions are: stratigraphic traps in the Arctic Coastal Plain, large anticlinal trends in the Foothills Fold Belt, and overthrust areas in the Brooks Range Orogen.

The greatest exploration possibilities probably are in the Arctic Coastal Plain. Along hinge lines on the flanks of regional highs and/or basins in this area, the sedimentary units are truncated, lap out against the basement, are overlapped in turn by younger rocks, and contain zones of facies changes. Offshore sand bars and reefs may occur in the subsurface.

In the Foothills Fold Belt and Brooks Range Orogen, large structures are the main exploratory objectives. The Foothills Fold Belt has a northern zone comprising shallow folds with complex axial shale cores and a southern zone comprising similar complex folds and thrust faults. Several structures in the northern part of the Foothills Fold Belt are hydrocarbon-bearing. The large structural trends in the middle and southern parts of the belt are largely untested, but may contain accumulations of petroleum.

The Brooks Range Orogen is dominated by thrust faults, and the subsurface geology in the area is not well known. However, the hydrocarbon potential of this thrust-faulted, folded, and complex belt may be somewhat similar to that in Rocky Mountain overthrust areas. Lack of known potential reservoirs in the Brooks Range Orogen is a drawback.

Potential NPRA reservoir beds of pre-Cretaceous age (fig. 4), in ascending order, are the: possible Mississippian-Pennsylvanian clastic facies of the Lisburne Group, Mississippian "Dolomite unit" of the Alapah Limestone, Pennsylvanian-Permian Wahoo Limestone, Permian Ikiakpaurak Member of the Echooka Formation, Triassic "Ivishak sandstone", Triassic Sag River Sandstone, Early Jurassic "Barrow sandstone," and Late Jurassic "Simpson sandstone." In the Jurassic-Neocomian Kingak Formation, known sandstones that may be potential reservoirs include the "Peard sandstone," Neocomian sandstones found at Tunalik 1, and the seismically defined "Kealok anomaly," which may contain

sandstone. Additionally, a number of undiscovered, unnamed sandstones probably occur within the Kingak. Sandstones of reservoir quality in Cretaceous rocks include the "Pebble Shale" sandstone, "Walakpa sandstone," "basal Torok," and marine and nonmarine sandstones of the Nanushuk Group.

LISBURNE GROUP

Potential traps in the Lisburne Group occur along the south flank of the Barrow High-Barrow Arch and the flanks of the Wainwright Arch-Utukok High, Meade Arch, Fish Creek Platform, Oumalik High-Key River Arch, and Umiat Platform. The Lisburne does not seem to be very prospective in the Brooks Range Orogen, because of the probable lack of porosity. Lisburne 1 was drilled to test the Lisburne Group; minor gas shows and some dead oil stains were found, but no intergranular porosity. Also, fractures seemed to be filled with calcite and quartz, suggesting that fractured reservoirs may not occur near Lisburne 1. Adequate porosity for significant production has not been found in the Lisburne Group. However, stacking velocity analyses suggest the possibility that Paleozoic sediments in the Umiat Basin contain clastic or porous carbonates and that lap-out edges on the flanks of regional highs may be clastic and porous.

The potentially porous dolomites in the Alapah Limestone may lap out on the "Acoustic basement" on the east flank of the Meade Arch, north flank of the Oumalik High, south flank of the Fish Creek Platform, and north flank of the Umiat Platform where the Alapah seems to be truncated by younger, probably impermeable, Mississippian rocks (figs. 10, 96). The "Dolomite unit" near the top of the Alapah is the main Lisburne reservoir rock in the Prudhoe Bay area.

The Wahoo Limestone laps out against the Barrow High and Meade Arch between Peard Bay and Smith Bay (figs. 9, 41, 96), and may be sealed by the interbedded shale and limestone of the overlying "Transition Zone." Heavy oil and tar recovered from tests in J. W. Dalton 1 indicate that porous zones in the area possibly could yield lighter oil in commercial quantities. The onlap of the Wahoo Limestone onto the Wainwright Arch may form a trap in the northeastern corner of the Wainwright Quadrangle. There, the Wahoo is believed to change laterally to clastics, as suggested by a low-velocity seismic anomaly in the area (seismic map 58).

ECHOOKA FORMATION

The Ikiakpaurak Member of the Echooka Formation onlaps the

basement on the Wainwright Arch, and may be sealed by the overlying "Kavik shale." In the northwestern NPRA, the Ikiakpaurak is composed of conglomeratic sandstone. Gas shows at Peard 1 suggest that hydrocarbons may be present elsewhere in the area. The Ikiakpaurak may also be a potential sandstone reservoir on the south flank of the Barrow High and on the north end of the Meade Arch, if it is overlapped and sealed by the "Kavik shale."

"IVISHAK SANDSTONE"

In the northernmost NPRA, the "Ivishak sandstone" is a potential reservoir in a narrow belt south of the Barrow High and along the northeastern coast through Smith Bay and Harrison Bay (figs. 48, 70). To the north, the "Pebble Shale" truncates the "Ivishak sandstone"; to the south, facies of the "Ivishak" change to siltstone and shale. The "Ivishak sandstone" is the main reservoir at Prudhoe Bay where it is permeable and porous. However, wherever it was penetrated in the NPRA, the unit is siltier and less permeable.

SAG RIVER SANDSTONE

The Sag River Sandstone is an excellent potential reservoir in the northernmost NPRA (figs. 50, 71) from the Peard 1 area through Smith Bay, and along the coast around Smith Bay.

KINGAK FORMATION SANDSTONES

The Kingak Formation contains several potential reservoir sandstones in the northeastern NPRA, including the Early Jurassic "Barrow sandstone." The Kingak is mostly shale east of the Meade Arch, but sands possibly occur on the south flank of the Fish Creek Platform and east flank of the Meade Arch, although no sandstones were found in wells in these areas.

Kingak sandstones in the west include the Late Jurassic "Simpson sandstone" and "Peard sandstone," as well as Neocomian sands in Tunalik 1 that had gas shows. These sandstones probably are truncated northward by the basal "Pebble Shale" unconformity, with facies changing to shale basinward.

Up-dip facies changes from sandstone to shale in the Kingak are indicated on the west side of the Meade Arch. The Jurassic "Simpson sandstone," drilled at Topagoruk 1, South

Simpson 1, South Meade 1, Kugrua 1, and Peard 1, appears to shale out to the north (figs. 57, 70). The same horizon is composed of siltstone and shale at Kuyanak 1, Walakpa 1, and Walakpa 2. A potentially large hydrocarbon accumulation may be trapped in the "Simpson sandstone" south of Kuyanak 1. A nearly east-west Jurassic high-velocity anomaly extending from south of Kuyanak 1 to Peard 1 and Kugrua 1 may approximate the axis of deposition of the "Simpson sandstone" (seismic map 56). Potential traps also may occur wherever the "Pebble Shale" unit or the "basal Torok" unconformably overlies the "Upper Kingak."

CRETACEOUS SANDSTONES

The gas-bearing "Walakpa gas sandstone" occurs at the base of the "Pebble Shale" unit on the south flank of the Barrow High. The "Walakpa gas sandstone" and "Pebble Shale" dip to the south where oil may occur below the gas accumulation (fig. 78). To date, drilling has not defined the maximum thickness of the sandstone, its geographic extent, or the amount of gas or other hydrocarbons present.

In the NPRA, the "Pebble Shale" unit contains several isolated sandstone bodies at the base and within the unit, referred to collectively as the "Pebble Shale" sandstone (figs. 61, 62). On the west flank of the Meade Arch, a large sandstone body at the base of the "Pebble Shale" is similar to the Put River Sandstone in Prudhoe Bay Field and Kemik Sandstone in the northeastern Brooks Range.

Any hydrocarbons that may be present in the basal "Pebble Shale" sandstone body located between Smith Bay and Harrison Bay probably are concentrated along the crest of the Barrow Arch. The "Pebble Shale" sandstone dips southward and northward from the crest of the Arch and good potential exists for hydrocarbon accumulation along the Barrow Arch below the "Pebble Shale."

TOROK FORMATION AND NANUSHUK GROUP

Several structures in the northern part of the Foothills Fold Belt (fig. 26) are hydrocarbon-bearing, shallow, complex folds with axial shale cores in the Torok (see also figs. 130, 131). An example of this type of fold is the Shaningarok anticline shown on seismic line R7XN-79 in figure 132. One of the foothills structures, the Umiat structure, contains both oil and gas and perhaps could be developed into an economic oil field under favorable conditions. Minor oil

production or oil and gas shows were encountered above 2,000 ft (610 m) in all 11 wells drilled in the Umiat structure from 1945 through 1952. Two sandstones in the Nanushuk Group were the source of all production.

The zone of shallow folds trending westward from the Gubik area (just east of the Reserve in figure 130) through the Umiat, Wolf Creek, Square Lake, Oumalik, and Meade areas also had hydrocarbon shows. At Oumalik 1, gas shows were detected throughout the Torok Formation. Because of gas shows in the Torok and possible closures in the complex folding and faulting, the "basal Torok" is a good secondary objective for wells drilled into a shallow fold; however, such closures in the Torok are difficult to define seismically because of the complex structure.

Awuna 1, the only well drilled in the southern Foothills Fold Belt (figs. 89, 131, 132), tested the shallow Nanushuk Group and "basal Torok" on the crest of the Awuna structure. Tests at Awuna 1 produced a substantial salt water flow from a thick Lower Cretaceous, fractured(?) sandstone. Numerous gas shows were encountered at 6,500 to 7,000 ft (1,981 to 2,134 m), and some oil shows were found from 1,850 to 2,600 ft (564 to 792 m). The Awuna structure and similar folds are associated with a pronounced thrust and fold belt called the Carbon trend.

On the Fish Creek Platform, the marine Nanushuk contains several potential reservoir sandstones that may be offshore bar deposits. Hydrocarbon traps may exist to the west where the sandstone possibly changes laterally to marine shale or impermeable nonmarine Nanushuk rocks.

The most favorable area for exploration in the marine Nanushuk is within the 20 percent sand limit, as shown by Bird and Andrews (1979) and Huffman and Ahlbrandt (1979). This area extends well beyond the area of the Fish Creek Platform and includes parts of the Meade Arch, Oumalik High, and Ikpikpuk and Umiat Basins. On the crest of the Fish Creek Platform, the marine Nanushuk contains less than 20 percent sand, nevertheless, gas shows were found at West Fish Creek 1; gas shows also were found in the "basal Torok" at West Fish Creek 1. Presumably, the marine Nanushuk is more favorable for exploration west of the Fish Creek Platform where a combination of high sand content and regional dip favor the accumulation of hydrocarbons (figs. 10-12).

Hydrocarbon seeps are known on the margin of the Simpson canyon, a Cretaceous cut-and-fill feature located on the north and west margins of the Simpson Peninsula (figs. 17-20). This probable submarine canyon was cut through the

Torok-Nanushuk sequence in Cretaceous time, and may have cut below the "Pebble Shale" unit in places. Microfossils indicate the canyon is filled by Late Cretaceous shales, siltstones, and silty sandstones. The shallow Nanushuk and the "Pebble Shale" unit may be the most likely source of the seeps.

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APPENDIX A

DRILLING RESULTS, 1945-1981

TABLE A1.--NPR-4 drilling results, 1947-1952

[All wells were wildcat wells except for Sentinel Hill 1 and Skull Cliff 1, which were core-test wells.]

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Fish Creek 1 lat 70°19'15"N long 151°58'08"W	05/17/49- 09/04/49	31.5(9.6)	7,020(2,320) Torok Formation	Abandoned oil well.
Grandstand 1 lat 68°57'58"N long 151°55'02"W	05/01/52- 08/08/52	665(203)	3,939(1,201) Torok Formation	Gas shows; plugged and abandoned.
Gubik 1 lat 69°26'46"N long 151°28'06"W	05/20/51- 08/11/51	156(46)	6,000(1,829) Torok Formation	Abandoned gas well.
Gubik 2 lat 69°25'10"N long 151°27'26"W	09/10/51- 12/14/52	163(50)	4,620(1,408) Torok Formation	Oil and gas shows; plugged and abandoned.
Kaolak 1 lat 69°56'N long 160°14'51"W	07/21/51- 11/12/51	178(54)	6,952(2,119) Torok Formation	Oil and gas shows; plugged and abandoned.
Knifeblade 1 lat 69°09'04"N long 154°43'21"W	10/13/51- 12/22/51	999(304)	1,805(550) Nanushuk Group	Dry; plugged and abandoned.
Knifeblade 2 lat 69°08'19"N long 154°44'12"W	07/26/51- 08/05/51	876(267)	373(114) Nanushuk Group	Dry; plugged and abandoned.
Knifeblade 2A lat 69°08'19"N long 154°44'12"W	08/06/51- 10/07/51	874(266)	1,805(550) Nanushuk Group	Oil shows; plugged and abandoned.
Meade 1 lat 70°02'30"N long 157°29'23"W	05/02/50- 08/21/50	211(64)	5,305(1,617) Torok Formation	Oil shows; plugged and abandoned.
Oumalik 1 lat 69°50'18"N long 155°59'24"W	06/11/49- 04/23/50	194(59)	11,872(3,614) Kingak Formation	Many gas shows; plugged and abandoned.
East Oumalik 1 lat 69°47'29"N long 155°32'39"W	10/23/50- 01/07/51	293(89)	6,035(1,839) Torok Formation	Oil and gas shows; plugged and abandoned.
Sentinel Hill 1 lat 69°36'57"N long 151°27'11"W	01/26/47- 03/23/47	209(64)	1,180(360) Seabee Formation	Dry; plugged and abandoned.
Simpson 1 lat 70°57'12"N long 155°21'52"W	06/14/47- 06/09/48	29(9)	7,002(2,134) "Argillite"	Oil and gas shows; plugged and abandoned.
North Simpson 1 lat 71°03'23"N long 154°58'06"W	05/06/50- 06/03/50	30(9)	3,774(1,150) Torok Formation	Dry; plugged and abandoned.

TABLE A1.--NPR-4 drilling results, 1947-1952 (Continued)

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Skull Cliff 1 lat 70°54'N long 157°36'W	02/02/47- 03/17/47	50(15)	779(237) Torok Formation	Dry; plugged and abandoned.
Square Lake 1 lat 69°34'±N long 153°18'±W	01/26/52- 04/18/52	340(104)	3,987(1,215) Torok Formation	Gas shows; plugged and abandoned.
Titaluk 1 lat 69°25'21"N long 154°34'04"W	04/22/51- 07/06/51	840(256)	4,020(1,225) Torok Formation	Dry; plugged and abandoned.
Topagoruk 1 lat 70°37'30"N long 155°53'36"W	06/15/50- 09/28/51	42(13)	10,503(3,201) "Argillite"	Oil and gas shows; plugged and abandoned.
East Topagoruk 1 lat 70°34'37.5"N long 155°22'39"W	02/18/51- 04/16/51	67(20)	3,589(1,094) Torok Formation	Gas shows; plugged and abandoned.
Wolf Creek 1 lat 69°23'11"N long 153°31'15"W	04/29/51- 06/04/51	714(218)	1,500(457) Nanushuk Group	Gas shows; plugged and abandoned.
Wolf Creek 2 lat 69°24'17"N long 153°31'15"W	06/06/51- 07/01/51	443(135)	1,618(493) Nanushuk Group	Gas shows; plugged and abandoned.
Wolf Creek 3 lat 69°23'11"N long 153°31'25"W	08/20/52- 11/03/52	750(229)	3,760(1,146) Torok Formation	Gas shows; plugged and abandoned.

TABLE A2.--NPR-4 and NPRA drilling results, 1975-1981

[All wells were wildcat wells except for Walakpa 2, a developmental gas well.]

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Atigaru Point 1 lat 70°33'22.03"N long 151°43'01.85"W	01/12/77- 03/13/77	27(8)	11,535(3,516) "Argillite"	Poor oil shows; plugged and abandoned.
Awuna 1 lat 69°09'11.58"N long 158°01'21.27"W	03/01/80- 04/20/81	1,129(344)	11,200(3,414) Torok Formation	Many gas shows; salt water flow from 8,225 to 8,412 ft during drillstem test; plugged and abandoned.
Cape Halkett 1 lat 70°46'02.702"N long 152°27'59.284"W	03/24/75- 06/01/75	39.5(12)	9,900(3,018) "Argillite"	Oil and gas shows; dry; plugged and abandoned.
J. W. Dalton 1 lat 70°55'13.79"N long 153°08'15.104"W	05/07/79- 08/01/79	37(11)	9,367(2,855) "Argillite"	Oil and gas shows, some heavy oil recovered during testing; plugged and abandoned.
West Dease 1 lat 71°09'32.65"N long 155°37'45.19"W	02/19/80- 03/26/80	24(7)	4,170(1,271) "Argillite"	Oil and gas shows; plugged and abandoned.
Drew Point 1 lat 70°52'47.141"N long 153°53'59.931"W	01/13/78- 03/13/78	35(11)	7,946(2,422) "Argillite"	Poor oil and gas shows; plugged and abandoned.
West Fish Creek 1 lat 70°19'35.99"N long 152°03'38.03"W	02/14/77- 04/27/77	113(34)	11,427(3,483) Lisburne clastics	Poor oil shows; plugged and abandoned.
W. T. Foran 1 lat 70°49'56.01"N long 152°18'11.23"W	03/07/77- 04/24/77	39(12)	8,864(2,702) "Argillite"	Oil and gas shows; plugged and abandoned.
South Harrison Bay 1 lat 70°25'29.31"N long 151°43'52.48"W	11/21/76- 02/08/77	45(14)	11,290(3,442) Lisburne Group	Poor oil shows; plugged and abandoned.
Iko Bay 1 lat 71°10'13"N long 156°10'01"W	02/01/75- 03/11/75	40(12)	2,731(832) "Argillite"	Marginal gas discovery; plugged and abandoned.
Ikpikpuk 1 lat 70°27'19.679"N long 154°19'52.780"W	11/28/78- 02/28/80	52(16)	15,481(4,719) "Argillite"	Oil and gas shows; plugged and abandoned.

TABLE A2.--NPR-4 and NPRA drilling results, 1975-1981 (Continued)

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Inigok 1 lat 70°00'17.483"N long 153°05'56.916"W	06/07/78- 05/22/79	163(50)	20,102(6,127) Endicott Group	Oil and gas, hydrogen sulfide, sulfur shows at 17,570 ft; plugged and abandoned.
North Inigok 1 lat 70°15'27.32"N long 152°45'57.53"W	02/13/81- 04/04/81	166(51)	10,170(3,100) Shublik Formation	Gas shows; plugged and abandoned.
North Kalikpik 1 lat 70°30'33.023"N long 152°22'04.169"W	02/27/78- 04/14/78	40(12)	7,395(2,254) Kingak Formation	Poor oil and gas shows; plugged and abandoned.
Koluktak 1 lat 69°45'08.62"N long 154°36'40.12"W	03/24/81- 04/19/81	205(62)	5,882(1,793) Torok Formation	Gas and minor oil shows; plugged and abandoned.
Kugrua 1 lat 70°35'13.283"N long 158°39'43.258"W	02/12/78- 05/29/78	85(26)	12,588(3,839) Lisburne Group	Oil and gas shows; dry; plugged and abandoned.
Kuyanak 1 lat 70°55'53.48"N long 156°03'53.08"W	02/13/81- 03/31/81	28(9)	6,690(2,039) "Argillite"	Minor oil and gas shows; plugged and abandoned.
Lisburne 1 lat 68°29'05.4381"N long 155°41'35.510"W	06/11/79- 06/02/80	1,862(568)	17,000(5,182) Lisburne Group	Gas shows; plugged and abandoned.
South Meade 1 lat 70°36'53.92"N long 156°53'23.60"W	02/07/78- 01/22/79	60(18)	9,945(3,031) "Argillite"	Poor gas shows; plugged and abandoned.
Peard 1 lat 70°42'56.321"N long 159°00'02.518"W	01/26/79- 04/13/79	103(31)	10,225(3,117) "Argillite"	Poor gas shows; plugged and abandoned.
Seabee 1 lat 69°22'48.519"N long 152°10'31.291"W	07/01/79- 04/15/80	322(98)	15,611(4,758) Kingak Formation	Oil and gas shows; plugged and abandoned.
East Simpson 1 lat 70°55'04.01"N long 154°37'04.75"W	02/19/79- 04/10/79	30(9)	7,739(2,359) "Argillite"	Oil and gas shows; plugged and abandoned.
East Simpson 2 lat 70°58'42.51"N long 154°40'25.74"W	01/29/80- 03/15/80	40(12)	7,505(2,288) "Argillite"	Oil and gas shows; plugged and abandoned.
South Simpson 1 lat 70°48'24.75"N long 154°58'54.61"W	03/09/77- 04/30/77	25(8)	8,795(2,681) "Argillite"	Oil and gas shows; dry; plugged and abandoned.
East Teshekpuk 1 lat 70°34'11.661"N long 152°56'36.905"W	03/12/76- 05/11/76	27.6(8)	10,664(3,250) Lisburne clastics	Oil and gas shows; dry; plugged and abandoned.

TABLE A2.--NPR-4 and NPRA drilling results, 1975-1981 (Continued)

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Tulageak 1 lat 71°11'21.62"N long 155°44'00.82"W	02/26/81- 03/23/81	27(8)	4,015(1,224) "Argillite"	A few poor oil shows; plugged and abandoned.
Tunalik 1 lat 70°12'21.453"N long 161°04'09.159"W	11/10/78- 01/07/80	110(34)	20,335(6,198) Lisburne Group	Significant gas shows, Alaska depth record; plugged and abandoned.
Walakpa 1 lat 71°05'57.63"N long 156°53'03.79"W	12/25/79- 02/08/80	50(15)	3,666(1,117) "Argillite"	Gas shows; plugged and abandoned.
Walakpa 2 lat 71°03'00.44"N long 156°57'09.70"W	01/03/81- 02/15/81	61(19)	4,360(1,329) "Argillite"	Temporarily abandoned gas well, Walakpa sand.

TABLE A3.--Barrow area drilling results, 1948-1981

[All wells were developmental wells except for Avak 1 and South Barrow 1, 2, 3, 4, 12, 14, and 16, which were wildcat wells.]

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Avak 1 lat 71°15'02"N long 156°26'06"W	10/21/51- 01/14/52	18.5(6)	4,020(1,225) "Argillite"	Tested "Disturbed Zone"; plugged and abandoned.
South Barrow 1 lat 71°19'12"N long 156°42'16"W	08/15/48- 11/11/48	18(5)	3,553(1,083) "Argillite"	Oil shows; plugged and abandoned.
South Barrow 2 lat 71°15'49"N long 156°38'03"W	12/18/48- 04/15/49	34.5(11)	2,505(764) "Argillite"	Flowed 500 thousand cubic feet of gas per day; abandoned.
South Barrow 3 lat 71°09'47"N long 156°34'44"W	06/23/49- 08/26/49	44(13)	2,900(884) "Argillite"	Oil and gas shows, plugged and abandoned.
South Barrow 4 lat 71°15'51"N long 156°37'50"W	03/09/50- 05/09/50	43(13)	2,538(774) "Argillite"	Flowed 1.8 million cubic feet of gas per day; abandoned.
South Barrow 5 lat 71°15'51"N long 156°37'59"W	05/17/55- 06/17/55	38.3(12)	2,456(749) "Argillite"	Flowed 7.9 million cubic feet of gas per day maximum; gas well.
South Barrow 6 lat 71°15'44"N long 156°36'53"W	07/28/64- 03/24/64	40(12)	2,363(720) "Barrow sandstone"	Initial production, 9.6 million cubic feet of gas per day; gas well.
South Barrow 7 lat 71°15'38"N long 156°35'43"W	03/04/68- 04/02/68	36(11)	2,351(717) "Barrow sandstone"	Upper "Barrow sandstone" source; gas well.
South Barrow 8 lat 71°15'54"N long 156°35'32"W	04/04/69- 05/01/69	31(9)	2,359(719) "Barrow sandstone"	Upper "Barrow sandstone" source; gas well.
South Barrow 9 lat 71°16'03"N long 156°36'53"W	03/19/70- 04/15/70	29(9)	2,450(747) "Barrow sandstone"	Initial production, 7 to 8 million cubic feet of gas per day; gas well.
South Barrow 10 lat 71°15'32"N long 156°37'34"W	03/07/73- 03/24/73	38(12)	2,349(716) "Barrow sandstone"	Gas well.
South Barrow 11 lat 71°15'22"N long 156°36'24"W	02/10/74- 03/05/74	36(11)	2,350(716) "Barrow sandstone"	Gas well.

TABLE A3.--Barrow area drilling results, 1948-1981 (Continued)

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
South Barrow 12 lat 71°14'14"N long 156°20'16"W	03/10/74- 05/04/74	26(8)	2,283(696) Shublik Formation	Oil and gas shows; dry; suspended.
South Barrow 13 lat 71°15'13.84"N long 156°37'40.41"W	12/17/76- 01/16/77	40(12)	2,534(773) "Argillite"	Marginal production; suspended gas well.
South Barrow 14 lat 71°13'58.79"N long 156°18'11.02"W	01/28/77- 03/03/77	31(9)	2,257(688) Sag River Sandstone equivalent	Upper and lower "Barrow sandstone" source; gas well.
South Barrow 15 lat 71°14'58.68"N long 156°20'42.13"W	08/23/80- 09/18/80	30(9)	2,278(694) "Barrow sandstone"	Upper "Barrow sandstone" source; gas well.
South Barrow 16 lat 71°16'56.681"N long 156°32'46.814"W	01/28/78- 02/18/78	30(9)	2,400(732) "Argillite"	Dry; plugged and abandoned.
South Barrow 17 lat 71°14'00.506"N long 156°15'34.328"W	03/02/78- 04/13/78	33(10)	2,382(726) "Argillite"	Edge well; produces water with gas; suspended.
South Barrow 18 lat 71°14'22.98"N long 156°18'41.00"W	09/22/80- 10/14/80	30(9)	2,135(651) "Barrow sandstone"	Lower "Barrow sandstone" source; gas well.
South Barrow 19 lat 71°14'29.470"N long 156°20'00.687"W	04/17/78- 05/17/78	30(9)	2,300(701) "Argillite"	Lower "Barrow sandstone" source; gas well.
South Barrow 20 lat 71°13'57.02"N long 156°20'11.98"W	04/07/80- 05/10/80	30(9)	2,356(718) "Argillite"	Oil and gas shows; suspended as marginal oil producer.

TABLE A4.--Umiat area drilling results, 1945-1952

[All wells were developmental wells except for Umiat 1, 2, and 3, which were wildcat wells.]

Well name and location	Date from spud to completion	Kelly bushing elevation, ft(m)	Total depth, ft(m), and deepest rock unit attained	Remarks
Umiat 1 lat 69°23'52"N long 152°19'45"W	06/22/45- 10/05/46	810(247)	6,005(1,830) Torok Formation	Oil shows; plugged and abandoned.
Umiat 2 lat 69°23'04"N long 152°05'01"W	06/25/47- 12/12/47	342(104)	6,212(1,893) Torok Formation	Oil shows; plugged and abandoned.
Umiat 3 lat 69°23'16"N long 152°05'14"W	11/15/46- 12/26/46	360(110)	572(174) Nanushuk Group	Pumped 24 barrels of oil per day; abandoned.
Umiat 4 lat 69°23'20"N long 152°04'53"W	05/26/50- 07/29/50	483(147)	840(256) Nanushuk Group	Pumped 100 barrels of oil per day; shut-in.
Umiat 5 lat 69°23'05"N long 152°04'56"W	07/05/50- 09/22/50	335(102)	1,077(328) Torok Formation	Pumped 400 barrels of oil per day; shut-in.
Umiat 6 lat 69°22'44"N long 152°05'40"W	08/14/50- 12/12/50	337(103)	825(251) Nanushuk Group	Bailed 25 barrels of oil per day; gas show; abandoned.
Umiat 7 lat 69°22'33"N long 152°06'17"W	12/14/50- 04/12/51	330(100)	1,384(422) Torok Formation	Oil and gas shows; plugged and abandoned.
Umiat 8 lat 69°23'59"N long 152°06'56"W	05/02/51- 08/28/51	740(226)	1,327(404) Torok Formation	Pumped 100 barrels of oil per day; flowed 1.9 million cubic feet of gas per day; shut-in.
Umiat 9 lat 69°23'14"N long 152°10'11"W	06/25/51- 01/15/52	424(129)	1,257(383) Torok Formation	Pumped 217 barrels of oil per day; shut-in.
Umiat 10 lat 69°24'04"N long 152°07'57"W	09/09/51- 01/10/52	746(227)	1,573(479) Torok Formation	Pumped 222 barrels of oil per day; shut-in.
Umiat 11 lat 69°24'29"N long 152°05'58"W	06/03/52- 08/29/52	481(147)	3,303(1,007) Torok Formation	Oil and gas shows; plugged and abandoned.

APPENDIX B

SEISMIC PROGRAMS, FY 1972-FY 1980

TABLE B1.--FY 1972 seismic program

[Geophysical Service Inc. (GSI) party 195, also called party G-1, conducted the survey from 26 April to 15 May 1972 in the Barrow area. Data quality was fair.]

Seismic line	Shotpoint range	Number of line miles
A	1-38	6.2
B	1-60	9.8
C	1-23	3.7
D	1-21	3.3
E	1-40	6.5
F	1-36	5.8
G	1-23	3.7
H	1-22	3.5
I	1-74	12.2
J	1-45	7.3
TOTAL		62.0

TABLE B2.--FY 1972 recording parameters

[Dynamite was the energy source. Seismic data were recorded on digital tape with TIAC, 21-track DFS-III instruments with an 8-124 Hz filter. Geophones were type HSJ-14.]

Number of channels	48
Multiplicity	3-fold
Group interval	110 ft
Spread (symmetrical)	55-2585 ft
Shotpoint offset	55 ft, in line
Shotpoint spacing	880 ft
Geophones per group	12
Geophone spacing	20 ft
Sample rate	2 ms
Record length	5 s
Charge	25 lb
Depth	55 ft

TABLE B3.--FY 1973 seismic program

[GSI party 195, also called party G-2, conducted the survey from 30 November to 20 December 1972 in the Barrow area. Data quality was fair.]

Seismic line	Shotpoint range	Number of line miles
K	1-69	5.67
L	1-84	6.92
M	1-67	5.50
N	1-119	9.83
Q	1-44	3.58
TOTAL		31.50

TABLE B4.--FY 1973 recording parameters

[Dynamite was the energy source. Seismic data were recorded on digital tape with TIAC, 21-track DFS-III instruments with an 8-124 Hz filter. Geophones were type HSJ-14.]

Number of channels	48
Multiplicity	6-fold
Group interval	110 ft
Spread (symmetrical)	55-2,585 ft
Shotpoint offset	55 ft, in line
Shotpoint spacing	440 ft
Geophones per group	12
Geophone spacing	20 ft
Sample rate	2 ms
Record length	5 s
Charge	25 lb
Depth	55 ft

TABLE B5.--FY 1974 seismic program

[GSI seismic crews recorded data from 1 March to 15 May 1974 covering 1,062.47 line miles, including 43 line miles in the Barrow area and 1,019.47 line miles in zone A. Data quality was good, except in local areas with abnormal permafrost conditions around lakes and active rivers.]

Seismic line	Shotpoint range	Number of line miles		
		Party 184 (Navy 2)	Party 186 (Navy 3)	[1]Party 195 (Navy 1)
		Barrow area		
O	1-30	---	---	4.83
P	1-17	---	---	2.67
R	1-23	---	---	3.67
S	1-31	---	---	5.00
T	1-24	---	---	3.83
U	1-46	---	---	7.50
V	1-52	---	---	8.50
W	1-25	---	---	4.00
X	1-19	---	---	3.00
TOTAL		---	---	43.00
		Zone A		
1	1-46	---	---	11.25
2	1-28	---	---	6.75
3	1-63	---	---	15.50
	127-225	---	24.75	---
4	1-80	---	---	19.75
	1-97	24.00	---	---
5	2-78	---	---	19 00
	101-149	---	24.75	---
6	1-65	---	---	16.00
7	1-100	---	24.75	---
	100-203	---	---	25.75
8	1-90	---	---	22.25
9	1-85	---	---	20.25
10	1-112	---	---	27.72
11	1-83	---	20.25	---
12	1-56	---	13.75	---
13	1-72	---	17.50	---
14	1-56	---	13.50	---
15	1-79	---	19.25	---
16	1-70	---	17.00	---
17	1-148	---	36.75	---
18	1-88	---	21.75	---
19	1-153	38.00	---	---
20	1-110	27.25	---	---
21	1-86	21.25	---	---
22	1-83	20.25	---	---
23	1-39	9.25	---	---
24	1-65	16.00	---	---
25	1-126	31.25	---	---
26	1-318	79.25	---	---
27	1-131	32.00	---	---

TABLE B5.--FY 1974 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles		
		Party 184 (Navy 2)	Party 186 (Navy 3)	Party 195 (Navy 1)
		Zone A (Continued)		
28	1-55	13.50	---	---
29	1-136	33.75	---	---
30	1-90	22.25	---	---
	91-250	---	40.00	---
31	1-40	9.75	---	---
32	1-63	---	---	15.50
32E	1-35	---	8.50	---
33	1-45	---	11.00	---
34	1-96	---	23.75	---
35	1-77	19.00	---	---
36	1-94	---	---	23.25
37	1-43	10.50	---	---
38	1-108	---	---	26.75
40	1-78	---	---	10.25
41	1-62	---	---	15.25
42	1-80	---	---	19.75
TOTAL		407.25	317.25	294.97

[1] Party 195 completed its Barrow area assignments 1-18 March 1974 and started recording in zone A on 29 March.

TABLE B6.--FY 1974 recording parameters

[Dynamite was the energy source. Seismic data were recorded on digital tape with TIAC, 21-track DFS-III instruments with an 8-124 Hz filter. Geophones were type HSJ-14.]

Parameter	Barrow area	Zone A	
		Parties 184 and 195	Party 186
Number of channels	48	48	48
Multiplicity	3-fold	6-fold	6-fold
Group interval	110 ft	330 ft	330 ft
Spread (symmetrical)	55-2,585 ft	165-7,755 ft	330-7,920 ft
Shotpoint offset	55 ft, in line	165 ft, in line	330 ft, in line
Shotpoint spacing	880 ft	1,320 ft	1,320 ft
Geophones per group	12	9	9
Geophone spacing	20 ft	15 ft	15 ft
Sample rate	2 ms	2 ms	2 ms
Record length	5 s	6 s	6 s
Nominal charge	25 lb	50 lb	50 lb
Nominal depth	60 ft	75 ft	75 ft

TABLE B7.--FY 1975 seismic program

[The seismic crews recorded data from 19 November 1974 to 23 May 1975 covering 2,440 line miles, including 20.34 line miles in the Iko Bay area and 2,419.66 line miles in the Lake Teshekpuk, coastal, and foothills areas. The bulk of the program extended from Cape Halkett westward, crossed Teshekpuk Lake, and terminated near the Meade Arch; the southern limits extended into the northern foothills of the Brooks Range.]

Seismic line	Shotpoint range	Number of line miles			
		Party 182 (Navy 4)	Party 184 (Navy 2)	Party 186 (Navy 3)	[1]Party 195 (Navy 1)
		Iko Bay area			
LX	101-155	---	---	---	9.17
XX	101-125	---	---	---	4.17
Y	1-25	---	---	---	4.00
Z	1-19	---	---	---	3.00
TOTAL					20.34
		Lake Teshekpuk, coastal, and foothills areas			
1D	1-47	---	---	11.25	---
2D	1-30	---	---	6.75	---
3D	2-69	---	---	16.75	---
4D	1-43	---	---	9.25	---
5D	1-26	---	---	6.25	---
6D	1-48	---	---	11.75	---
7D	2-57	---	---	13.50	---
3	63-93	7.75	---	---	---
	94-127	---	8.50	---	---
3X	1-194	---	---	48.25	---
5X	1-197	---	49.00	---	---
7X	6-210	51.00	---	---	---
17X	148-328	40.00	---	---	---
25X	1-103	---	---	---	25.50
26X	319-487	---	42.25	---	---
29X	136-193	14.50	---	---	---
	194-260	---	---	---	16.75
30X	1-319	---	---	79.50	---
32	35-107	18.25	---	---	---
35	77-139	15.75	---	---	---
36X	94-230	---	34.25	---	---
	231-373	---	---	35.75	---
37X	1-267	---	66.50	---	---
38X	1-37	---	---	---	9.00
39	1-202	---	50.25	---	---
40X	1-125	---	31.00	---	---
43	1-203	---	50.50	---	---
44	1-88	---	---	21.75	---
45	1-267	---	66.50	---	---
46	1-283	---	70.50	---	---
47	1-380	---	---	---	94.75
	411-536	---	---	31.50	---
48	1-132	---	---	---	32.75
49	1-348	---	---	---	86.75
50	1-43	---	---	---	10.75

TABLE B7.--FY 1975 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles			
		Party 182 (Navy 4)	Party 184 (Navy 2)	Party 186 (Navy 3)	Party 195 (Navy 1)
Lake Teshekpuk, coastal, and foothills areas (Continued)					
51	1-327	---	---	---	81.50
	400-557	---	---	39.50	---
52	1-289	---	---	---	72.00
53	10-170	39.75	---	---	---
	170-289	---	---	30.00	---
54	1-175	---	---	43.50	---
	201-334	---	---	---	33.50
55	1-89	---	---	---	22.00
56	1-73	---	---	---	18.00
57	1-187	---	---	---	46.50
58	3-568	141.25	---	---	---
59XW	1-326	---	---	81.25	---
	327-578	---	---	---	63.00
60	1-62	---	---	15.25	---
61	1-56	---	---	13.75	---
62	1-60	---	---	14.75	---
	73-238	41.50	---	---	---
63	4-139	33.75	---	---	---
	140-489	---	---	87.50	---
64	1-68	---	---	16.75	---
65	1-89	---	---	14.50	---
66	1-162	---	---	40.25	---
67	1-50	---	---	---	12.25
68	1-187	---	---	46.50	---
69	1-57	---	---	14.00	---
70	1-175	---	43.50	---	---
71	1-76	---	18.75	---	---
72	1-76	---	18.50	---	---
75	1-68	16.75	---	---	---
75	1-212	52.75	---	---	---
76	1-81	20.00	---	---	---
77	1-90	22.25	---	---	---
TOTAL		515.25	550.00	749.75	625.00

[1]Party 195 completed its Iko Bay area assignments 19-30 November 1974, then started recording in the Lake Teshekpuk, coastal, and foothills areas.

TABLE 88.--FY 1975 recording parameters

[Dynamite was the energy source. Seismic data were recorded on digital tape with TIAC, 21-track DFS-III instruments with an 8-124 Hz filter. Geophones were type HSJ-8H7 in the Iko Bay area and Mandrell, 10 Hz, elsewhere.]

Parameter	Iko Bay area	Coastal and plains area	Foothills area
Number of channels	48	48	48
Multiplicity	3-fold	6-fold	6-fold
Group interval	110 ft	330 ft (parties 184 and 195); 660 ft (party 186)	330 ft (parties 184 and 195); 660 ft (party 186)
Spread (symmetrical)	55-2,585 ft	165-7,755 ft (parties 184 and 195); 330-7,920 ft (party 186)	165-7,755 ft (parties 184 and 195); 330-7,920 ft (party 186)
Shotpoint offset	55 ft, in line	165 ft (parties 184 and 195); 330 ft (party 186)	165 ft (parties 184 and 195); 330 ft (party 186)
Shotpoint spacing	880 ft	1,320 ft	1,320 ft
Geophones per group	9	9	9
Geophone spacing	15 ft	15-20 ft	15-20 ft
Sample rate	2 ms	2 ms	2 ms
Record length	5 s	6 s	6 s
Nominal charge	25 lb	50 lb	100 lb
Nominal depth	60 ft	75 ft	105 ft

TABLE B9.--FY 1976 seismic program

[The seismic crews recorded data from 23 January to 5 May 1976 covering 1,439.75 line miles, including 37 line miles in the Simpson detail program, 1,218.25 line miles in the western sector reconnaissance program, and 184.50 line miles in the western sector extended program. Data quality was good.]

Seismic line	Shotpoint range	Number of line miles: [1]Party 182 (Navy 4)	Number of line miles: Party 186 (Navy 3)
Simpson detail program			
DS-1	1-74	18.50	---
DS-2	34-1	8.50	---
DS-3	1-40	10.00	---
TOTAL		37.00	---
Western sector reconnaissance program			
26	[2]487-817	---	81.25
30	[3]610-322	---	69.50
55	101-316	54.00	---
56	101-240	35.00	---
	443-333	27.75	---
58	1125-664	115.50	---
61	101-388	---	72.00
	389-455	16.75	---
64	101-299	49.75	---
65	90-291	50.50	---
120	1-234	58.50	---
121	1-220	55.00	---
122	130-372	---	60.75
123	1-144	---	36.00
124	1-248	---	62.00
125	1-359	89.75	---
126	[4]1-127	---	30.50
127	1-202	---	50.50
128	1-146	---	36.50
129	1-176	---	44.00
133	1-152	38.00	---
134	80-222	---	35.75
135	1-54	---	13.50
136	1-142	35.50	---
TOTAL		626.00	592.25

TABLE B9.--FY 1976 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles: Party 182 (Navy 4)	Number of line miles: Party 186 (Navy 3)
Western sector extended program			
68	345-476	---	33.00
127	328-202A	---	32.00
130	1-137	34.25	---
	146-278	---	33.25
135	55-162	---	27.00
138	1-100	---	25.00
TOTAL		34.25	150.25

[1]Party 182 completed its Simpson area assignments 23-31 January 1976 and started recording in the western sector on 1 February.

[2]Skipped shotpoints 786-791 in the Kuk River.

[3]Skipped shotpoints 541-551 in the Kuk River.

[4]Skipped shotpoints 66-70 in the Kuk River.

TABLE B10.--FY 1976 recording parameters

[Seismic data were recorded on digital tape using a TIAC, 21-track DFS-III system with an 8-124 Hz filter and standard roll-along cabling. Electrostatic cameras were used for monitor records. Geophones were type Geospace 20D.]

Number of channels	48
Multiplicity	6-fold
Group interval	330 ft
Spread (symmetrical)	165-7,750 ft
Shotpoint offset	165 ft
Shotpoint spacing	1,320 ft
Geophones per group	18
Geophone spacing	25 ft
Sample rate	2 ms
Record length	6 s
Nominal charge	
Gelatin type	25-50 lb
Pelletized	105 lb
Nominal depth	75-90 ft

TABLE B11.--FY 1977 seismic program

[The seismic crews recorded data from 20 January to 23 May 1977 covering 2,638.67 line miles in the northern foothills and thrust belt of the Brooks Range, including 576.75 line miles in the detail program and 2,061.92 line miles in the reconnaissance program. Coverage is 6-fold except as noted. The quality of data acquired from the Coastal Plain was generally good; data from the foothills were generally of poor quality.]

Seismic line	Shotpoint range	Number of line miles				
		Party 1173	Party 1182	Party 1184	Party 1186	Party 1195
		Detail program				
D-1	1-48	---	12.00	---	---	---
D-2	1-38	---	9.50	---	---	---
D-3	1-80	---	20.00	---	---	---
D-4	1-42	---	10.50	---	---	---
D-5	1-132	---	33.00	---	---	---
D-6	1-33	---	8.25	---	---	---
D-7	1-32	---	8.00	---	---	---
D-8	[1]1-137	---	32.50	---	---	---
D-9	1-44	---	11.00	---	---	---
D-90	1-90	---	22.50	---	---	---
D-91	2-91	---	22.50	---	---	---
D-92	1-76	---	19.00	---	---	---
D-93	1-346	---	86.50	---	---	---
D-94	1-69	---	17.25	---	---	---
D-95	1-86	---	21.50	---	---	---
D-96	1-73	---	18.25	---	---	---
D-97	1-115, 201-285	---	50.00	---	---	---
D-98	1-79	---	19.75	---	---	---
D-99	1-162	---	40.50	---	---	---
D-100	1-46	---	11.50	---	---	---
D-101	1-69	---	17.25	---	---	---
D-102	1-45	---	11.25	---	---	---
D-103	1-41	---	10.25	---	---	---
D-104	1-40	---	10.00	---	---	---
D-105	[2]1-73	---	18.00	---	---	---
D-106	1-40	---	10.00	---	---	---
D-108	1-104	---	26.00	---	---	---
TOTAL		---	576.75	---	---	---
		Reconnaissance program				
3X	300-350	---	---	---	---	16.83
	350-423	---	---	---	---	[3]12.25
5X	300-395	---	---	---	---	[3]15.92
	395-435	---	---	---	---	13.50
7X	300-330	---	---	---	---	10.17
	330-490	---	---	---	---	[3]26.75
19X	501-554	17.83	---	---	---	---
	554-629	[3]12.58	---	---	---	---

TABLE B11.--FY 1977 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles				
		Party 1173	Party 1182	Party 1184	Party 1186	Party 1195
		Reconnaissance program (Continued)				
25X	501-513, 539-566	[3]6.58	---	---	---	---
	513-539, 566-636	27.83	---	---	---	---
29X	374-396	7.50	---	---	---	---
	396-470	[3]12.42	---	---	---	---
36X	400-472	---	---	---	---	[3]12.08
	472-532	---	---	---	---	20.17
37X	400-467	---	---	---	---	22.50
	467-760	---	---	---	---	48.92
45X	601-673	---	---	24.17	---	---
	673-952	---	---	[3]46.58	---	---
46X	340-434	---	---	31.50	---	---
	434-700	---	---	[3]44.42	---	---
49X	400-486	---	---	28.83	---	---
	486-757	---	---	[3]45.25	---	---
59	687-730	14.67	---	---	---	---
63X	615-492	---	---	---	41.34	---
64X	300-413	---	---	---	37.83	---
	413-659	---	---	---	[3]41.08	---
68E	600-710	---	---	[3]18.42	---	---
	710-943	---	---	77.83	---	---
68W	1000-1109	36.67	---	---	---	---
68WX	476-545	---	---	---	23.33	---
71	1-7, 108-162	[3]20.33	---	---	---	---
	7-108	[3]16.83	---	---	---	---
72	103-140	---	---	---	---	12.50
	140-250	---	---	---	---	18.42
73	1-41	[3]6.75	---	---	---	---
	41-83	14.17	---	---	---	---
78	1-74	24.67	---	---	---	---
79	1-36	11.83	---	---	---	---
	36-91	9.25	---	---	---	---
80	1-54	17.83	---	---	---	---
	54-132	[3]13.08	---	---	---	---
81	1-84	28.00	---	---	---	---
83	1-95	31.67	---	---	---	---
85	1-736	---	---	---	---	122.67
86	1-748	---	---	---	---	124.67
87	100-216	---	---	38.83	---	---
	216-606	---	---	[3]65.08	---	---
88	93-212	---	---	39.83	---	---
	212-505	---	---	[3]48.92	---	---
89	500-582, 590-635	---	---	[3]21.50	---	---
107	101-372	---	---	[3]45.33	---	---
	379-592	---	---	---	[3]35.67	---
122X	401-629	---	---	---	[3]38.08	---
	629-763	---	---	---	44.83	---
124X	249-375	---	---	---	42.17	---
	375-639	---	---	---	[3]44.08	---
127	330-494	---	---	---	---	[3]27.42
	494-500	---	---	---	---	2.17

TABLE B11.--FY 1977 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles				
		Party 1173	Party 1182	Party 1184	Party 1186	Party 1195
Reconnaissance program (Continued)						
131	1-134	---	---	---	44.67	---
133X	200-298	---	---	---	33.00	---
137	1-86	---	---	---	28.67	---
138E	500-572, 590-1084	[3]94.42	---	---	---	---
	572-590, 1084-1301	75.50	---	---	---	---
138W	201-270	---	---	---	23.33	---
TOTAL		500.42	---	576.50	478.08	506.92

[1]Deducted seven skipped holes.

[2]Deducted one hole.

[3]Coverage is 12-fold.

TABLE B12.--FY 1977 recording parameters

[Reconnaissance data were recorded on digital tape using DFS-V instruments with SEG B format and an 8-128 Hz filter. Detail data were recorded using DFS-IV instruments with TIAC-C format, and an 8-124 Hz filter. Recording polarity was SEG standard. Geophones were type Geospace 20D, 10 Hz.]

Parameter	Detail survey	Reconnaissance survey
Number of channels	48	96
Multiplicity	6-fold	6-fold and 12-fold
Group interval	330 ft	220 ft
Spread (symmetrical)	165-7,755 ft	110-10,450 ft
Shotpoint offset	165 ft	110 ft
Shotpoint spacing	1,320 ft	1,760 ft (6-fold) and 880 ft (12-fold)
Geophones per group	18	18
Geophone spacing	25 ft	25 ft
Sample rate	2 ms	2 ms
Record length	6 s	8 s
Nominal charge	50-100 lb	105-110 lb
Nominal depth	75-105 ft	105 ft

TABLE B13.--FY 1978 seismic program, Barrow area

[Party 1182 conducted the surveys from 13 January to 31 May 1978, recording data covering 577.0209 line miles in the northern area extending from Peard Bay to Camp Lonely. The quality of land reconnaissance data was generally good, but that of the high-resolution data was poor, as was that of the shallow-water data.]

		Number of line miles			
				Shallow-water surveys	
Seismic line	Shotpoint range	High resolution survey, 6-fold X 55 ft coverage	Land reconnaissance survey, 6-fold X 220 ft coverage	12-fold X 220 ft coverage	24-fold X 220 ft coverage
B-1	8-397	---	---	---	3.9583
B-2	1-144	4.2917	7.0000	---	---
B-2A	1-110	4.5833	---	---	---
B-3	1-132	5.5000	---	---	---
	1000-1216	---	0.2708	---	8.8333
B-4	1-124	5.1667	---	---	---
B-5	1-246	10.2500	---	---	---
	1-81	---	13.5000	---	---
B-6	1-80	3.3333	---	---	---
	1000-1124	---	0.2708	---	5.0000
B-6A	1-54	2.2500	---	---	---
B-7	1-101	4.2083	---	---	---
B-8	100-202	4.2917	---	---	---
	1000-1216	---	0.2708	---	8.8333
B-9	1-138	5.7500	---	---	---
B-10	1-192	8.0000	---	---	---
B-10A	101-164	2.6667	---	---	---
B-11	1-305	12.7083	---	---	---
	426-705	---	40.8750	---	5.7917
B-11A	1-101	4.2083	---	---	---
B-12	1-226	9.4167	---	---	---
B-13	101-273	3.7500	---	---	---
	1000-1216	---	3.9167	---	19.1250
B-14	156-1566	---	19.5625	---	52.0417
B-15	1-21	---	0.2708	---	3.2083
B-16	1-23	---	0.2708	---	3.5000
B-17	1-70	---	8.1042	---	3.5000
B-18	1-197	---	9.9583	---	22.8750
B-19	1-144	---	18.6042	0.6250	4.7708
B-20	6-110	---	11.7708	---	5.5417
B-21	4-252	---	1.9375	---	8.5000
B-22	1-394	---	17.8750	4.5000	7.4583
B-23	1-122	---	20.3333	---	---
B-24	1-76	---	12.6667	---	---
B-25	50-2	---	8.1667	---	---
B-26	31-1	---	5.1667	---	---
B-28	4-300	---	5.6042	---	6.8333
B-29	280-4	---	3.1042	---	8.5000
B-30	4-128	---	---	---	5.2083
B-30X	4-356	---	---	---	14.7083
B-30XE	4-203	---	---	---	8.3333
	204-228	---	1.1042	---	---

TABLE B13.--FY 1978 seismic program, Barrow area (Continued)

		Number of line miles			
				Shallow-water surveys	
Seismic line	Shotpoint range	High resolution survey, 6-fold X 55 ft coverage	Land reconnaissance survey, 6-fold X 220 ft coverage	12-fold X 220 ft coverage	24-fold X 220 ft coverage
P-1	1-392	---	6.3750	---	14.4583
1X	4-41	---	1.1042	---	---
	42-121	---	---	---	3.8750
75X	4-584	---	10.0417	---	14.2917
121X	441-220	---	0.5833	---	8.6667
122X	1-117	---	1.3750	---	3.6250
TOTAL		90.3750	230.0834	5.1250	251.4375

TABLE B14.--FY 1978 seismic program, southern foothills area

[Parties 1173, 1184, and 1186 conducted the surveys from 13 January to 31 May 1978, recording data covering 674.6667 line miles.]

		Number of line miles			
		[1]Party 1173	Party 1184		[2]Party 1186
Seismic line	Shotpoint range	12-fold X 110 ft coverage	6-fold X 110 ft coverage	12-fold X 110 ft coverage	6-fold X 110 ft coverage
R-1	1-648	[1]70.9583	---	---	---
R-2	100-809	---	54.2500	32.0417	---
R-2A	100-405	---	---	25.5000	---
R-2B	100-162	---	---	5.2500	---
R-3	500-770	---	---	---	45.1667
R-4	1-373	---	---	---	[2]47.1667
R-6	106-380	22.9167	---	---	---
	381-1118	---	---	61.5000	---
R-7	100-385	---	---	---	47.6667
37X	887-1097	17.5833	---	---	---
45X	996-1361	---	24.0833	6.4583	---
47X	715-1300	---	63.9167	6.0417	---
51X	600-911	---	52.0000	---	---
89X	305-499	---	32.5000	---	---
89XS	700-800	---	---	8.4167	---
107XE	1700-2106	33.9167	---	---	---
107XW	593-882	---	---	---	17.3333
TOTAL		145.3750	226.7500	145.2083	157.3333

[1] Includes 33.9167 line miles recorded 6-fold X 110 ft.

[2] Includes 5.0000 line miles recorded 24-fold X 110 ft, which was experimental.

TABLE 815.--FY 1978 seismic program, Umiat area

[Parties 1173 and 1184 conducted the surveys from 13 January to 31 May 1978, recording data covering 328.8333 line miles. Data quality was excellent.]

		Number of line miles		
		Party 1173		Party 1184, 12-fold X 220 ft coverage
Seismic line	Shotpoint range	6-fold X 220 ft coverage	12-fold X 220 ft coverage	
U-1	1-107	10.5000	12.5833	---
U-2	1-98	9.1667	11.7500	---
U-3	1-127	18.1667	12.0833	---
U-4	1-196	23.8333	20.7500	---
U-5	1-118	11.1667	14.0833	---
U-6	1-94	9.5000	10.9167	---
U-7	1-99	---	16.5000	---
U-8	4-47	---	7.3333	---
U-9	63-278	30.5000	20.7500	---
U-10	1-91	30.3333	---	---
17X	329-463	12.1667	16.4167	---
73X	101-137	---	---	6.1667
80X	133-200	---	11.3333	---
138EX	1504-1580	---	12.8333	---
TOTAL		155.3333	166.8333	6.1667

TABLE B16.--FY 1978 seismic program, Driftwood area

[Party 1186 conducted the survey from 13 January to 31 May 1978.]

Seismic line	Shotpoint range	Number of line miles, 12-fold X 220 ft coverage
R-5	500-734	39.1667
85X	2000-2216	36.1667
86X	756-974	36.5000
107XW	593-882	31.1667
127X	1000-1129	21.1667
130X	293-589	49.5000
133X	351-600	41.6667
137X	500-809	51.6667
TOTAL		335.3335

TABLE B17.--FY 1978 recording parameters, northern program

[Dynamite was the energy source except on ocean ice where the energy source was an air gun. Seismic data were recorded using DFS-V instruments. An 8-256 Hz filter was used for the high-resolution survey and an 8-128 Hz filter elsewhere. Recording polarity was non-SEG standard because of a hard-wired fault originating at the factory.]

Parameter	Survey type		
	High resolution	Land reconnaissance	Shallow water
Number of channels	48	48	48
Multiplicity	6-fold	6-fold	12-fold and 24-fold
Group interval	55 ft	220 ft	220 ft
Spread (symmetrical)	28-1,293 ft	110-5,170 ft	110-5,170 ft
Shotpoint offset	28 ft	110 ft	110 ft
Shotpoint spacing	220 ft	880 ft	440 ft (12-fold) and 220 ft (24-fold)
Geophones per group	3	18	18
Sample rate	1 ms	2 ms	2 ms
Record length	6 s	6 s	3 s
Nominal charge	25 lb	25 lb	---
Nominal depth	50 ft	50 ft	---

TABLE B18.--FY 1978 recording parameters, southern program

[Dynamite was the energy source. Seismic data were recorded on digital tape using DFS-V instruments with an 8-128 Hz filter. Recording polarity was SEG standard.]

Parameter	Umiat area	Southern foothills area	Driftwood area
Number of channels	96	96	96
Multiplicity	6-fold and 12-fold	6-fold, 12-fold, and 24-fold	12-fold
Group interval	220 ft	110 ft	220 ft
Spread (symmetrical)	110-10,450 ft	55-5,225 ft	110-10,450 ft
Shotpoint offset	110 ft	55 ft	110 ft
Shotpoint spacing	1,760 ft (6-fold) and 880 ft (12-fold)	880 ft (6-fold), 440 ft (12-fold), and 220 ft (24-fold)	880 ft
Geophones per group	18	9	18
Sample rate	2 ms	2 ms	2 ms
Record length	8 s	8 s	8 s
Nominal charge	50 lb	110 lb	110 lb
Nominal depth	60-75 ft	105 ft	105 ft

TABLE B19.--FY 1979 seismic program, Barrow area

[Party 1182 conducted the surveys from 8 January to 3 May 1979, recording data covering 1,003.3333 line miles over an area extending from Peard Bay through Barrow to Teshekpuk Lake. The quality of reconnaissance survey data was good to excellent except for data acquired near large bodies of water, which was poor. High-resolution data quality was only fair.]

		Number of line miles		
		High resolution survey, 6-fold X 110 ft coverage	Reconnaissance surveys	
Seismic line	Shotpoint range		6-fold X 220 ft coverage	6-fold X 330 ft coverage
D7XN	101-194	---	---	23.5000
D9XN	1-89	---	---	22.2500
75XW	1-110	---	18.3333	---
75XW(S)	1-94	---	15.6667	---
601	1-301	---	50.3333	---
602	1-161	---	---	40.2500
604	1-137	---	---	34.2500
606	1-148	---	---	37.0000
608	1-124	---	---	31.0000
610	1-189	---	---	47.2500
612	1-203	---	---	[1]50.7500
614	2-121	---	---	[1]30.2500
616	1-236	---	[1]39.3333	---
618	1-224	---	[1]37.3333	---
618N	1-67	---	[1]11.1667	---
620	1-64	---	[1]10.6667	---
622	1-220	---	[1]36.6667	---
624	1-57	---	9.5000	---
626	1-93	---	15.5000	---
626N	1-41	---	6.8333	---
628	1-168	---	28.0000	---
628N	1-103	---	17.1667	---
651	1-63	[1]5.2500	---	---
652	62-1	[1]5.1667	---	---
653	52-1	[1]4.3333	---	---
654	1-49	[1]4.0833	---	---
655	1-56	[1]4.6667	---	---
657	1-79	[1]6.5833	---	---
658	38-1	[1]3.1667	---	---
659	1-67	---	11.1667	---
659W	1-152	---	25.3333	---
660	49-1	[1]4.0833	---	---
661	1-71	[1]5.9167	---	---
663	1-83	---	---	20.7500
664	1-106	---	17.6667	---
665	1-136	---	22.6667	---
666	1-91	---	15.1667	---
667	1-148	---	24.6667	---
668	1-67	---	11.1667	---
669	1-63	---	10.5000	---
670	1-81	---	13.5000	---
671	1-236	---	39.3333	---
672	1-133	---	22.1667	---

TABLE B19.--FY 1979 seismic program, Barrow area (Continued)

Seismic line	Shotpoint range	Number of line miles		
		High resolution survey, 6-fold X 110 ft coverage	Reconnaissance surveys	
			6-fold X 220 ft coverage	6-fold X 330 ft coverage
674	1-148	---	24.6667	---
676	1-75	---	12.5000	---
678	1-61	---	10.1667	---
680	1-112	---	18.6667	---
682	1-173	---	28.8333	---
684	1-109	---	18.1667	---
TOTAL		43.2500	622.8333	337.2500

[1]Recorded non-SEG standard polarity.

TABLE B20.--FY 1979 seismic program, southern foothills, Driftwood, and Umiat areas

[Parties 1184 and 1186 conducted the surveys from 8 January to 3 May 1979 and recorded data covering 897.5992 line miles, including 861.4742 line miles in the Southern foothills, 31.5833 line miles in the Driftwood area, and 4.5417 line miles in the Umiat area. The quality of data was generally fair to poor.]

Seismic line	Shotpoint or vibrating point range	Number of line miles			
		[1]Party 1184		Party 1186	
		24-fold X 6 sweeps coverage	24-fold X 8 sweeps coverage	6-fold X 110 ft coverage	12-fold X 220 ft coverage
		Southern foothills area			
R1X	700-1650	---	19.7917	---	---
R1X	700-746	---	[2]2.0000	---	---
R3XN	500-254	---	---	---	41.1667
R3XS	800-1280	10.0417	---	---	---
R5XN	350-491	---	---	---	23.6667
R6XN	400-2030	34.0000	---	---	---
R7XN	650-401	---	---	---	41.6667
R7XS	800-210	12.3333	---	---	---
46XS	2048-2000	---	1.0000	---	---
	2000-1714, 1568-802	[3]---	22.0000	---	---
	1712-1568	[3]3.0000	---	---	---
	1568-1532	[3]0.7083	0.0833	---	---
	774-802	---	1.1667	---	---
47XS	1242-372	---	18.1667	---	---
51XS	1904-1004	18.7917	---	---	---
64XS	752-1508	15.7917	---	---	---
603	1-291	---	---	48.5000	---
605	100-520	---	---	---	70.1667
607	1-220	---	---	---	36.6667
609	1-518	---	---	86.3333	---
611	1048-3192	---	44.7083	---	---
613	2296-1288	21.0417	---	---	---
615	100-1682, 2058-1682	7.8750	33.0000	---	---
630	399-686	---	---	---	48.0000
632	260-504	---	---	---	40.8333
634	742-664	---	---	13.1667	---
	1192-742	27.6315	9.5300	---	---
636	976-861	19.3333	---	---	---
	976-1594	---	---	12.9167	---
638	557-600	---	---	7.3333	---
	600-1674	22.4157	---	---	---
640	100-196	[4]2.0208	---	---	---
	198-1322	---	32.6667	---	---
673	104-676	11.9583	---	---	---
TOTAL		206.9440	184.1134	168.2500	302.1668

TABLE B20.--FY 1979 seismic program, southern foothills, Driftwood, and Umiat areas (Continued)

Seismic line	Shotpoint or vibrating point range	Number of line miles			
		Party 1184		Party 1186	
		24-fold X 6 sweeps coverage	24-fold X 8 sweeps coverage	6-fold X 110 ft coverage	12-fold X 220 ft coverage
Driftwood area					
611	1000-622	---	---	---	[5]31.5833
Umiat area					
U-9	87-114	4.5417	---	---	---

[1]Party 1184 used a Vibroseis surface input source.

[2]Experimental.

[3]Coverage was 48-fold X 6 sweeps.

[4]Coverage was 48-fold X 12 sweeps.

[5]Coverage was 12-fold X 110 feet.

TABLE B21.--FY 1979 recording parameters, northern program

[Dynamite was the energy source. Seismic data were recorded using DFS-V digital instruments. An 8-256 Hz filter was used for the high-resolution survey; an out-128 Hz filter was used for the 6-fold x 220 ft reconnaissance survey; and and an 8-128 Hz filter was used elsewhere. Recording polarity was non-SEG standard from 8 January to 14 February because of a hard-wired fault originating at the factory. Subsequent recording was with SEG standard polarity.]

	Survey type		
	High resolution, seismic lines 651-655,657,658, 660, and 661	Reconnaissance	
Parameter		Seismic lines 602,604,606,608, 610,612, and 614	All other seismic lines
Number of channels	48	48	48
Multiplicity	6-fold	6-fold	6-fold
Group interval	110 ft	220 ft	330 ft
Spread (symmetrical)	55-2,585 ft	110-5,170 ft	165-7,755 ft
Shotpoint offset	55 ft	110 ft	165 ft
Shotpoint spacing	440 ft	880 ft	1,320 ft
Geophones per group	9	18	18
Sample rate	1 ms	2 ms	2 ms
Record length	6 s	6 s	6 s
Nominal charge	25 lb	25 lb	25 lb
Nominal depth	50 ft	50 ft	50 ft

TABLE B22.--FY 1979 recording parameters, southern program (party 1184)

[The energy source was Vibroseis surface input. Seismic data were recorded using DFS-V digital instruments with an 8-64 Hz filter. Recording polarity was SEG standard.]

Parameter	Seismic lines			
	R3XS, R6XW, R7XS, 51XS, 64XS, 613, 615, 634, 636, 638, and 673	R1X, 46XS, 611, 615, 634, and 640	46XS	640 and U-9
Number of channels	96	96	96	96
Multiplicity	24-fold	24-fold	48-fold	48-fold
Sweeps	6	8	6	12
Duration	15 s	11 s	11 s	11 s
Group interval	110 ft	110 ft	110 ft	110 ft
Spread (symmetrical)	275-5,445 ft	275-5,445 ft	275-5,445 ft	275-5,445 ft
Vibroseis point spacing	220 ft	220 ft	110 ft	110 ft
Vibrating point	275 ft	275 ft	275 ft	275 ft
Vibrator number X separation, in line	3X70 ft	3X70 ft	3X70 ft	3X70 ft
Vibrator patch, in line (for diversity stack)	110 ft	110 ft	110 ft	110 ft
Geophones per group[1]	18	18	18	18
Sample rate	4 ms	4 ms	4 ms	4 ms
Record length[2]	6 s	6 s	6 s	6 s
Filter	8-64 Hz	8-64 Hz	8-64 Hz	8-64 Hz

[1]Number of geophones per group was nine prior to 24 February 1979.

[2]Correlated.

TABLE B23.--FY 1979 recording parameters, southern program (party 1186)

[Dynamite was the energy source. Seismic data were recorded using DFS-V digital instruments with an 8-128 Hz filter. Recording polarity was SEG standard.]

Parameter	Seismic lines		
	603, 609, 634, 636, and 638	R3XN, R5XN, R7XN 605, 607, 630, and 632	611
Number of channels	96	96	96
Multiplicity	6-fold	12-fold	12-fold
Group interval	110 ft	220 ft	110 ft
Spread (symmetrical)	55-5,225 ft	110-10,450 ft	55-5,225 ft
Shotpoint offset	55 ft	110 ft	55 ft
Shotpoint spacing	880 ft	880 ft	440 ft
Geophones per group	18	18	18
Sample rate	2 ms	2 ms	2 ms
Record length	8 s	8 s	8 s
Nominal charge	110 lb	110 lb	110 lb
Nominal depth	105 ft	105 ft	105 ft

TABLE B24.--FY 1980 seismic program

[The seismic crews recorded data covering 1,096.4629 line miles, including 630.8586 line miles in the Fortress Mountain area, 104.0001 line miles in the Lisburne area, 77.9167 line miles in the Meat Mountain area, and 283.6875 line miles in the Tunalik area.]

		Number of line miles			
		Party 1182		Party 1186	
Seismic line	Shotpoint range	6-fold X 110 ft coverage	6-fold X 330 ft coverage	6-fold X 110 ft coverage	12-fold X 110 ft coverage
		Fortress Mountain area			
26XW	1-51	3.1250	---	---	---
[1]707	100-201	---	---	17.0000	---
[1]709	100-183	---	---	14.0000	---
[2]711	100-261	10.3333	---	---	---
713	100-161	10.3333	---	---	---
[2]715	100-159	10.0000	---	---	---
715	160-280	20.1667	---	---	---
[2]717	100-232	---	---	22.1667	---
719	100-253	---	---	25.6667	---
[1]720	100-216	---	---	19.5000	---
722	100-207	---	---	18.0000	---
723	100-370	45.1667	---	---	---
[2]724	100-245	---	---	24.3333	---
725	1-367	61.1667	---	---	---
726	101-257	---	---	26.1667	---
727	100-382	47.1667	---	---	---
728	100-193	15.6667	---	---	---
729	100-304	34.1667	---	---	---
731	94-353	---	---	43.3333	---
732	100-198	16.5000	---	---	---
733	100-261	---	---	27.0000	---
734	100-241	23.6667	---	---	---
736	100-220	20.1667	---	---	---
742	100-256	26.1667	---	---	---
744	100-256	26.1667	---	---	---
746	100-242	---	---	23.8333	---
TOTAL		369.8586	---	261.0000	---
		Lisburne program			
743	500-630	---	---	---	10.9167
745	1-274	---	---	---	22.8333
760	100-236	---	---	---	11.4167
762	2-235	---	---	---	19.5000
764	504-733	---	---	---	19.1667
766	504-745	---	---	---	20.1667
TOTAL		---	---	---	104.0001

TABLE B24.--FY 1980 seismic program (Continued)

Seismic line	Shotpoint range	Number of line miles			
		Party 1182		Party 1186	
		6-fold X 110 ft coverage	6-fold X 330 ft coverage	6-fold X 110 ft coverage	12-fold X 110 ft coverage
Meat Mountain program					
735	100-285	---	---	---	15.5000
737	100-276	---	---	---	14.7500
741	100-272	---	---	---	14.4167
750	100-196	---	---	---	8.0833
752	100-202	---	---	---	8.5833
756	102-202	---	---	---	8.4167
758	100-197	---	---	---	8.1667
TOTAL		---	---	---	77.9167
Tunalik program					
D1XE	1-44	---	11.0000	---	---
D4XW	1-35	---	8.7500	---	---
D5XW	1-176	---	44.0000	---	---
26XW	1-50	---	12.5000	---	---
134XW	1-83	---	20.7500	---	---
701	1-91	---	22.7500	---	---
702	1-59	---	14.7500	---	---
703	1-125	---	31.1875	---	---
704	1-65	---	16.2500	---	---
705	1-105	---	26.2500	---	---
706	1-75	---	18.7500	---	---
708	1-73	---	18.2500	---	---
710	1-101	---	25.2500	---	---
712	1-53	---	13.2500	---	---
TOTAL		---	283.6875	---	---

[1] Gubik area.

[2] Kurupa area.

TABLE B25.--FY 1980 recording parameters

[Dynamite was the energy source. Seismic data were recorded using DFS-V digital instruments with 8-128 Hz filters. Recording polarity was SEG standard.]

Parameter	Fortress Mountain area	Lisburne and Meat Mountain areas	Tunalik area
Number of channels	96	96	48
Multiplicity	6-fold	12-fold	6-fold
Group interval	110 ft	110 ft	330 ft
Spread (symmetrical)	55-5,225 ft	55-5,225 ft	165-7,755 ft
Shotpoint offset	55 ft	55 ft	165 ft
Shotpoint spacing	880 ft	440 ft	1,320 ft
Geophones per group	18	18	18
Sample rate	2 ms	2 ms	2 ms
Record length	8 s	8 s	6 s
Nominal charge	110 lb	110 lb	50 lb
Nominal depth	105 ft	105 ft	75 ft

TABLE B26.--Seismic lines recorded FY 1972-FY 1980

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
A	1-38	6.2	1972	195
B	1-60	9.8	1972	195
B-1	8-397	3.9583	1978	1182
B-2	1-144	11.2917	1978	1182
B-2A	1-110	4.5833	1978	1182
B-3	1-132	5.5000	1978	1182
	1000-1216	9.1041	1978	1182
B-4	1-124	5.1667	1978	1182
B-5	1-246	10.2500	1978	1182
	1-81	13.5000	1978	1182
B-6	1-80	3.3333	1978	1182
	1000-1124	5.2708	1978	1182
B-6A	1-54	2.2500	1978	1182
B-7	1-101	4.2083	1978	1182
B-8	100-202	4.2917	1978	1182
	1000-1216	9.1041	1978	1182
B-9	1-138	5.7500	1978	1182
B-10	1-192	8.0000	1978	1182
B-10A	101-164	2.6667	1978	1182
B-11	1-305	12.7083	1978	1182
	426-705	46.6667	1978	1182
B-11A	1-101	4.2083	1978	1182
B-12	1-226	9.4167	1978	1182
B-13	101-273	3.7500	1978	1182
	1000-1216	23.0417	1978	1182
B-14	156-1566	71.6042	1978	1182
B-15	1-21	3.4791	1978	1182
B-16	1-23	3.7708	1978	1182
B-17	1-70	11.6042	1978	1182
B-18	1-197	32.8333	1978	1182
B-19	1-144	24.0000	1978	1182
B-20	6-110	17.3125	1978	1182
B-21	4-252	10.4375	1978	1182
B-22	1-394	29.8333	1978	1182
B-23	1-122	20.3333	1978	1182
B-24	1-76	12.6667	1978	1182
B-25	50-2	8.1667	1978	1182
B-26	31-1	5.1667	1978	1182
B-28	4-300	12.4375	1978	1182
B-29	280-4	11.6042	1978	1182
B-30	4-128	5.2083	1978	1182
B-30X	4-356	14.7083	1978	1182
B-30XE	4-228	9.4375	1978	1182
C	1-23	3.7	1972	195
D	1-21	3.3	1972	195
D-1	1-48	12.0	1977	1182
D1XE	1-44	11.0000	1980	1182
D-2	1-38	9.5	1977	1182
D-3	1-80	20.0000	1977	1182
D-4	1-42	10.50	1977	1182
D4XW	1-35	8.7500	1980	1182
D-5	1-132	33.00	1977	1182
D5XW	1-176	44.00	1980	1182
D-6	1-33	8.25	1977	1182
D-7	1-32	8.00	1977	1182
D7XN	101-194	23.5000	1979	1182
D-8	1-137	32.50	1977	1182
D-9	1-44	11.00	1977	1182

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
D9XN	1-89	22.2500	1979	1182
D90	1-90	22.50	1977	1182
D91	2-91	22.50	1977	1182
D92	1-76	19.00	1977	1182
D93	1-346	86.50	1977	1182
D94	1-69	17.25	1977	1182
D95	1-86	21.50	1977	1182
D96	1-73	18.25	1977	1182
D97	1-115, 201-285	50.00	1977	1182
D98	1-79	19.75	1977	1182
D99	1-162	40.50	1977	1182
D100	1-46	11.50	1977	1182
D101	1-69	17.25	1977	1182
D102	1-45	11.25	1977	1182
D103	1-41	10.25	1977	1182
D104	1-40	10.00	1977	1182
D105	1-73	18.00	1977	1182
D106	1-40	10.00	1977	1182
D108	1-104	26.00	1977	1182
DS-1	1-74	18.50	1976	182
DS-2	34-1	8.50	1976	182
DS-3	1-40	10.00	1976	182
E	1-40	6.5	1972	195
F	1-36	5.8	1972	195
G	1-23	3.7	1972	195
H	0-22	3.5	1972	195
I	1-73	12.2	1972	195
J	1-45	7.3	1972	195
K	1-69	5.67	1973	195
L	1-84	6.92	1973	195
LX	101-155	9.17	1975	195
M	1-67	5.50	1973	195
N	1-119	9.83	1973	195
O	1-30	4.83	1974	195
P	1-17	2.67	1974	195
P-1	1-392	20.8333	1978	1182
Q	1-44	3.58	1973	195
R	1-23	3.67	1974	195
R-1	1-648	70.9583	1978	1173
R-1X	700-746	2.0000	1979	1184
	700-1650	19.7917	1979	1184
R-2	100-809	86.2917	1978	1184
R-2A	100-405	25.5000	1978	1184
R-2B	100-162	5.2500	1978	1184
R-3	500-770	45.1667	1978	1186
R3XN	500-254	41.1667	1979	1186
R3XS	800-1280	10.0417	1979	1184
R-4	1-373	47.1667	1978	1186
R-5	500-734	39.1667	1978	1186
R5XN	350-491	23.6667	1979	1186
R-6	106-380	22.9167	1978	1173
	381-1118	61.5000	1978	1184
R6XW	400-2030	34.0000	1979	1184
R-7	100-385	47.6667	1978	1186
R7XN	650-401	41.6667	1979	1186
R7XS	800-210	12.3333	1979	1184
S	1-31	5.0000	1974	195
T	1-24	3.8300	1974	195

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
U	1-46	7.5000	1974	195
U-1	1-107	23.0833	1978	1173
U-2	1-98	20.9167	1978	1173
U-3	1-127	30.2500	1978	1173
U-4	1-196	44.5833	1978	1173
U-5	1-118	25.2500	1978	1173
U-6	1-94	20.4167	1978	1173
U-7	1-99	16.5000	1978	1173
U-8	4-47	7.3333	1978	1173
U-9	63-278	51.2500	1978	1173
	87-114	4.5417	1979	1184
U-10	1-91	30.3333	1978	1173
V	1-52	8.5000	1974	195
W	1-25	4.0000	1974	195
X	1-19	3.0000	1974	195
XX	101-125	4.1700	1975	195
Y	1-25	4.0000	1975	195
Z	1-19	3.0000	1975	195
1	1-46	11.2500	1974	195
1D	1-47	11.5000	1975	186
1X	4-41	1.1042	1978	1182
	42-121	3.8750	1978	1182
2	1-28	6.75	1974	195
2D	1-30	6.75	1975	186
3	1-63	15.50	1974	195
	1-80	20.00	1977	1182
	63-93	7.75	1975	182
	94-127	8.50	1975	184
	127-225	24.75	1974	186
3D	2-69	16.75	1975	186
3X	1-194	48.25	1975	186
	300-350	16.83	1977	1195
	350-423	12.25	1977	1195
4	1-80	19.75	1974	195
4D	1-43	9.25	1974	186
5	1-97	24.0000	1974	184
	2-78	19.0000	1974	195
	101-149	24.75	1974	186
5D	1-26	6.25	1975	186
5X	1-197	49.00	1975	184
	300-395	15.92	1977	1195
	395-435	13.50	1977	1195
6	1-65	16.00	1974	195
6D	1-48	11.75	1975	186
7	1-100	24.75	1974	186
	100-203	25.75	1974	195
7D	2-57	13.50	1975	186
7X	6-210	51.00	1975	182
	300-330	10.17	1977	1195
	330-490	26.75	1977	1195
8	1-90	22.25	1974	195
9	1-85	20.25	1974	195
10	1-112	27.72	1974	195
11	1-83	20.25	1974	186
12	1-56	13.75	1974	186
13	1-72	17.50	1974	186
14	1-56	13.50	1974	186
15	1-79	19.25	1974	186
16	1-70	17.00	1974	186

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
17	1-148	36.75	1974	186
17X	148-328	40.00	1975	182
	329-463	28.5834	1978	1173
18	1-88	21.75	1974	186
19	1-153	38.00	1974	184
19X	501-554	17.83	1977	1173
	554-629	12.58	1977	1173
20	1-110	27.25	1974	184
21	1-86	21.25	1974	184
22	1-83	20.25	1974	184
23	1-39	9.25	1974	184
24	1-65	16.00	1974	184
25	1-126	31.25	1974	184
25X	1-103	25.50	1975	195
	501-513, 539-566	6.58	1977	1173
	513-539, 566-636	27.83	1977	1173
26	1-318	79.25	1974	184
	487-817	81.25	1976	186
26X	319-487	42.25	1975	184
26XW	1-51	3.1250	1980	1182
27	1-131	32.00	1974	184
28	1-55	13.50	1974	184
29	1-136	33.75	1974	184
29X	136-193	14.50	1975	182
	194-260	16.75	1975	195
	374-396	7.50	1977	1173
	396-470	12.42	1977	1173
30	1-90	22.25	1974	184
	91-250	40.00	1974	186
	610-322	69.50	1976	186
30X	1-319	79.50	1975	186
31	1-40	9.75	1974	184
32	1-63	15.50	1974	195
	35-107	18.25	1975	182
32E	1-35	8.50	1974	186
33	1-45	11.00	1974	186
34	1-96	23.75	1974	186
35	1-77	19.00	1974	184
	77-139	15.75	1975	182
36	1-94	23.25	1974	195
36X	94-230	34.25	1975	184
	231-373	35.75	1975	186
	400-472	12.08	1977	1195
	472-532	20.17	1977	1195
37	1-43	10.50	1974	184
37X	1-267	66.50	1975	184
	400-467	22.50	1977	1195
	467-760	48.92	1977	1195
	887-1097	17.5833	1978	1173
38	1-108	26.75	1974	195
38X	1-37	9.00	1975	195
39	1-202	50.25	1975	184
40	1-77	10.25	1974	195
40X	1-125	31.00	1975	184
41	1-62	15.25	1974	195
42	1-80	19.75	1974	195

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
43	1-203	50.50	1975	184
44	1-88	21.75	1975	186
45	1-267	66.50	1975	184
45X	601-673	24.17	1977	1184
	673-952	46.58	1977	1184
	996-1361	30.5416	1978	1184
46	1-283	70.5	1975	184
46X	340-434	31.5	1977	1184
	434-700	44.42	1977	1184
46XS	774-802	1.1667	1979	1184
	2000-1714, 1568-802	22.0000	1979	1184
	1568-1532	0.7916	1979	1184
	1712-1568	3.0000	1979	1184
	2048-2000	1.0000	1979	1184
47-75	1-380	94.75	1975	195
	411-536	31.50	1975	186
47X	715-1300	69.9584	1978	1184
47XS	1242-372	18.1667	1979	1184
48	1-132	32.7500	1975	195
49X	400-486	28.8300	1977	1184
	486-757	45.25	1977	1184
49	1-348	86.75	1975	195
50	1-43	10.75	1975	195
51	1-327	81.50	1975	195
	400-557	39.50	1975	186
51X	600-911	52.0000	1978	1184
51XS	1904-1004	18.7917	1979	1184
52	1-289	72.00	1975	195
53	10-170	39.75	1975	182
	170-289	30.00	1975	186
54	1-175	43.50	1975	186
	201-334	33.50	1975	195
55	1-89	22.00	1975	195
	101-316	54.00	1976	182
56	1-73	18.00	1975	195
	101-240	35.00	1976	182
	443-333	27.75	1976	182
57	1-187	46.50	1975	195
58	3-568	141.25	1975	182
	1125-664	115.50	1976	182
59	687-730	14.67	1977	1173
59XW	1-326	81.25	1975	186
	327-578	63.00	1975	195
60	1-62	15.25	1975	186
61	1-56	13.75	1975	186
	101-388	72.00	1976	186
	389-455	16.75	1976	182
62	1-60	14.75	1975	186
	73-238	41.50	1975	182
63	4-139	33.75	1975	182
	140-489	87.50	1975	186
63X	615-492	41.3334	1977	1186
64	1-68	16.75	1975	186
	101-299	49.75	1976	182
64X	300-413	37.83	1977	1186
	413-659	41.08	1977	1186
64XS	752-1508	15.7917	1979	1184

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
65	1-89	14.5000	1975	186
	90-291	50.50	1976	182
66	1-162	40.2500	1975	186
67	1-50	12.25	1975	195
68	1-187	46.50	1975	186
	345-476	33.0000	1976	186
68E	600-710	18.42	1977	1184
	710-943	77.83	1977	1184
68W	1000-1109	36.6667	1977	1173
68WX	476-545	23.33	1977	1186
69	1-57	14.00	1975	186
70	1-175	43.50	1975	184
71	1-76	18.75	1975	184
	1-7, 108-162	20.33	1977	1173
	7-108	16.83	1977	1173
72	1-76	18.50	1975	184
	103-140	12.50	1977	1195
	140-250	18.42	1977	1195
73	1-41	6.75	1977	1173
	41-83	14.17	1977	1173
73X	101-137	6.1667	1978	1184
74	1-68	16.75	1975	182
75	1-212	52.75	1975	182
75X	4-584	24.3333	1978	1182
75XW	1-110	18.3333	1979	1182
75XW(S)	1-94	15.6667	1979	1182
76	1-81	20.0000	1975	182
77	1-90	22.25	1975	182
78	1-74	24.67	1977	1173
79	1-36	11.83	1977	1173
	36-91	9.25	1977	1173
80	1-54	17.83	1977	1173
	54-132	13.08	1977	1173
80X	133-200	11.3333	1978	1173
81	1-84	28.0000	1977	1173
83	1-95	31.6700	1977	1173
85	1-736	122.6700	1977	1195
85X	2000-2216	36.1667	1978	1186
86	1-748	124.6700	1977	1195
86X	756-974	36.5000	1978	1186
87	100-216	38.83	1977	1184
	216-606	65.08	1977	1184
88	93-212	39.83	1977	1184
	212-505	48.92	1977	1184
89	500-582, 590-635	21.50	1977	1184
89X	305-499	32.5000	1978	1184
89XS	700-800	8.4167	1978	1184
107	101-372	45.33	1977	1184
	379-592	35.67	1977	1186
107XE	1700-2106	33.9167	1978	1173
107XW	593-882	48.5000	1978	1186
120	1-234	58.50	1976	182
121	1-220	55.00	1976	182
121X	441-220	9.25	1978	1182
122	130-372	60.75	1976	186
	1-117	5.00	1978	1182

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
122X	401-629	38.08	1977	1186
	629-763	44.83	1977	1186
123	1-144	36.00	1976	186
124	1-248	62.00	1976	186
124X	249-375	42.17	1977	1186
	375-639	44.08	1977	1186
125	1-359	89.75	1976	182
126	1-127	30.50	1976	186
127	1-202	50.50	1976	186
	202-328	32.00	1976	186
	330-494	27.42	1977	1195
	494-500	2.17	1977	1195
127X	1000-1129	21.1667	1978	1186
128	1-146	36.50	1976	186
129	1-176	44.00	1976	186
130	1-137	34.25	1976	182
	146-278	33.25	1976	186
130X	293-589	49.5000	1978	1186
131	1-134	44.67	1977	1186
133	1-152	38.00	1976	182
133X	200-298	33.00	1977	1186
	351-600	41.6667	1978	1186
134	80-222	35.75	1976	186
134XW	1-83	20.7500	1980	1182
135	1-54	13.50	1976	186
	55-162	27.00	1976	186
136	1-142	35.50	1976	182
137	1-86	28.67	1977	1186
137X	500-809	51.6667	1978	1186
138	1-100	25.0000	1976	186
138E	500-572, 590-1084	94.42	1977	1173
	572-590, 1084-1301	75.50	1977	1173
138EX	1504-1580	12.8333	1978	1173
138W	201-270	23.33	1977	1186
601	1-301	50.3333	1979	1182
602	1-161	40.2500	1979	1182
603	1-291	48.5000	1979	1186
604	1-137	34.2500	1979	1182
605	100-520	70.1667	1979	1186
606	1-148	37.0000	1979	1182
607	1-220	36.6667	1979	1186
608	1-124	31.0000	1979	1182
609	1-518	86.3333	1979	1186
610	1-189	47.2500	1979	1182
611	1000-622	31.5833	1979	1186
	1048-3192	44.7083	1979	1184
612	1-203	50.7500	1979	1182
613	2296-1288	21.0417	1979	1184
614	2-121	30.2500	1979	1182
615	100-1682, 2058-1682	40.8750	1979	1184
616	1-236	39.3333	1979	1182
618	1-224	37.3333	1979	1182
618N	1-67	11.1667	1979	1182
620	1-64	10.6667	1979	1182
622	1-220	36.6667	1979	1182
624	1-57	9.5000	1979	1182

TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
626	1-93	15.5000	1979	1182
626N	1-41	6.8333	1979	1182
628	1-168	28.0000	1979	1182
628N	1-103	17.1667	1979	1182
630	399-686	48.0000	1979	1186
632	260-504	40.8333	1979	1186
634	742-664	13.1667	1979	1186
	1192-742	37.1615	1979	1184
636	976-861	19.3333	1979	1186
	976-1594	12.9167	1979	1184
638	557-600	7.3333	1979	1186
	600-1674	22.4167	1979	1184
640	100-196	2.0208	1979	1184
	198-1322	32.6667	1979	1184
651	1-63	5.2500	1979	1182
652	62-1	5.1667	1979	1182
653	52-1	4.3333	1979	1182
654	1-49	4.0833	1979	1182
655	1-56	4.6667	1979	1182
657	1-79	6.5833	1979	1182
658	38-1	3.1667	1979	1182
659	1-67	11.1667	1979	1182
659W	1-152	25.3333	1979	1182
660	49-1	4.0833	1979	1182
661	1-71	5.9167	1979	1182
663	1-83	20.7500	1979	1182
664	1-106	17.6667	1979	1182
665	1-136	22.6667	1979	1182
666	1-91	15.1667	1979	1182
667	1-148	24.6667	1979	1182
668	1-67	11.1667	1979	1182
669	1-63	10.5000	1979	1182
670	1-81	13.5000	1979	1182
671	1-236	39.3333	1979	1182
672	1-133	22.1667	1979	1182
673	104-676	11.9583	1979	1184
674	1-148	24.6667	1979	1182
676	1-75	12.5000	1979	1182
678	1-61	10.1667	1979	1182
680	1-112	18.6667	1979	1182
682	1-173	28.8333	1979	1182
684	1-109	18.1667	1979	1182
701	1-91	22.7500	1980	1182
702	1-59	14.7500	1980	1182
703	1-125	31.1875	1980	1182
704	1-65	16.2500	1980	1182
705	1-105	26.2500	1980	1182
706	1-75	18.7500	1980	1182
707	100-201	17.0000	1980	1186
708	1-73	18.2500	1980	1182
709	100-183	14.0000	1980	1186
710	1-101	25.2500	1980	1186
711	100-261	10.3333	1980	1182
712	1-53	13.2500	1980	1182
713	100-161	10.3333	1980	1182
715	100-159	10.0000	1980	1182
	160-280	20.1667	1980	1182
717	100-232	22.1667	1980	1186
719	100-253	25.6667	1980	1186

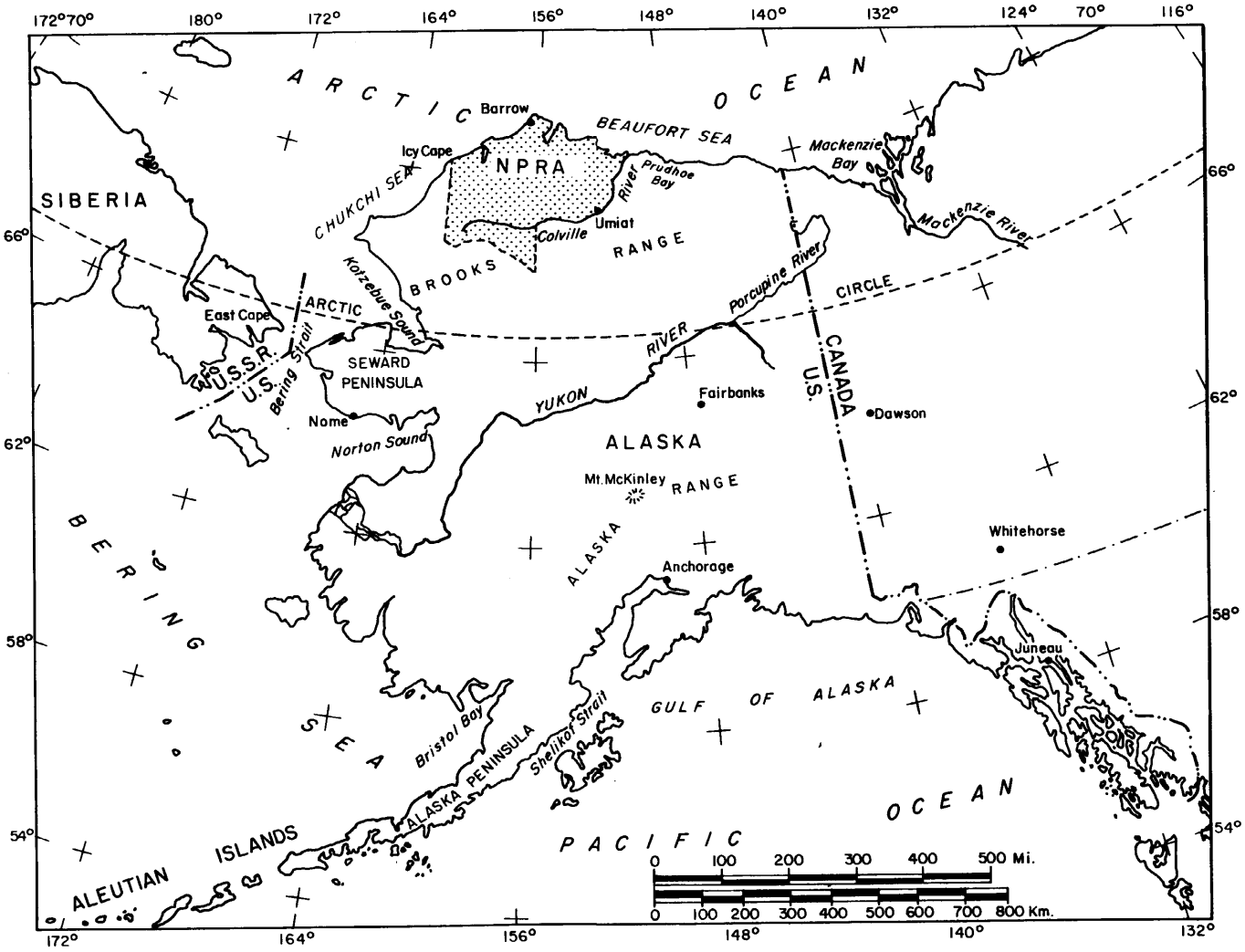
TABLE B26.--Seismic lines recorded FY 1972-FY 1980 (Continued)

Seismic line	Shotpoint range	Number of line miles	Fiscal year	Seismic crew
720	100-216	19.5000	1980	1186
722	100-207	18.0000	1980	1186
723	100-370	45.1667	1980	1182
724	100-245	24.3333	1980	1186
725	1-367	61.1667	1980	1182
726	100-257	26.1667	1980	1186
727	100-382	47.1667	1980	1182
728	100-193	15.6667	1980	1182
729	100-304	34.1667	1980	1182
731	94-353	43.3333	1980	1186
732	100-198	16.5000	1980	1182
733	100-261	27.0000	1980	1186
734	100-241	23.6667	1980	1182
735	100-285	15.5000	1980	1186
736	100-220	20.1667	1980	1182
737	100-276	14.7500	1980	1186
741	100-272	14.4167	1980	1186
742	100-256	26.1667	1980	1182
743	500-630	10.9167	1980	1186
744	100-256	26.1667	1980	1182
745	1-274	22.8333	1980	1186
746	100-242	23.8333	1980	1186
750	100-196	8.0833	1980	1186
752	100-202	8.5833	1980	1186
756	102-202	8.4167	1980	1186
758	100-197	8.1667	1980	1186
760	100-236	11.4167	1980	1186
762	2-235	19.5000	1980	1186
764	504-733	19.1667	1980	1186
766	504-745	20.1667	1980	1186

FIGURE 1

INDEX MAP SHOWING LOCATION OF NPRA

The NPRA covers over 36,000 sq mi (93,240 sq km) on the Alaskan North Slope, extending from the Colville River westward to the 162° parallel and northward to the Chukchi and Beaufort Seas.



INDEX MAP SHOWING LOCATION OF NPRA

TGZ-0170

FIGURE I

FIGURE 2

INDEX MAP, PET-4 AND NPRA TEST WELLS AND SELECTED CORE TESTS, 1944-53, 1974-81

Most of the wells drilled during the Pet-4 and NPRA programs were in the northeastern Arctic Coastal Plain. Discoveries resulting from the Pet-4 program include the Barrow gas field and Umiat oil field. In addition, the Simpson oil field (not shown) was discovered as the result of a core-test program, but never was delineated fully. A heavy oil discovery at Fish Creek was tested, but not evaluated completely. The Walakpa gas field was discovered during the NPRA program.

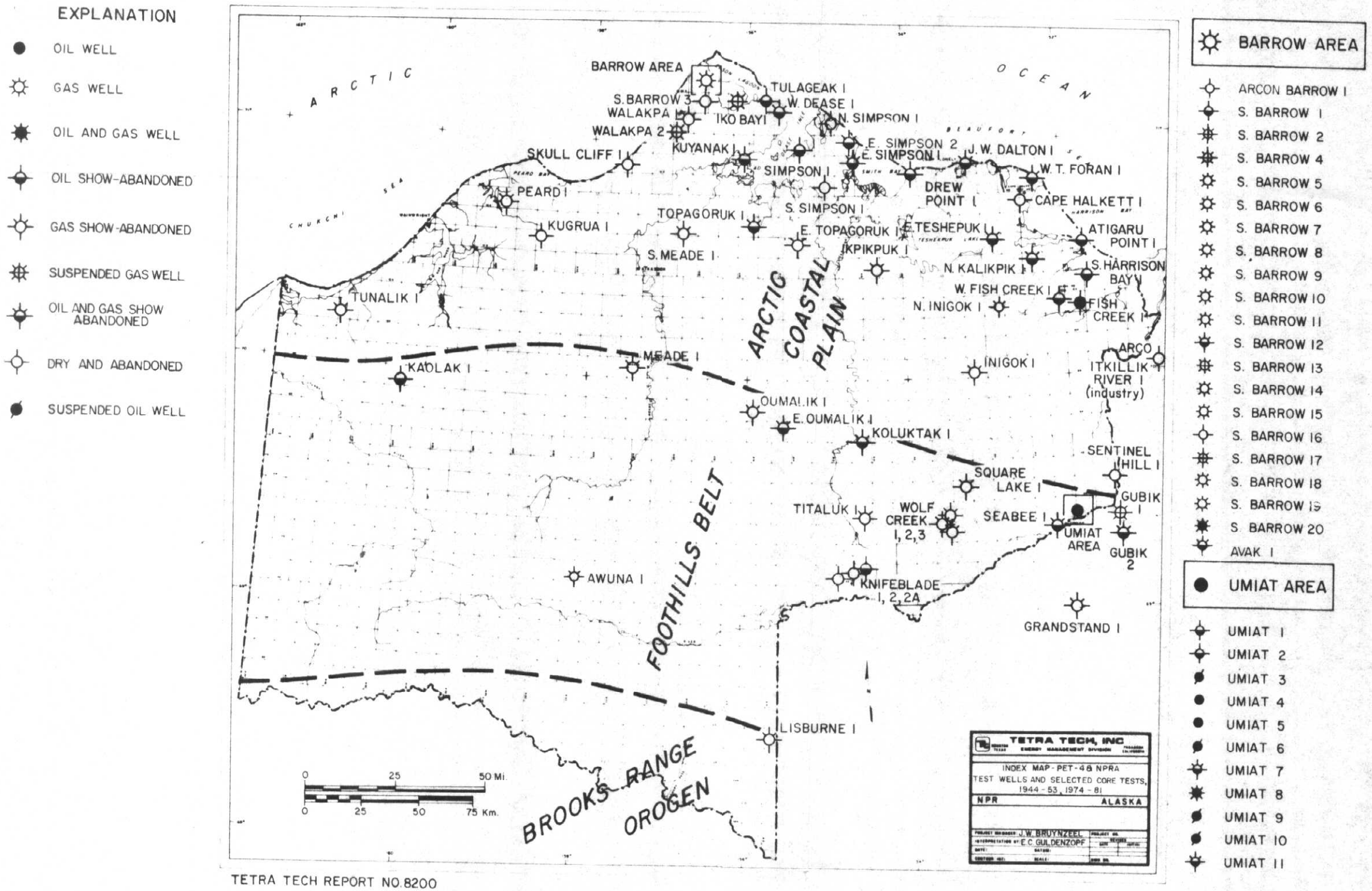


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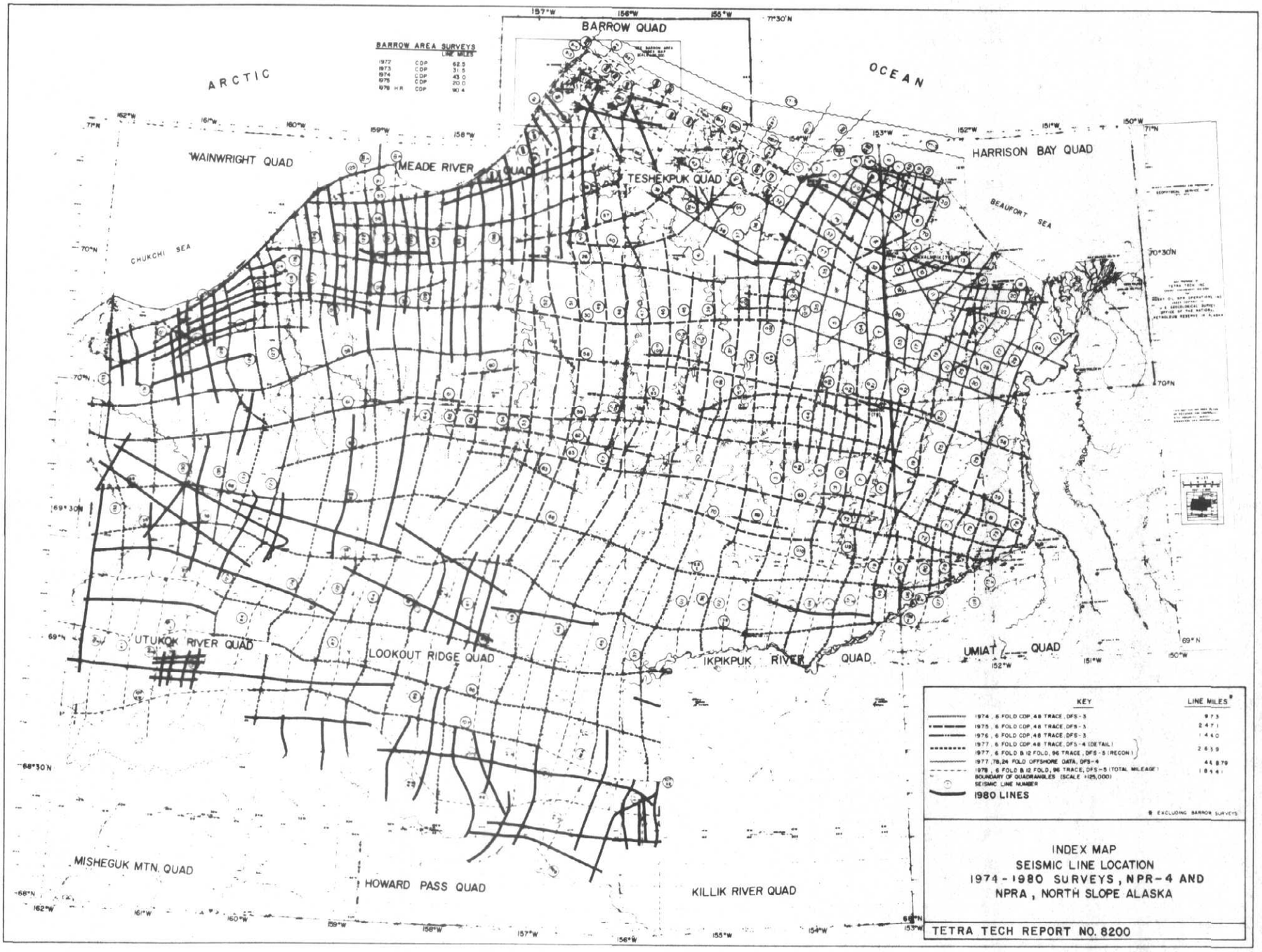
FIGURE 2

FIGURE 3

INDEX MAP, SEISMIC LINE LOCATION 1974-1980 SURVEYS, NPR-4 AND NPRA, NORTH SLOPE ALASKA

In the northern coastal plain, the seismic grid average was 7 mi by 9 mi (8-mi loop average, 63 sq mi per loop). In the southern folded belts, the seismic grid average was 10 mi by 15 mi (12-mi loop average, 150 sq mi per loop).



TGZ-0170 FIGURE 3

FIGURE 4

GEOLOGIC COLUMN

Figure 4 is a generalized and diagrammatic geologic column for the NPRA. The geological time scale includes an isotopic time scale in million years before the present (MYBP).

The parastratigraphic units used in this report are designated by uppercase letters that represent geologic periods; lowercase letters and numbers are used to denote subdivisions of the time units. The boundaries of each parastratigraphic unit may not correspond exactly to the standard geologic period boundaries; rather, they correspond to major worldwide sea-level lowstands. These sea-level lowstands are represented in the rock record by unconformities or correlative conformities at lithostratigraphic contacts.

Lithofacies distribution is indicated in time and space. The horizontal axis represents the lateral distribution of each unit from the north to the south. The approximate northern limit of each sedimentary "wedge" is near the Arctic coastline, and the southern limit is near 70° N. The vertical lines represent hiatuses (for example, lacunae) or the interval of geologic times not represented by rocks at specific positions along stratigraphic surfaces. "ON" and "DN" represent onlap and downlap, respectively; "H" means "hiatus." Major unconformities (U) recognized, either in surface outcrops, in the subsurface, or on seismic sections, also are noted. The rest of the lithologic and stratigraphic symbols are conventional.

The figure summarizes the conventional lithostratigraphic nomenclature for the North Slope. Informal lithostratigraphic names are indicated by quotation marks (for example, "basal Torok," "Peard sandstone").

The interpreted seismic horizons are positioned at the appropriate parastratigraphic units or lithofacies boundaries. Certain seismic horizons can be correlated to major unconformable surfaces (horizons 0400, 0720, 0800, and 0900). Other seismic horizons approximate the boundaries of parastratigraphic units. For a more detailed discussion see "Parastratigraphic Units" in this report.

GEOLOGIC COLUMN

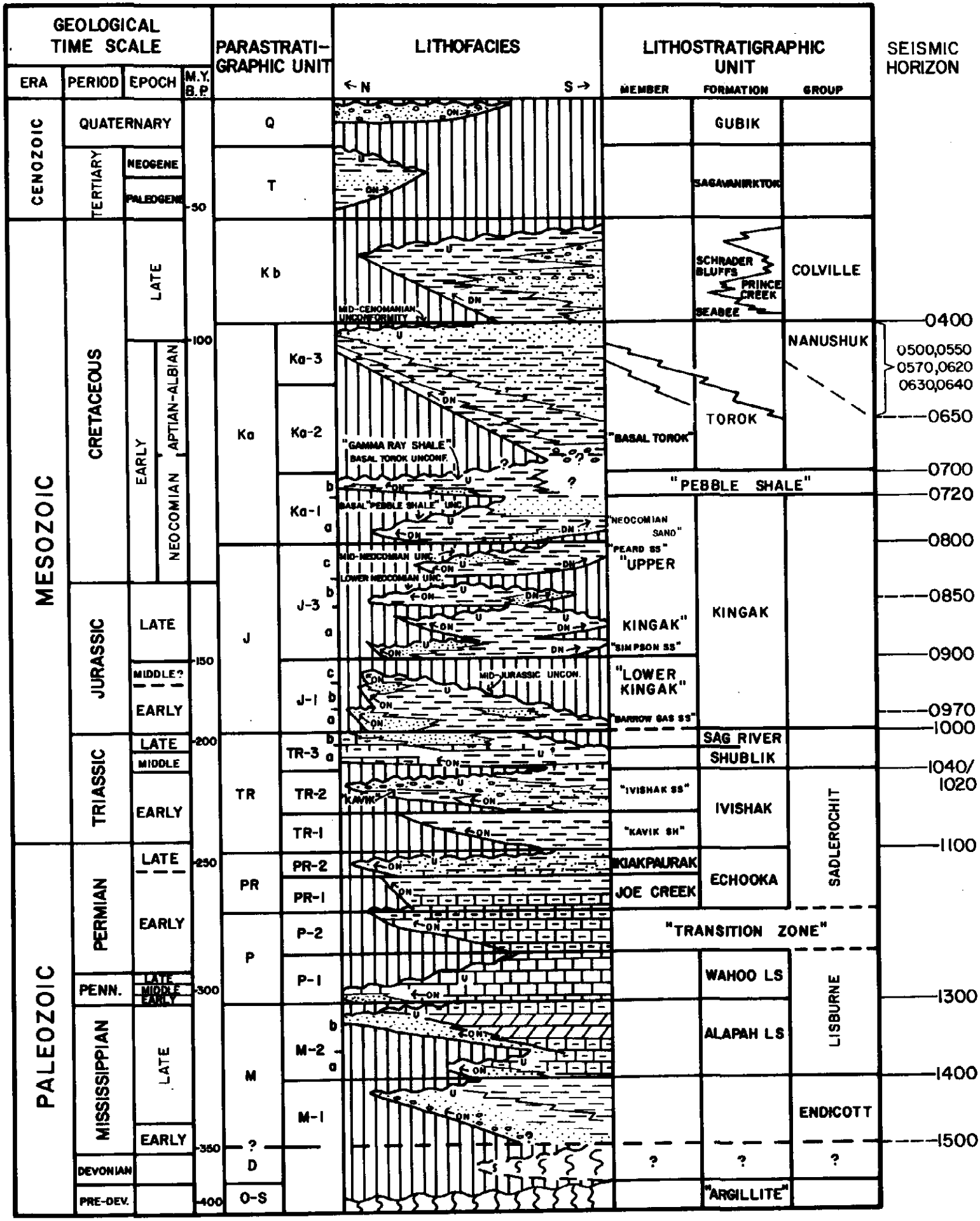


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FIGURE 4

FIGURE 5

CORRELATION CHART OF PARASTRATIGRAPHIC TOPS OF KEY NPRA WELLS

Figure 5 shows the tops of the parastratigraphic units identified in key NPRA wells and correlates these units with the geologic periods and seismic horizons.

FIGURE 5

Era	Period	Parastratigraphic Unit	Seismic Horizons	Atigaru Point 1 KB 27' 1/12/77-3/18/77	Awuna 1 KB 1129 3/1/80-4/20/81	S. Barrow 3 KB 44' 8/26/49-6/23/49	S. Barrow 13 KB 40' 12/17/76-1/2/77	S. Barrow 17 KB 33' 3/2/78-4/2/78	Cape Halkett 1 KB 39.5' 3/24/75-5/23/75	J.W. Dalton 1 KB 37' 5/7/79-8/1/79	W. Dease 1 KB 24' 2/18/80-3/23/80	Drew Point 1 KB 35' 11/13/78-3/13/78	W. Fish Creek 1 KB 113' 2/14/77-4/27/77	W.T. Foran 1 KB 39' 3/7/77-4/24/77	S. Harrison Bay 1 KB 45' 11/21/76-2/8/77	Iko Bay 1 KB 40' 2/1/75-3/11/75
Cenozoic	Quaternary	Q		SFC?		SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?
Cenozoic	Tertiary	T		200?		N.P	N.P	N.P	200?	210?	N.P	?140	N.P	310?	100?	N.P
Mesozoic	Cretaceous – Late	Kb		980?		N.P	N.P	N.P	1020?	1050?	N.P	380?	100?	1580?	350?	N.P
Mesozoic	Cretaceous – Early	Ka: Mid-Cenomanian Unconformity	0400	3470		N.P	N.P	N.P	3095	2680	N.P	1730?	2618	3480	3220	N.P
Mesozoic	Cretaceous – Early	Ka: Ka-3		3470		N.P	N.P	N.P	3095	2680	100	1730?	2618	3480	3220	N.P
Mesozoic	Cretaceous – Early	Ka: Ka-2	--0650	N.P	SFC?	75?	75?	75?	N.P	N.P	2073?	5492?	N.P	N.P	N.P	75?
Mesozoic	Cretaceous – Early	Ka: Ka-1 Basal Torok Unconformity		7276		1230	1840	1405	7278	7483	2905	6701	7277	7338	7289	1512
Mesozoic	Cretaceous – Early	Ka: Ka-1 b	0700	7276		1230	1840	1405	7278	7483	2905	6701	N.P	7338	N.P	1512
Mesozoic	Cretaceous – Early	Ka: Ka-1 Basal "Pebble Shale" Unconformity	0720	7319		1660	2236	1767	7604	7754	3369	6885	N.P	7542?	N.P	1893
Mesozoic	Cretaceous – Early	Ka: Ka-1 a		N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Mesozoic	Cretaceous – Early	J: J-3 Mid-Neocomian Unconformity		N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Mesozoic	Cretaceous – Early	J: J-3 c	0800	N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	7277	N.P	N.P	N.P
Mesozoic	Jurassic – Late	J: J-3 b	--0850	N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	?7460	N.P	7289	N.P
Mesozoic	Jurassic – Late	J: J-3 aII		?7319		1660	N.P	N.P	N.P	N.P	N.P	N.P	7900	N.P	7430	N.P
Mesozoic	Jurassic – Late	J: J-3 aI		?7359		1718	N.P	N.P	N.P	N.P	N.P	N.P	8750	N.P	8090	N.P
Mesozoic	Jurassic – Early-Middle	J: J-1 Mid-Jurassic Unconformity	0900	?7502		1835	N.P	N.P	N.P	N.P	N.P	N.P	8996	N.P	8235	N.P
Mesozoic	Jurassic – Early-Middle	J: J-1 c		?7502		1835	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	8235	1893
Mesozoic	Jurassic – Early-Middle	J: J-1 b		7729		1910	2236	1767	7604	N.P	3369	N.P	8996	N.P	8380	1933
Mesozoic	Jurassic – Early-Middle	J: J-1 a	--0970 1000	7910		2320	2290	2023	7658	N.P	3599	6885	9026	N.P	8656	2295
Mesozoic	Triassic – M-L	TR: TR-3 b		8252		2583	2423	2270	7782	N.P	3800	6956	9248	N.P	8902	2536
Mesozoic	Triassic – M-L	TR: TR-3 a	--1040/1020	8346		2630	N.P	N.P	7913	7754	3951	7060	9284	7542?	8956	2642
Mesozoic	Triassic – Early	TR: TR-2		8601		N.P	N.P	N.P	8128	7893	N.P	7570	9515	7635	9240	N.P
Mesozoic	Triassic – Early	TR: TR-1	1100	9245		N.P	N.P	N.P	8702	8230	N.P	N.P	10172	8133	9932	N.P
Paleozoic	Permian	PR: PR-2		9407		N.P	N.P	N.P	N.P	N.P	N.P	N.P	10441	N.P	10133	N.P
Paleozoic	Permian	PR: PR-1		N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Paleozoic	Permian	P: P-2		N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P
Paleozoic	Pennsylvanian	P: P-1		9518		N.P	N.P	N.P	8775	8317	N.P	N.P	10496	8195	10232	N.P
Paleozoic	Mississippian	M: M-2 b	1300	10490		N.P	N.P	N.P	9160	N.P	N.P	N.P	?11118	N.P	N.R.	N.P
Paleozoic	Mississippian	M: M-2 a		?11021		N.P	N.P	N.P	N.P	N.P	N.P	N.P	?N.P	N.P		N.P
Paleozoic	Mississippian	M: M-1	1400	N.P		N.P	N.P	N.P	?9325	?9196	N.P	N.P	?N.P	?8572		N.P
Paleozoic		? D	--1500	N.P		N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.R.	N.P		N.P
Paleozoic		O-S		11208		2795	2473	2350	9708	9268	4018	7848		8760		2700
Total Depth				11535	11200	2890	2534	2382	9900	9367	4170	7946	11427	8864	11290	2731

Parastratigraphic Unit	Ikpikpuk 1 KB 52' 11/28/78-2/28/80	Inigok 1 KB 163' 6/7/78-5/23/79	N. Inigok 1 KB 166' 2/12/81-4/3/81	N. Kalikpik 1 KB 40' 2/5/78-5/5/78	Kaolak 1 KB 178' 7/21/51-11/12/51	Koluktak 1 KB 205' 3/20/81-4/19/81	Kugrua 1 KB 85' 2/12/78-5/29/78	Kuyanak 1 KB 28' 2/13/81-3/31/81	Lisburne 1 KB 1862' 6/11/79-5/21/80	S. Meade 1 KB 60' 2/7/78-1/22/79	Oumalik 1 KB 194' 6/11/49-4/23/50	Peard 1 KB 103' 1/26/79-4/9/79	Seabee 1 KB 322' 7/1/79-4/14/80
Q	SFC?			SFC?	SFC?		SFC?	SFC?		SFC?	SFC?	SFC?	
T	N.P			N.P	N.P		N.P	N.P		N.P	N.P	N.P	
Kb	N.P	SFC?	SFC?	100?	N.P		N.P	N.P		N.P	N.P	N.P	
Mid-Cenomanian Unconformity	N.P	2248	2108	2394	N.P		N.P	N.P		N.P	N.P	N.P	
Ka-3	80?	2248	2108	2394	113	SFC?	80?	85?		80	80?	80	SFC?
Ka-2	6093?	8018?	N.P	N.P	3255?	2270?	1790?	1428?	SFC?	1890?	880?	1200?	11440?
Basal Torok Unconformity	7237	9042	7384	6888	N.R	N.R.	6892	4642	?6070	6474	?10880	6196	13068?
Ka-1 b	7237	9042	7384	6888			6892	4642	?6070	6474	?10880	6196	13068?
Basal "Pebble Shale" Unconformity	7485	9260	7648	7147			7308	5159	?6820	6780	11160?	6578	13340
Ka-1 a	N.P	N.P	N.P	N.P			N.P	N.P	?	N.P	N.P	N.P	N.P
Mid-Neocomian Unconformity	N.P	N.P	N.P	N.P			N.P	N.P	?	N.P	N.P	N.P	N.P
J-3 c	7485	9260	7648	?N.P			7308	N.P	?6820	6780	11160?	6578	13340
J-3 b	7670	10260	8144	?N.P			8005	N.P	?	7101	N.R.	7220?	N.R.
J-3 aII	8520	10840	8701	?7147			8440	5159	?	7560		7620?	
J-3 aI	9040	11700	9469	N.R.			8705	5376	?	7850		7820	
Mid-Jurassic Unconformity	9264	11963	9789				8898	5656	?	8056		8020	
J-1 c	9264	N.P	N.P				8898	5656	?	8056		8020	
J-1 b	9375	N.P	N.P				9044	5710	?	8254		8060	
J-1 a	9625	11963	9789				9334	6114	?	8491		N.P	
TR-3 b	9844	12113	9925				9514	6243	?	8770		8225	
TR-3 a	9895	12157	10018				9646	6375	?6945	8892		8441	
TR-2	10375	12500	N.R.				10018	N.P	?	9130		8741	
TR-1	11074	13330					10820	N.P	?7195	N.P		9358	
PR-2	11288	13656					10990	N.P	?7320	N.P		9471	
PR-1	11529	13849					N.P	N.P	?	N.P		N.P	
P-2	11606	14026					11178	N.P	N.P	N.P		N.P	
P-1	11818	14211					11535	N.P	N.P	N.P		N.P	
M-2 b	13485	15718					N.R.	N.P	?7408	N.P		N.P	
M-2 a	14549	16911						N.P	?8240	N.P		N.P	
M-1	15117	17870						N.P	N.R.	N.P		N.P	
? D	N.P	N.R.						N.P		9537		N.P	
O-S	?15317							6559		9892		9635	
Total Depth	15481	20102	10170	7395	6952	5882	12588	6690	17000	9945	11872	10225	15611

Parastratigraphic Unit	Simpson 1 KB 29' 6/14/47-6/9/48	E. Simpson 1 KB 30' 2/19/79-4/10/79	E. Simpson 2 KB 40' 1/31/80-3/13/80	S. Simpson 1 KB 25' 2/20/77-5/5/77	E. Teshekpuk 1 KB 27.6' 3/12/76-5/11/76	Topagoruk 1 KB 42' 6/15/50-9/28/51	Tulageak 1 KB 27' 2/25/81-3/24/81	Tunalik 1 KB 110' 11/10/78-11/3/79	Walakpa 1 KB 50' 12/25/79-2/7/80	Walakpa 2 KB 61' 1/3/81-2/12/81	Colville 1 KB 50' 11/12/65-3/8/66	Itkillik River 1 KB 60' 2/15/72-7/23/72
Q	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	SFC?	?	?
T	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	N.P	?	SFC?
Kb	N.P	80?	100?	N.P	100?	N.P	N.P	N.P	N.P	N.P	SFC?	335?
Mid-Cenomanian Unconformity	N.P	460	460	N.P	1914	N.P	N.P	N.P	N.P	N.P	2635	4240
Ka-3	80?	460	460	75	1914	80?	100	100	N.P	100	2635	4240
Ka-2	4310?	3192?	3576?	5470?	N.P	2640?	1700?	3057?	100?	455?	N.P	N.P
Basal Torok Unconformity	5290	6375	6327	6275	6851	6685	2502	10634	1705	2202	5565	7575
Ka-1 b	5290	6375	6327	6275	6851	6685	2502	10634	1705	2202	5565	7575
Basal "Pebble Shale" Unconformity	5630	6586	6529	6530	7130	7015	2949	10900	2087	2636	5915	7900
Ka-1 a	N.P	N.P	N.P	N.P	N.P	N.P	N.P	10900	N.P	N.P	N.P	N.P
Mid-Neocomian Unconformity	N.P	N.P	N.P	N.P	N.P	N.P	N.P	12605	N.P	N.P	N.P	N.P
J-3 c	N.P	N.P	N.P	N.P	N.P	N.P	N.P	12605	N.P	N.P	N.P	7900
J-3 b	N.P	N.P	N.P	N.P	N.P	7015	N.P	13360	N.P	N.P	5915	8015
J-3 aII	N.P	N.P	N.P	N.P	7130	7509	N.P	13670	2087	2636	6280	8700
J-3 aI	N.P	N.P	N.P	6530	7214	7748	N.P	13850?	2310	2962	?	?
Mid-Jurassic Unconformity	N.P	N.P	N.P	6716	7507	7918	N.P	14122	2584	3230	7198	9720
J-1 c	N.P	N.P	N.P	6716	7507	7918	2949	N.P	2584	3230	7198	N.P
J-1 b	5630	6586	N.P	7019	7883	8099	3150	N.P	2660?	3296?	7365	9720
J-1 a	6045	6766	6529	7407	8128	8385	3528	14122	2992	3646	7590	9870
TR-3 b	6150	6868	6616	7530	8545	8700	3761	14262	3224	3843	7710	9974
TR-3 a	6266	7025	6770	7673	8674	8850	3878	14350	3350	3990	7756	10048
TR-2	?6535	7456	N.P	8197	8855	9220	N.P	14820	N.P	N.P	8080	10370
TR-1	N.P	N.P	N.P	8550	9443	9669	N.P	15561	N.P	N.P	8653	11070
PR-2	N.P	N.P	N.P	8588	9611	9762	N.P	16884	N.P	N.P	8835	11360
PR-1	N.P	N.P	N.P	N.P	N.P	?9830	N.P	17002	N.P	N.P	8913	N.P
P-2	N.P	N.P	N.P	N.P	N.P	N.P	N.P	17098	N.P	N.P	N.P	?
P-1	N.P	N.P	N.P	N.P	9649	N.P	N.P	19095	N.P	N.P	8960	11465
M-2 b	N.P	N.P	N.P	N.P	?10389	N.P	N.P	N.R.	N.P	N.P	8992	?12760
M-2 a	N.P	N.P	N.P	N.P	?N.R.	N.P	N.P		N.P	N.P	?9280	?
M-1	N.P	N.P	7152	N.P		N.P	N.P		N.P	N.P	?9390	?14010
? D	N.P	N.P	N.P	N.P		10031	N.P		N.P	N.P	N.P	N.P
O-S	6540	7624	7428	8750		N.R	3945		3634	4303	9700	14940
Total Depth	7002	7739	7505	8795	10654	10503	4015	20335	3666	4360	9930	15310

LEGEND

?	NOT IDENTIFIED
?9160	UNIT QUESTIONABLE
9160?	EXACT DEPTH QUESTIONABLE
N.P	NOT PRESENT
N.R.	NOT REACHED
SFC?	SURFACE

TETRA TECH, INC — HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

CORRELATION CHART OF PARASTRATIGRAPHIC TOPS OF KEY NPRA WELLS

NPR — ALASKA

PROJECT MANAGER: J. W. BRUYNZEEL — PROJECT NO. TC-7174

INTERPRETATION BY: D. HIGGS — REVISED: DATE / INITIAL

DATE: JULY, 1981 — DATUM:

CONTOUR INT: — SCALE: — DWG NO.

TGC 0170

TETRA TECH REPORT NO. 8200 — FIGURE 5

FIGURE 6

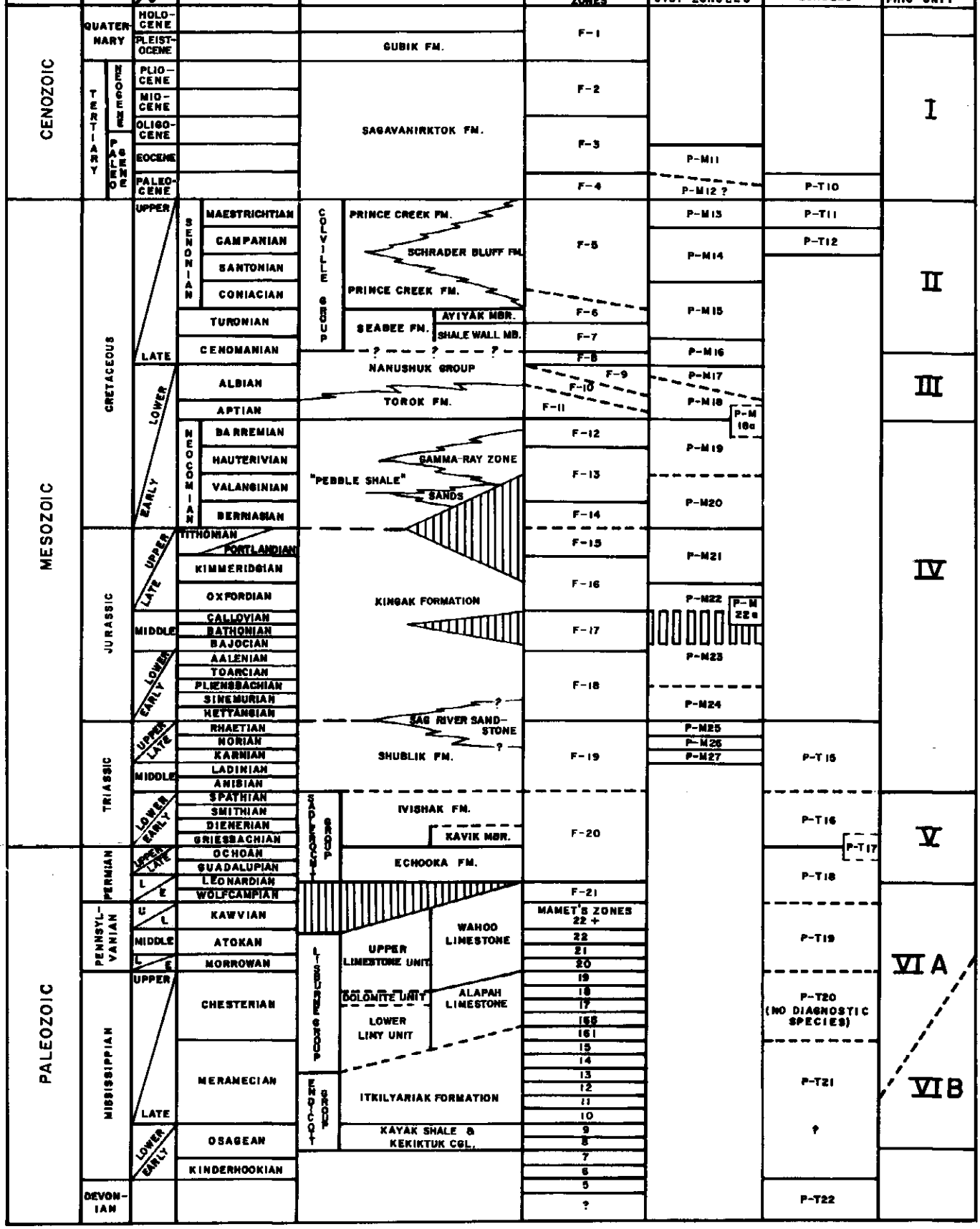
ALASKAN NORTH SLOPE GENERALIZED SUBSURFACE BIOSTRATIGRAPHIC CORRELATION CHART

This chart, modified from Anderson, Warren, and Associates (AWA) in December 1980, shows the correlation of the AWA and Mamet foraminiferal zones, AWA dinoflagellate-cyst zonules, and AWA spore-pollen zones with standard geologic time units and the conventional North Slope lithostratigraphic units.

The column on the far right shows generalized biostratigraphic groupings that contain similar fossils. This grouping compares favorably with the regional cycle chart (fig. 120) in this report.

ALASKAN NORTH SLOPE GENERALIZED SUBSURFACE BIOSTRATIGRAPHIC CORRELATION CHART (12/80)

MODIFIED FROM ANDERSON, WARREN, AND ASSOCIATES, INC.



TETRA TECH REPORT NO. 8200

TGZ-0170

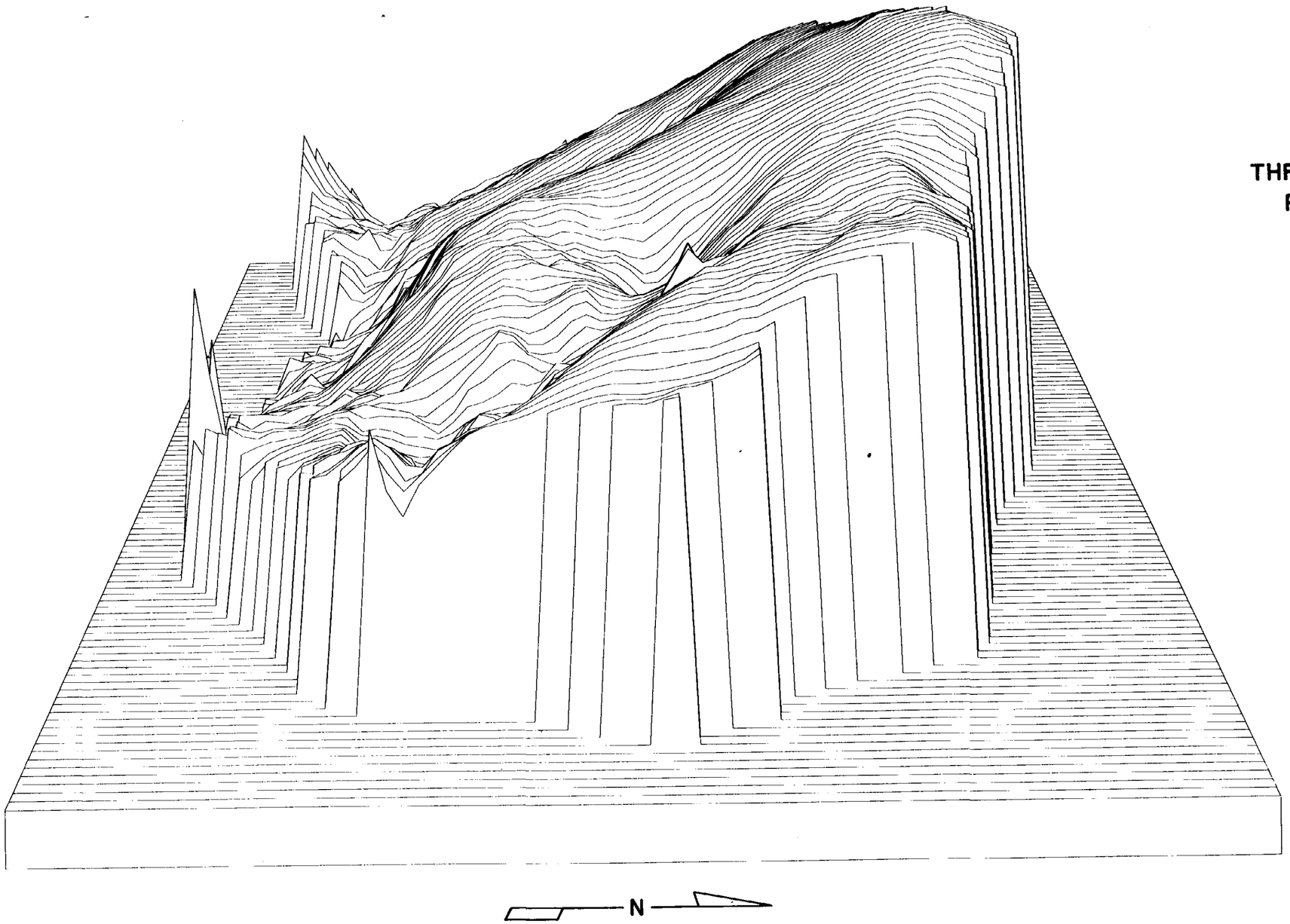
FIGURE 6

FIGURE 7

THREE-DIMENSIONAL PERSPECTIVE OF HORIZON 1500

This computer-plotted image of horizon 1500 as viewed from the east was generated from about 6,000 records in an NPRA geophysical data base. The illustration is a generalized configuration of the "Acoustic basement" as represented by horizon 1500.

FIGURE 7



THREE - DIMENSIONAL
PERSPECTIVE OF
HORIZON 1500

TGZ-0170

FIGURE

FIGURE 8

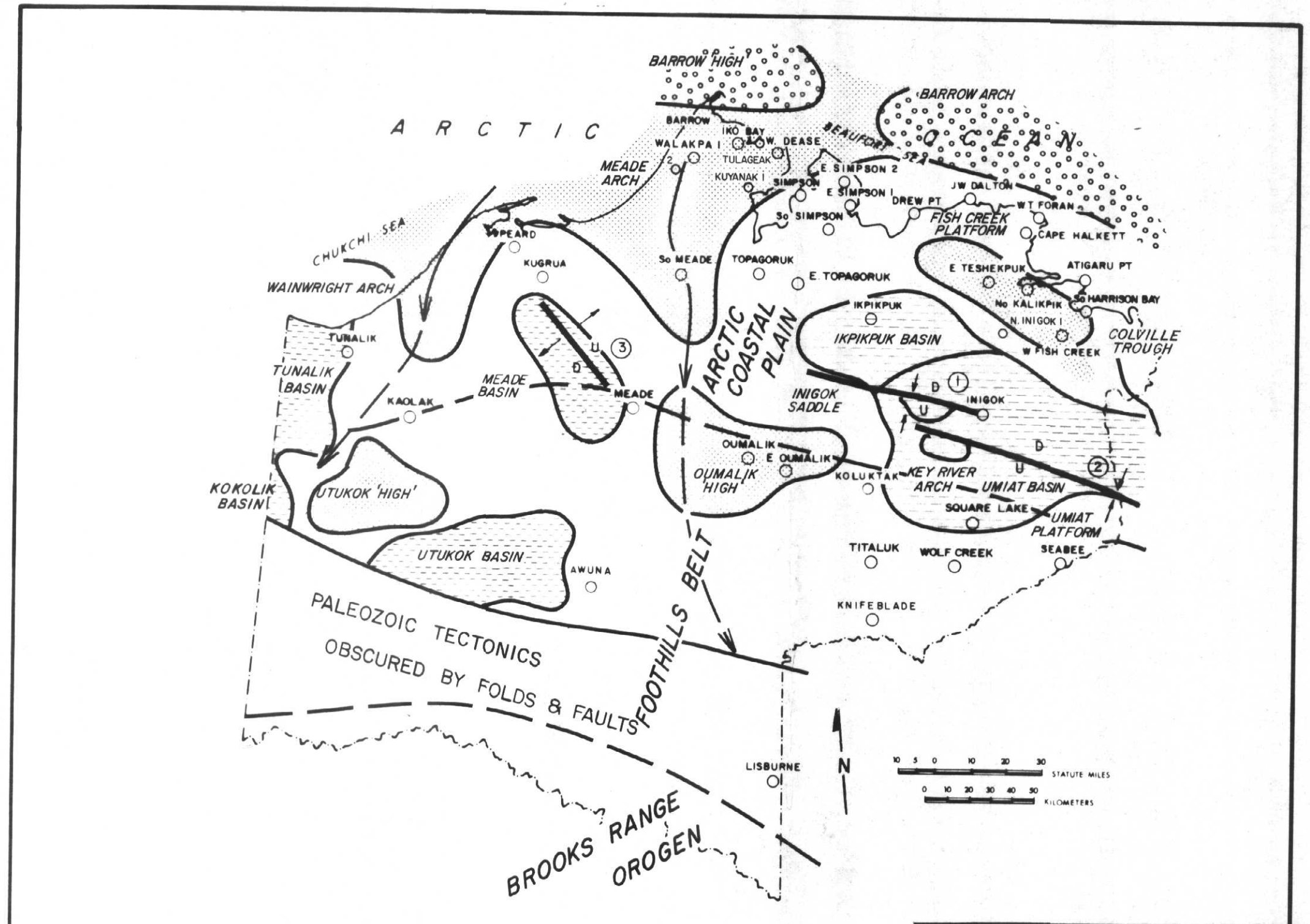
FIGURE 8

PALEOZOIC TECTONIC ELEMENTS, NPRA

The Paleozoic tectonic elements are defined by a combination of seismic interpretation and seismic stratigraphy. The margins of the Paleozoic basins are defined by the convergence of seismic horizons 1100, 1200, 1300, and 1400 with 1500, which is the "Acoustic basement." Even though some Paleozoic sedimentary rocks may be present below horizon 1500 in some parts of the Reserve, the horizon is useful for defining the general shape of the basement.

The main tectonic elements recognized south of the Continental Shelf are the Barrow High, Barrow Arch, Fish Creek Platform, Colville Trough, Umiat Basin, Key River Arch, Oumalik High, Ikpikpuk Basin, Meade Arch, Meade Basin, Wainwright Arch, Tunalik Basin, Utukok High, and Utukok Basin.

Minor flexures between basins include the Inigok Saddle between the Ikpikpuk and the Umiat Basins. Several minor rollovers bound by high-angle faults are present in the Paleozoic rocks in the Ikpikpuk River and Umiat Quadrangles; the most prominent structure of this type is the Key River Arch. The eastern margin of the Meade Basin is bound by a high-angle fault system that may be displaced several thousands of feet. In much of the southern foothills, the Paleozoic tectonic configuration is obscured by the effect of complex structures in the shallow Cretaceous rocks.



TETRA TECH, INC
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PALEOZOIC TECTONIC ELEMENTS, NPRA

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUYNZEEL		PROJECT NO.
INTERPRETATION BY: E.C. GULDENZOPF		REVISED: DATE / INITIAL
DATE: APRIL, 1981	DATUM:	
CONTOUR INT:	SCALE:	DWG NO.

TETRA TECH REPORT NO. 8200

FIGURE 8

FIGURE 9

CORRELATION CROSS SECTION B-B', TUNALIK 1 TO ATIGARU POINT 1

Cross section B-B' includes Tunalik 1, Peard 1, Kugrua 1, South Meade 1, Topagoruk 1, Ikpikpuk 1, East Teshekpuk 1, North Kalikpik 1, and Atigaru Point 1. Datum is sea level. The main geologic features are:

1. The basic tectonic features of the NPRA, from the west to the east, are the Tunalik Basin, Wainwright Arch, extreme northern end of the Meade Basin, Meade Arch, Ikpikpuk Basin, and Fish Creek Platform. Over the Meade Arch at South Meade 1 and Topagoruk 1, the basement is composed of steeply dipping Early(?) to Middle Devonian metasediments (unit D). Elsewhere, the basement is composed of Ordovician-Silurian "Argillite" (unit O-S).

2. An isolated, erosional remnant of the Late Mississippian M-1 unit (Endicott Group) is preserved north of the Fish Creek Platform at Atigaru Point 1. This remnant may have been deformed by the same tectonic event that folded the Devonian strata on the Meade Arch.

3. Units M-1, M-2, P-1, and P-2 (Endicott, Alapah, Wahoo, and "Transition Zone," respectively) lap onto the basement over the Fish Creek Platform and against the Meade and Wainwright Arches.

4. A 745-ft (229-m) thick basalt contained in the P-2 unit at Tunalik 1 is believed to be an extrusive, because the core samples indicate an andesitic flow.

5. Pre-Triassic rocks lap out toward the Wainwright and Meade Arches, and thin over the Fish Creek Platform. Unit PR-2 (Ikiakpaurak Member of the Echooka Formation) overlies unit O-S ("Argillite") at Peard 1. Unit PR-1 (Joe Creek Member of the Echooka Formation) overlies Devonian rocks at Topagoruk 1.

6. Unit TR-1 ("Kavik shale") thickens between Peard 1 and Tunalik 1. At South Meade 1, unit TR-2 ("Ivishak sandstone") overlies the Devonian and becomes increasingly silty toward the west. At Tunalik 1, TR-2 is composed entirely of siltstone and silty sandstone. TR-3b (Sag River Sandstone) grades into shale to the west between Peard 1 and Tunalik 1.

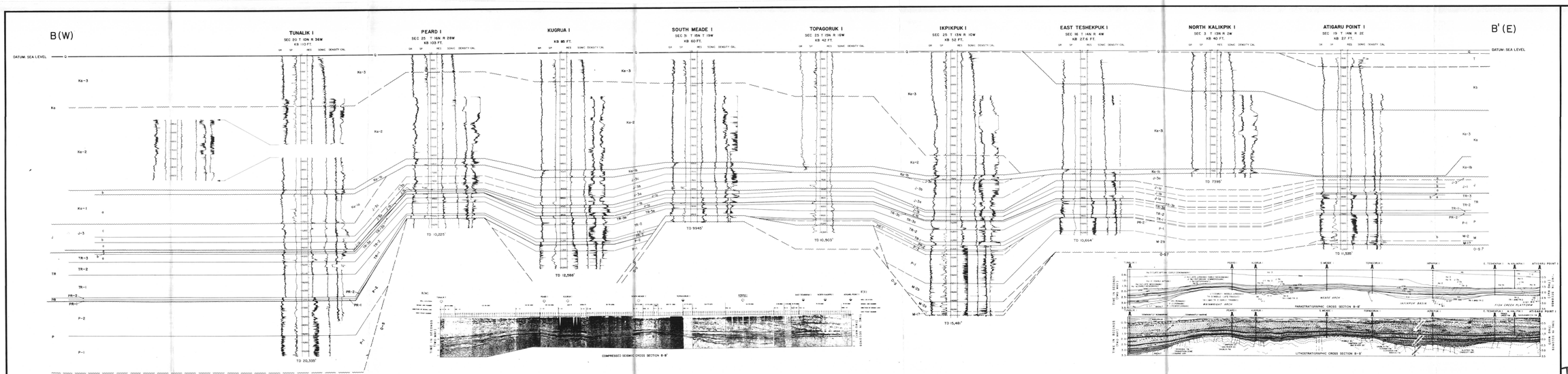

B(W)
B'(E)
DATUM: SEA LEVEL
TUNALIK I
SEC 20 T 10N R 36W
KB 110 FT.
PEARD I
SEC 25 T 10N R 28W
KB 103 FT.
KUGRUA I
KB 85 FT.
SOUTH MEADE I
SEC 5 T 10N T 19W
KB 60 FT.
TOPAGORUK I
SEC 25 T 13N R 10W
KB 42 FT.
IKPIKPUK I
SEC 25 T 13N R 10W
KB 52 FT.
EAST TESHEKPUK I
SEC 16 T 14N R 4W
KB 27.6 FT.
NORTH KALIKPIK I
SEC 3 T 13N R 2W
KB 40 FT.
ATIGARU POINT I
SEC 19 T 14N R 2E
KB 27 FT.
TD 20,335'
TD 10,225'
TD 12,588'
TD 9945'
TD 10,503'
TD 15,481'
TD 10,664'
TD 7395'
TD 10,580'
COMPRESSED SEISMIC CROSS SECTION B-B'
PARASTRATIGRAPHIC CROSS SECTION B-B'
LITHOSTRATIGRAPHIC CROSS SECTION B-B'
NO HORIZONTAL SCALE
INDEX MAP
TETRA TECH, INC.
CORRELATION CROSS SECTION B-B'
TUNALIK I / ATIGARU POINT I
NPR
ALASKA
ONPRA
HUSKY OIL NPR OPERATIONS INC.
FIGURE 9

FIGURE 10

LITHOSTRATIGRAPHIC CROSS SECTION B-B',
TUNALIK 1 TO ATIGARU POINT 1

Features of interest, from the bottom upward and from west (left) to east (right), are:

1. A series of block faults occurs in the "Acoustic basement" on the west and east flanks of the Wainwright Arch, both flanks of the Meade Arch near South Meade 1 and Topagoruk 1, and west of Peard 1.

2. The clastic Endicott Group is relatively thin in the Ikpikpuk Basin, and it may pinch out on the east flank of the Meade Arch.

3. The Wahoo Limestone probably overlies the "Acoustic basement" west of the Meade Arch. The Mississippian Alapah Limestone was not reached by any of the western wells, but it may be present in the deeper parts of the Meade and Tunalik Basins. Alternatively, the Alapah and clastic rocks of the Endicott Group may be present west of the Meade Arch as part of the "Acoustic basement." If complexly folded, faulted, or metamorphosed, these formations are indistinguishable from the "Argillite" or Early-Middle(?) Devonian.

4. The "Transition Zone," consisting of argillaceous limestone and shale, is relatively thick west of the Meade Arch and thinner east of the Arch. Toward the north, as at Kugrua 1, the "Transition Zone" truncates the Wahoo Limestone. The Echooka Formation overlies the upper part of the Wahoo and the "Transition Zone."

5. The "Kavik shale" member of the Ivishak Formation is thickest west of the Wainwright Arch. The "Ivishak sandstone" member is siltier toward the west; at Tunalik 1, this member is nearly all siltstone.

6. The Shublik Formation is a distinctive marker across the width of the NPRA. The Shublik contains more sand on the Barrow High-Meade Arch trend and Wainwright Arch than elsewhere on the Reserve.

7. The Sag River Sandstone grades into shale between Peard 1 and Tunalik 1.

8. Several sandstone bodies, including the "Simpson sandstone" and others, are present in the Kingak Formation on the west side of the Meade Arch. The Kingak is generally shaly east of the Meade Arch, although sands may occur around the edges of basins.

9. The "Pebble Shale," a distinctive marker across the Reserve, is absent locally over parts of the Fish Creek Platform, and is questionably absent on the west flank of the Wainwright Arch.

10. The Torok Formation and Nanushuk Group, undivided, progrades toward the east. The nonmarine Chandler Formation of the Nanushuk Group is not present on the Fish Creek Platform. West of East Teshekpuk 1, the shales of the Seabee Formation of the Colville Group overlie the marine Grandstand Formation of the Nanushuk. The Colville Group is restricted to the east of Ikpikpuk 1. The Tertiary Sagavanirktok Formation is present only at Atigaru Point 1.

FIGURE 10

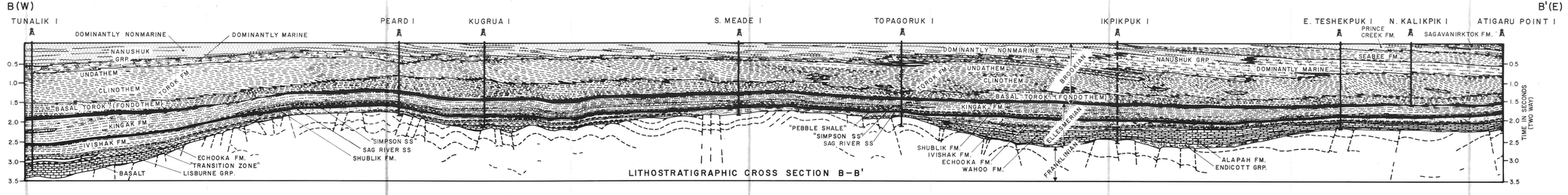
7. The "Lower Kingak" (unit J-1) is truncated by the mid-Jurassic unconformity. J-1a, J-1b, and J-1c are present in all wells except Peard 1 and Tunalik 1 in the west. J-1a ("Barrow sandstone") laps out against the Wainwright Arch between Kugrua 1 and Peard 1. At Tunalik 1, the J-1 unit is truncated deeply by the mid-Jurassic unconformity and only 140 ft (43 m) of J-1a remains.

8. The basal "Pebble Shale" unconformity truncates the "Upper Kingak" (units J-3 and Ka-1a). The "Simpson sandstone" within J-3a grades into shale west of Peard 1 and east of Topagoruk 1. At East Teshekpuk 1, North Kalikpik 1, and Atigaru Point 1, J-3a is directly below the basal "Pebble Shale" unconformity. In all other wells except Topagoruk 1 and Tunalik 1, J-3c lies beneath the unconformity. At Topagoruk 1, J-3b is present; at Tunalik 1, the Ka-1a (Valanginian-Hauterivian) part of the "Upper Kingak" truncates J-3c below the mid-Neocomian unconformity.

9. Unit Ka-1b ("Pebble Shale") thins toward the east.

10. The time-transgressive Ka-2 and Ka-3 units (Torok-Nanushuk) are above the "basal Torok" unconformity. The original regional dip was northeastward where the Torok-Nanushuk rocks are younger. At East Teshekpuk 1, North Kalikpik 1, and Atigaru Point 1, Torok fondothem (bottomset) beds within Ka-3 overlie the "basal Torok" unconformity. In all other wells, Torok fondothem beds within Ka-2 overlie the unconformity.

11. Quaternary surficial materials overlie Ka-3 from Tunalik 1 eastward to Ikpikpuk 1 and unit Kb (Colville Group) at East Teshekpuk 1 and North Kalikpik 1. At Atigaru Point 1, north of the Fish Creek Platform, unit T (Sagavanirktok Formation) is just below the surface and unconformably overlies unit Kb.



LITHOSTRATIGRAPHIC CROSS SECTION B–B'

INDEX MAP

TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974–1981 (FINAL REPORT)

LITHOSTRATIGRAPHIC CROSS SECTION B-B'

TUNALIK I-ATIGARU POINT I

NPR — ALASKA

FOR

ONPRA

HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. W. BRUYNZEEL		PROJECT NO. TO-1174	
INTERPRETATION BY: C. GULDENDORF		REVISED	
		DATE	REPTD
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TG3-0170

FIGURE 10

FIGURE 11

PARASTRATIGRAPHIC CROSS SECTION B-B',
TUNALIK 1 TO ATIGARU POINT 1

Features of interest, from the bottom upward and from west (left) to east (right), are:

1. Few large, obvious structures are present below horizon 1500 ("Acoustic basement"). A few refractions along lines 125-76 and 26X-75 indicate probable faults (fig. 16). Most of the apparent "bedding" probably is due to multiples. Local block faulting may have preserved the Lower-Middle(?) Devonian(?) at Topagoruk 1.

2. West of the Meade Arch, the oldest rocks identified above the "Acoustic basement" are in units P-1 and P-2 (Pennsylvanian to Permian). Some Mississippian rocks may be present in the Meade Basin farther south.

3. East of the Meade Arch, M-1 and M-2 (Mississippian) overlie the "Acoustic basement" (presumably unit O-S) in the Ikpikpuk Basin.

4. Unit P-2 is relatively thicker west of the Meade Arch. Northward, P-2 unconformably overlies and truncates P-1, as at Kugrua 1. Eastward, P-2 thins and is overlain by PR. On the Fish Creek Platform, PR directly overlies P-1.

5. Units TR-1 and TR-2 (Early-Middle Triassic), which are relatively thicker in the Tunalik Basin than elsewhere, overlie the "Acoustic basement" over the crests of the Wainwright and Meade Arches.

6. Horizons 1000 and 1040 are near the top and bottom, respectively, of the TR-3 unit. These seismic horizons form a reflector couplet that is traceable across the section.

7. Unit J-1 is relatively thinner to the west of the Meade Arch than to the east of it.

8. Horizon 0850 and other seismic horizons that subdivide J-3 are relatively close together near Tunalik 1, but spread farther apart to the east and are overlain by horizon 0720 east of Topagoruk 1.

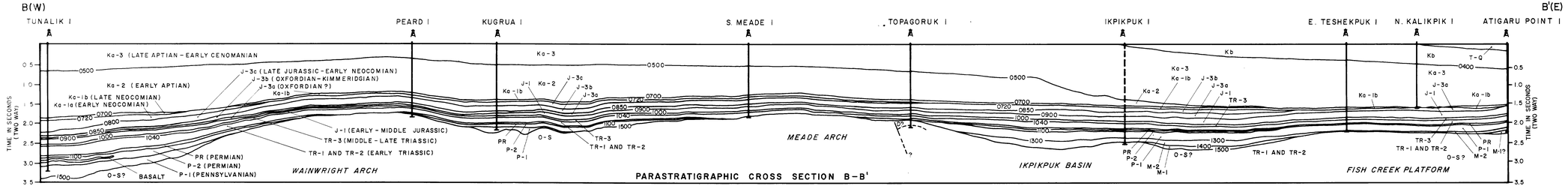
9. Horizon 0800 near the base of the Ka-1a unit is overlain by horizon 0720 between Tunalik 1 and Peard 1.

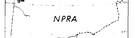
10. Ka-1b is absent on the Fish Creek Platform (based on drilling) and is thought to be absent on the west flank of the Wainwright Arch.

11. Horizon 0500 (mid-Aptian(?)), near the top of unit Ka-2, downlaps toward the east. Horizon 0500 is traceable into a clinoform until it downlaps onto horizon 0700 east of Ikpikpuk 1.

12. Horizon 0400 (mid-Cenomanian unconformity) is truncated below surface rocks just east of Ikpikpuk 1. Units T and Q are present beneath surface deposits just east of North Kalikpik 1.

FIGURE 11





TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

PARASTRATIGRAPHIC CROSS SECTION B-B'

TUNALIK I - ATIGARU POINT I

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUNSWIGEL	PROJECT NO. TC-1974
INTERPRETATION BY: C. GULDENDORF	REVISED: DATE / INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL
CONTOUR (RI):	SCALE:
	DWG NO.

TETRA TECH REPORT NO. 8200

TGE-0170

FIGURE 11

FIGURE 12

COMPRESSED SEISMIC CROSS SECTION B-B', TUNALIK 1 TO ATIGARU POINT 1

Compressed seismic cross section B-B' is a west-to-east (left-to-right) section that starts at Tunalik 1, ends at Atigaru Point 1, and ties areas of well control across several of the basement tectonic elements on the Reserve. Features of interest are:

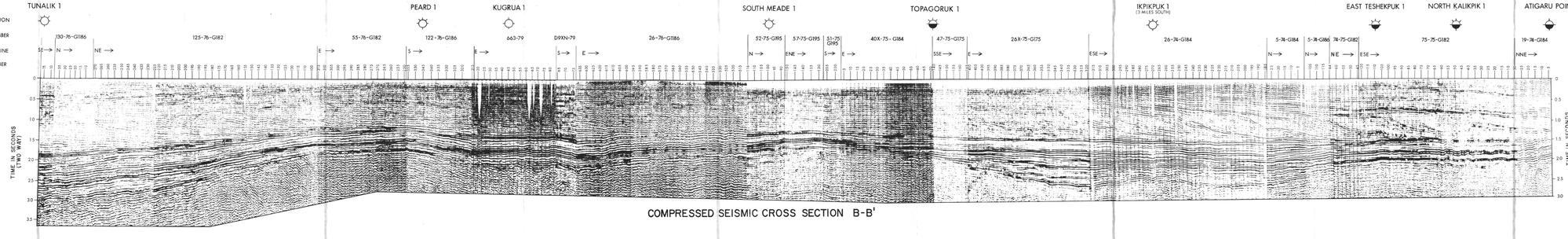
1. Few "dip reversals" due to seismic line intersections are present. Only lines 122-76, 51-75, and 47-75 show any significant reversals.

2. Below "Acoustic basement," there is some indication of structure in the O-S, D(?), or younger strata. Some of these features are refractions, probably from faults. Some apparent bedding is probably caused by multiples from higher strata. Therefore, all interpreted structures below "Acoustic basement" are conjectural.

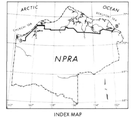
3. At Tunalik 1, a high-velocity basalt layer at about 3.0 seconds masks the strata below it, making it difficult to identify "Acoustic basement" in this area.

4. Basement tectonic elements shown include the Tunalik Basin on the west, Wainwright Arch to the west of Peard 1, Meade Arch between South Meade 1 and Topagoruk 1, Ikpikpuk Basin near Ikpikpuk 1, and Fish Creek Platform on the east side of the section. The northern end of the Meade Basin is shown at Kugrua 1.

FIGURE 12



COMPRESSED SEISMIC CROSS SECTION B-B'



INDEX MAP

TETRA TECH, INC

PASADENA, CALIFORNIA — ENERGY MANAGEMENT DIVISION — HOUSTON, TEXAS

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

COMPRESSED
SEISMIC CROSS SECTION B-B'
TUNALIK 1-ATIGARU POINT 1

NPR — ALASKA

ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. W. BRUYNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULDENZOPF, K. CLARY		REVISED DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TGZ-0170

FIGURE 12

FIGURE 13

CORRELATION CROSS SECTION D-D',
SOUTH BARROW 13 TO LISBURNE 1

Cross section D-D' includes South Barrow 13, South Barrow 3, Walakpa 1, Walakpa 2, Kuyanak 1, South Meade 1, Oumalik 1, and Lisburne 1. Datum is sea level. The main geologic features shown are:

1. Pre-Jurassic rocks lap out against the Barrow High. At South Meade 1, the basement comprises steeply dipping Early(?) to Middle Devonian metasediments; unit TR-2 ("Ivishak sandstone") overlies the basement and laps out between South Meade 1 and Kuyanak 1. In wells north of South Meade 1, the basement is the Ordovician-Silurian unit ("Argillite"). Unit TR-3a (Shublik Formation) overlies the basement at Kuyanak 1, Walakpa 2, Walakpa 1, and South Barrow 3, and laps out between South Barrow 3 and South Barrow 13. At South Barrow 13, unit TR-3b (Sag River Sandstone) overlies the basement and is composed of siltstones and silty calcareous glauconitic sandstones. TR-3b grades into shale to the north between Walakpa 1 and South Barrow 3.

2. The mid-Jurassic unconformity truncates unit J-1 ("Lower Kingak") toward the Barrow High.

3. Oumalik 1 was drilled into rocks questionably assigned to the J-3c unit. At Oumalik 1, all units below J-3c are projected, based on seismic-stratigraphic analysis.

4. The basal "Pebble Shale" unconformity truncates J-3 ("Upper Kingak"). Consequently, J-3 is absent at South Barrow 13. South of the Barrow High, J-3 thickens and is over 1,200 ft (366 m) thick at South Meade 1.

5. The thickness of the Ka-1b ("Pebble Shale") unit is questionable at Oumalik 1 due to a lack of a gamma-ray curve and at Lisburne 1 due to the lack of a well-defined "Gamma Ray Shale" zone.

6. The Torok fondothem (bottomset) beds within the time-transgressive Ka-2 unit (Torok Formation and Nanushuk Group) overlie Ka-1b in all wells. At Lisburne 1, the fondothem beds are on the surface.

7. At South Barrow 13, South Barrow 3, and Walakpa 1, Torok clinothem (foreset) beds within Ka-2 underlie Quaternary surface rocks. At Walakpa 2, clinothem beds within Ka-3 are below unit Q. Nonmarine beds of the Nanushuk Group, within Ka-3, are beneath surface deposits at Kuyanak 1 and South Meade 1. At Oumalik 1, Ka-3 is below unit Q and is composed of Nanushuk marine strata.

8. A zone of thrust faulting just north of Lisburne 1 precludes direct correlation with wells to the north. Five fault-separated repeat sequences are at Lisburne 1. Figure 69 defines tops of these plates.

9. All pre-Cretaceous rocks thin at Lisburne 1. Numerous high gamma-ray curve deflections in the interval TR-3a to Ka-1b may indicate several unconformities and slow deposition.

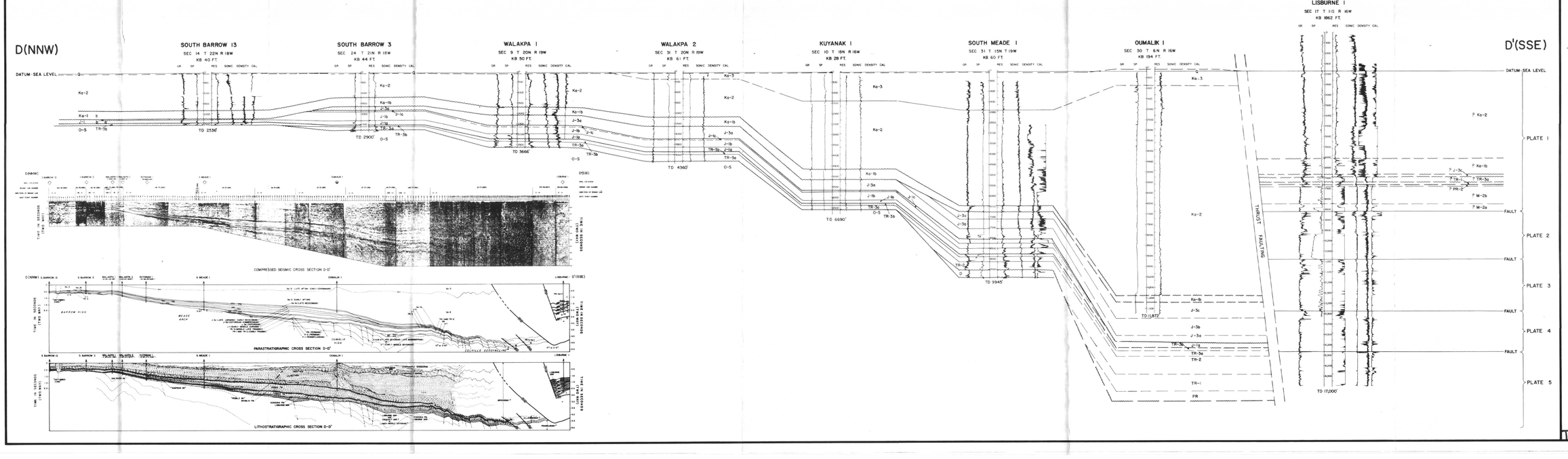

D(NNW)
D'(SSE)
SOUTH BARROW 13
SEC 14 T 22N R 18W
KB 40 FT.
SOUTH BARROW 3
SEC 24 T 21N R 18W
KB 44 FT.
WALAKPA 1
SEC 9 T 20N R 19W
KB 50 FT.
WALAKPA 2
SEC 31 T 20N R 19W
KB 61 FT.
KUYANAK 1
SEC 10 T 18N R 16W
KB 28 FT.
SOUTH MEADE 1
SEC 31 T 15N T 19W
KB 60 FT.
OUMALIK 1
SEC 30 T 6N R 16W
KB 194 FT.
LISBURNE 1
SEC 17 T 11S R 16W
KB 1862 FT.
GR SP RES SONIC DENSITY CAL
DATUM SEA LEVEL
TD 2536'
TD 2900'
TD 3666'
TD 4360'
TD 6690'
TD 9945'
TD 11,872'
TD 17,000'
THRUST FAULTING
PLATE 1
PLATE 2
PLATE 3
PLATE 4
PLATE 5
FAULT
COMPRESSED SEISMIC CROSS SECTION D-D'
PARASTRATIGRAPHIC CROSS SECTION D-D'
LITHOSTRATIGRAPHIC CROSS SECTION D-D'
TIME IN SECONDS (TWO WAY)
NO HORIZONTAL SCALE
NPRA
INDEX MAP
TETRA TECH, INC
ENERGY MANAGEMENT DIVISION
PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)
CORRELATION CROSS SECTION D-D'
SOUTH BARROW 13-LISBURNE 1
NPR
ALASKA
FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.
PROJECT MANAGER: J. W. MILLINGTON
DATE: JUNE, 1980
DATUM: SEA LEVEL
DWG NO.
TETRA TECH, RECORDING
TGZ-0170
FIGURE 13

FIGURE 14

LITHOSTRATIGRAPHIC CROSS SECTION D-D',
SOUTH BARROW 13 TO LISBURNE 1

Features of interest, from the bottom upward and from north (left) to south (right), are:

1. Limestones of the Lisburne Group are the oldest rocks overlying "Acoustic basement." To the north of the Oumalik High, the Lisburne (Wahoo(?)) limestones are overlain by the argillaceous limestones and shales of the "Transition Zone." The "Transition Zone" overlaps the Lisburne near South Meade 1.

2. The Echooka Formation overlies the Lisburne-"Transition Zone" sequence on both the Meade Arch and the north side of the Oumalik High. The Echooka is overlapped by the Ivishak Formation to the north of South Meade 1.

3. South of South Meade 1, the "Ivishak sandstone" member of the Ivishak Formation probably grades into siltstone, and the Sag River Sandstone and "Simpson sandstone" of the Kingak Formation probably grade into shale. On the Barrow High, the Sag River Sandstone grades into shale. South of Kuyanak 1, the "Simpson sandstone" grades into shale.

4. At Kuyanak 1, the shale and siltstone equivalent to the "Simpson sandstone" are overlain by an unnamed sandstone that is separate and distinct from the "Simpson." This sandstone probably correlates with the "Walakpa gas sand," which was penetrated in Walakpa 1 and Walakpa 2, and may be equivalent to the "Pebble Shale" sandstone found in several other wells.

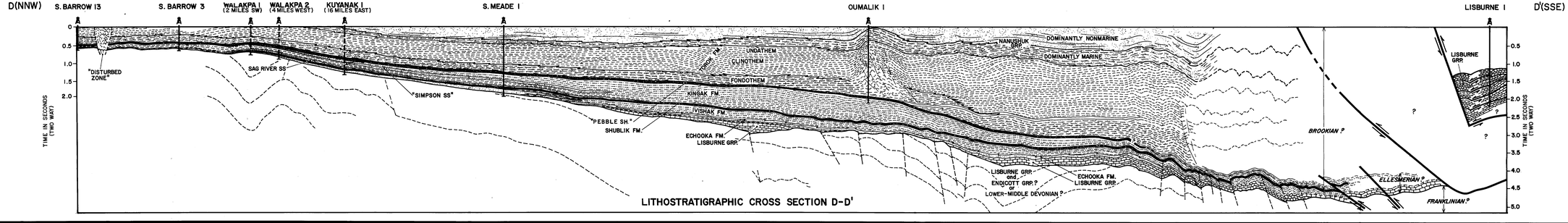
5. The Kingak Formation, made up of shales and siltstones, is thickest over the Oumalik High. North of the Oumalik High, the formation thins because of onlap and truncation. South of the Oumalik High, this pattern suggests a northern source area for this sequence.

6. The "Pebble Shale," a distinctive marker over the northern three-fourths of the section, is very difficult to trace into the Brooks Range Orogen to the south.

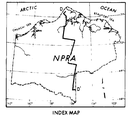
7. The Nanushuk-Torok sequence progrades toward the north on north-south sections, and toward the east on west-east line segments. In a vertical sequence near Oumalik 1, the Torok fondothem, clinothem, and undathem, and the Nanushuk marine and nonmarine beds overlie one another upward.

8. Oumalik 1 was drilled on an anticline with a root that is detached from the "Pebble Shale" level. The anticline is probably diapiric; the shale core originated within the Torok Formation. The best hydrocarbon prospects in this and similar structures are probably in the shallow horizons. Only those reservoir rocks within the upper section (for example, the Nanushuk and Torok fondothem) are likely prospects because closure is not likely in deeper, potential reservoir rocks.

FIGURE 14



LITHOSTRATIGRAPHIC CROSS SECTION D-D'



TETRA TECH, INC
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

LITHOSTRATIGRAPHIC CROSS SECTION D-D'
SOUTH BARROW 13-LISBURNE 1

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUNNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULDENZOPF		REVISED	
		DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TGZ-0170 FIGURE 14

FIGURE 15

FIGURE 15

PARASTRATIGRAPHIC CROSS SECTION D-D',
SOUTH BARROW 13 TO LISBURNE 1

Features of interest, from the bottom upward and from north (left) to south (right), are:

1. The "Acoustic basement" below horizon 1500 is Ordovician-Silurian (unit O-S) in the Barrow area, according to Carter and Laufeld (1975). At South Meade 1, a thin layer of unit D (Devonian) overlies the O-S unit. Projection of poor seismic reflections toward the south suggests that folded and faulted basement rocks may become younger to the south.

2. The axis of an ancient fold belt may underlie the Oumalik High, shown near the middle of the section. There, several discontinuous, parallel, south-dipping reflectors occur below horizon 1500. These reflectors are probably bedded sedimentary or metasedimentary rocks of Early-Middle(?) Devonian, Late Devonian (D), or Mississippian (M-1 to M-2) age.

3. The Oumalik High may be a synclinorium that is the axis of a pre-Pennsylvanian geosyncline. It is not known whether these rocks and the O-S rocks on the Barrow High were deformed at different times or during a single orogeny. Geologic studies in the Brooks Range suggest that these rocks were deformed during Devonian time.

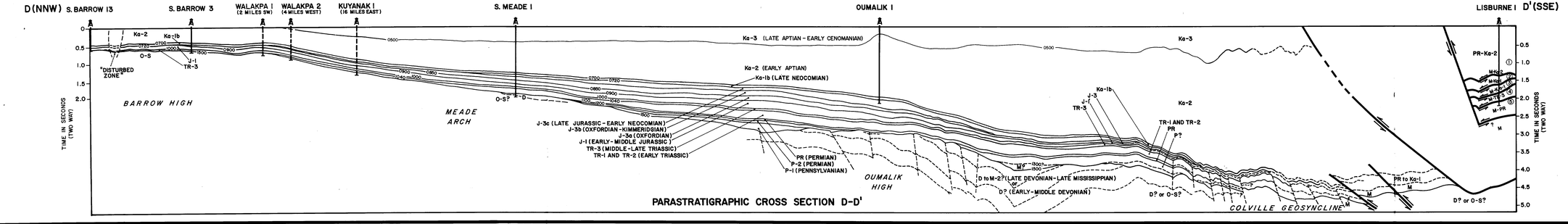
4. The oldest known rocks overlying horizon 1500 are Pennsylvanian. P-1 laps against the Meade Arch to the south of South Meade 1, and against the Oumalik High on both sides of Oumalik 1.

5. Progressively younger rocks lap onto the Meade Arch-Barrow High. From South Meade 1 to the north, the onlap sequence is P-1, P-2, PR, TR-1, TR-2, TR-3, and J-1.

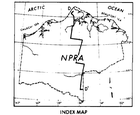
6. Unit Ka-1b truncates progressively older rocks from South Meade 1 toward the north. The truncation sequence is J-3c, J-3b, J-3a, and J-1.

7. The Barrow High was uplifted in post-Early Cretaceous time. The Ka-2 unit is exposed below surface beds on the Barrow High. To the south, horizon 0500 (mid-Aptian(?)) is near the boundary between Ka-2 and Ka-3. Ka-3 is near the surface south of the Barrow High.

8. The five plates penetrated in Lisburne 1 seem to be a series of splay thrusts originating from a sole fault below the base of the well (total depth of 17,000 ft or 5,182 m).



PARASTRATIGRAPHIC CROSS SECTION D-D'



INDEX MAP

TETRA TECH, INC.

HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (TRIBAL REPORT)

PARASTRATIGRAPHIC CROSS SECTION D-D'

SOUTH BARROW 13 - LISBURNE 1

NPR — ALASKA

FOR

ONPRA

HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C.D.A.SANDERS		REVISED DATE	CAPTION
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TG2-0170

FIGURE 15

FIGURE 16

FIGURE 16

COMPRESSED SEISMIC CROSS SECTION D-D',
SOUTH BARROW 13 TO LISBURNE 1

Compressed seismic cross section D-D' is a north-to-south section starting at South Barrow 13 on the left and ending at Lisburne 1 on the right. This section bisects all of the major structural-tectonic regimes within the Reserve. The left side of the section is through the Arctic Coastal Plain, the middle part cuts the Foothills, and the right side is through the Brooks Range Orogen. Features of interest are:

1. Seismic lines B10-78 and B5-78 are high-resolution. These lines contain more detail than conventional seismic line segments because they were reduced photographically before being compressed.

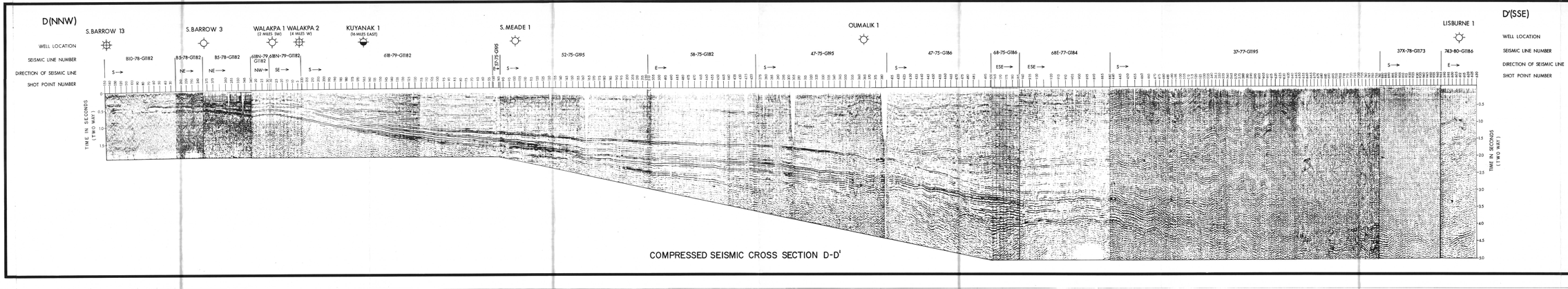
2. Abrupt changes in dip occur at seismic line intersections 52-75 to 58-75, 58-75 to 47-75, 47-75 to 68-75, 68E-77 to 37-77, and 37X-78 to 743-80. Lines 58-75, 68-75, 68E-77, and 743-80 are mainly west-east lines. The rest are mainly north-south lines.

3. Below "Acoustic basement" are a series of dipping, folded, and faulted parallel reflectors that originate from bedded rocks.

4. A prominent diapiric(?) fold occurs in the middle of the section at Oumalik 1. This folding affects the section above about 2.2 seconds. A velocity "pull-down" below the fold is related to the thick section of low-density shale above it.

5. Beginning with line 37-77, the data become increasingly difficult to interpret. From shotpoint 500 to the right, the section is nearly uninterpretable, possibly because of reflections from a large number of acoustic interfaces in a jumbled "crunch zone" at a compressional plate boundary.

6. Basement tectonic elements shown on this section are the Barrow High north of Walakpa 1, Meade Arch south of South Meade 1, and Colville geosyncline on lines 37-77 and 37X-78 to the north of Lisburne 1.



COMPRESSED SEISMIC CROSS SECTION D-D'

INDEX MAP

TETRA TECH, INC

HOUSTON TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

COMPRESSED
SEISMIC CROSS SECTION D-D'
SOUTH BARROW 13 - LISBURNE 1

NPR — ALASKA

BY

ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. M. BRUYNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULNAZYAN, K. CLARY		REVISIONS	
		DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TGE-0170

FIGURE 16

FIGURE 17

CORRELATION CROSS SECTION E-E', SOUTH BARROW 13 TO SEABEE 1

Cross section E-E' includes South Barrow 13, South Barrow 17, Iko Bay 1, Tulageak 1, West Dease 1, Simpson 1, South Simpson 1, Ikpikpuk 1, Inigok 1, and Seabee 1. Datum is sea level. The main geologic features shown are:

1. The basement, unit O-S ("Argillite"), was reached by all wells except Inigok 1 and Seabee 1. At Inigok 1, the deepest unit penetrated was M-1 (Endicott Group). Seabee 1 reached total depth in J-3c ("Upper Kingak"), and Ka-1a may be present below Ka-1b, but the quality of log, paleontologic, and seismic data is insufficient to separate Ka-1a from J-3c. Stratigraphic relationships shown below J-3c are based on seismic-stratigraphic analysis.

2. Units M-1, M-2 (Alapah Limestone), P-1 (Wahoo Limestone), P-2 ("Transition Zone"), and PR-1 (Joe Creek Member of the Echooka Formation) lap out against the Barrow Arch between Ikpikpuk 1 and South Simpson 1.

3. Units PR-2 (Ikiakpaurak Member of the Echooka Formation) and TR-1 ("Kavik shale") lap out against the Barrow High between South Simpson 1 and Simpson 1.

4. TR-2 ("Ivishak sandstone") is questionably at Simpson 1 and laps out against the Barrow High between Simpson 1 and West Dease 1.

5. The mid-Jurassic unconformity truncates unit J-1 ("Lower Kingak") at South Simpson 1, Ikpikpuk 1, Inigok 1, and Seabee 1. The basal "Pebble Shale" unconformity truncates J-1 at Simpson 1, West Dease 1, Tulageak 1, Iko Bay 1, South Barrow 17, and South Barrow 13.

6. The "Upper Kingak," which includes unit J-3 and possibly unit Ka-1a, is thickest in the south at Seabee 1 and thins toward the Barrow High due to truncation by the basal "Pebble Shale" unconformity. At South Simpson 1, only the J-3a subdivision of J-3 is present. North of South Simpson 1, J-3 is absent.

7. Unit Ka-1b ("Pebble Shale") is present in all wells.

8. The Torok fondothem (bottomset) beds within the time-transgressive Ka-2 unit overlie Ka-1b ("Pebble Shale") at South Barrow 13 and Iko Bay 1. In all other wells, Torok fondothem beds within the time-transgressive Ka-3 unit (Torok-Nanushuk) overlie Ka-1b.

9. Quaternary surface beds are in all wells except Inigok 1 and Seabee 1. At Inigok 1, the Kb unit (Colville Group) is at the surface. At Seabee 1, Nanushuk nonmarine beds within unit Ka-3 are at the surface. Progressively younger rocks underlie unit Q to the southeast. The Torok clinothem (foreset) beds, within Ka-2, are at South Barrow 13 and South Barrow 17; at Iko Bay 1, Torok undathem (topset) beds, within Ka-2, are below unit Q. Nanushuk marine beds within Ka-3 are below unit Q at Tulageak 1, West Dease 1, and Simpson 1; Nanushuk nonmarine beds are at South Simpson 1 and Ikpikpuk 1.

FIGURE 17

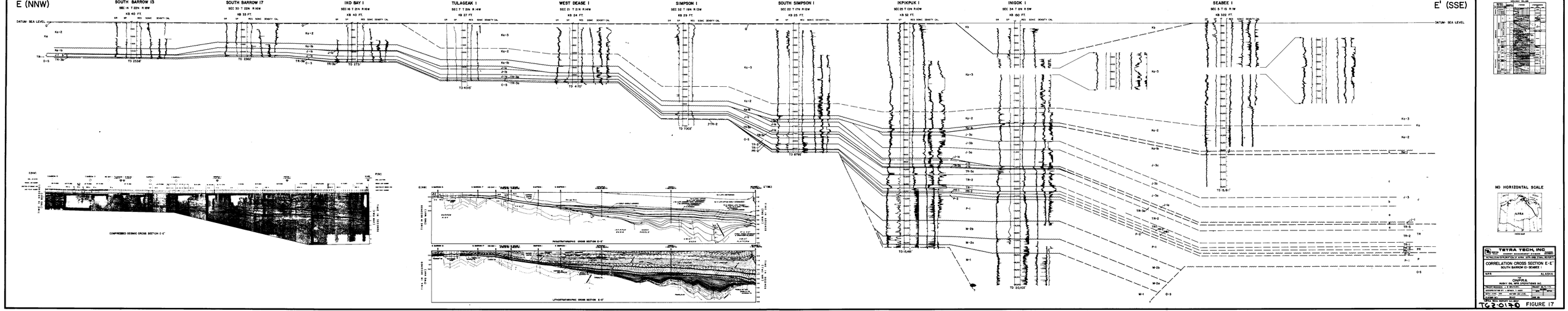

E (NNW)
E' (SSE)
SOUTH BARROW 13
SOUTH BARROW 17
IKO BAY 1
TULAGEAK 1
WEST DEASE 1
SIMPSON 1
SOUTH SIMPSON 1
IKPIKPUK 1
INIGOK 1
SEABEE 1
DATUM: SEA LEVEL
COMPRESSED SEISMIC CROSS SECTION E-E'
PHOTOSTRATIGRAPHIC CROSS SECTION E-E'
LITHOSTRATIGRAPHIC CROSS SECTION E-E'
NO HORIZONTAL SCALE
NPRA
TETRA TECH, INC.
CORRELATION CROSS SECTION E-E'
SOUTH BARROW 13-SEABEE 1
NPR
ALASKA
ONPRA
HUGHY SEL NPR OPERATIONS INC.
TG2-0170
FIGURE 17

FIGURE 18

LITHOSTRATIGRAPHIC CROSS SECTION E-E',
SOUTH BARROW 13 TO SEABEE 1

Features of interest, from the bottom upward and from northwest (left) to the southeast (right), are:

1. The "Acoustic basement" is composed of "Argillite" (phyllite and quartzite) in the Barrow area. Southeastward, probable "Argillite" was encountered at Iko Bay 1, Simpson 1, and South Simpson 1. A quartzite, questionably assigned to the "Argillite," was penetrated at total depth in Ikpikpuk 1. At Inigok 1, rocks below "Acoustic basement" are identical to those several hundred feet above the basement. Seabee 1 did not reach "Acoustic basement."

2. The Endicott Group in Inigok 1 consists of an upper relatively thin shale and a lower thick sandstone, coal, and siltstone sequence. Microfossils suggest that the Endicott is time-transgressive toward the northwest. At Inigok 1, the top of the Endicott is within Mamet foraminiferal zone 10-11 or older, whereas at Ikpikpuk 1 it is within zone 16 or older.

3. A low-angle unconformity occurs below the Wahoo Limestone south of Inigok 1. Toward the northwest, the Wahoo overlies the Alapah Limestone and Endicott Group. The Alapah is probably much thicker in the Umiat Basin than elsewhere on the cross section, and a part of it may be correlatable with the Wachsmuth Limestone, which was not identified in any NPRA well. The sub-Wahoo unconformity is not obvious in the seismic sections, because the Wahoo and Alapah are both carbonates and have similar physical properties.

4. The Echooka Formation onlaps the basement just northwest of South Simpson 1. It is overlapped by the Ivishak Formation, which in turn onlaps the basement between South Simpson 1 and Simpson 1. The "Ivishak sandstone" member of the Ivishak Formation becomes siltier toward the southeast.

5. The Shublik Formation and Sag River Sandstone lap out on the Barrow High. The Sag River is represented in the Barrow area by an equivalent unnamed siltstone.

6. The "Barrow sandstone," which lies on top of the Shublik-Sag River siltstone equivalent in the Barrow area, is the main reservoir in the Barrow gas fields.

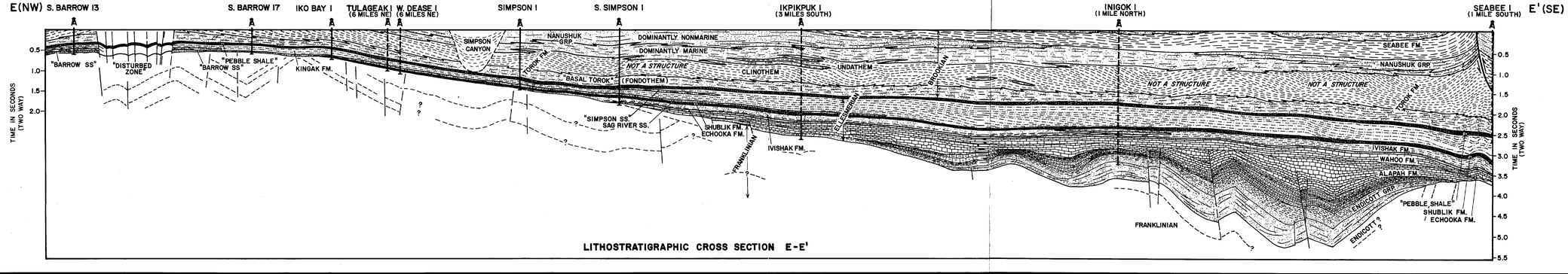
7. The "Upper Kingak" and "Lower Kingak" consist mainly of shale and siltstone, with the exception of the "Barrow sandstone."

8. The "Pebble Shale" truncates progressively older Jurassic rocks toward the northwest. On the Barrow High, the "Pebble Shale" overlies the "Lower Kingak."

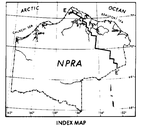
9. The Torok Formation is a prograding deposit. The undathem, clinothem, and fondothem ("basal Torok") correspond to the shelf, slope, and basin, respectively. This line is nearly along the depositional strike of the Torok-Nanushuk sequence. The shelf and slope intervals are composed mostly of shale, and the basin interval is interbedded shale, siltstone, and silty sandstone. Several of the interbedded sandstones are probably turbidites.

10. The Nanushuk Group consists of the dominantly marine Grandstand Formation and the mostly nonmarine Chandler Formation in all wells except Inigok 1; only the Grandstand Formation was identified at Inigok 1, according to Molenaar (1979).

11. The Colville Group (Seabee and Schrader Bluff Formations) is restricted to the southeast of Ikpikpuk 1. The Colville, which was eroded from the crest of the Umiat structure because of uplift, is a thinner replica of the Torok-Nanushuk sequence. The depositional pattern of the Seabee Formation is similar to that of the Torok clinothem and undathem, whereas the Schrader Bluff is similar to the Nanushuk nonmarine beds.



LITHOSTRATIGRAPHIC CROSS SECTION E-E'



INDEX MAP

TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

LITHOSTRATIGRAPHIC CROSS SECTION E-E'
SOUTH BARROW 13 - SEABEE I

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. N. BRUNDEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULDENDORF		REVISED: DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200 — FIGURE 18

T62-0170

FIGURE 19

PARASTRATIGRAPHIC CROSS SECTION E-E',
SOUTH BARROW 13 TO SEABEE 1

Features of interest, from the bottom upward and from the northwest (left) to the southeast (right), are:

1. Structures below horizon 1500 in the "Acoustic basement" are inferred. According to Carter and Laufeld (1975), the basement is Ordovician-Silurian in the Barrow area. Inferred bedding and dip changes indicate that the metasedimentary rocks comprising the "Acoustic basement" southeast of the Barrow High may be younger than unit O-S. Southeast of Ikpikpuk 1, horizon 1500 is probably within unit M-1. The reflectors below horizon 1500 are probably from the M-1 unit, but may be as old as Devonian.

2. Progressively younger rocks lap onto basement rocks from the southeast toward the northwest. The onlap sequence is: M-1 and P-1 between Ikpikpuk 1 and South Simpson 1, PR just northwest of South Simpson 1, TR-1 and TR-2 just northwest of Simpson 1, and TR-3 and J-1 just southeast of South Barrow 13. Between Ikpikpuk 1 and South Simpson 1, P-1 truncates M-2.

3. Horizon 1300, which underlies the P-1 unit, is a regional angular unconformity that is not clearly defined seismically. Horizon 1100 is near the top of the P or PR units across the section.

4. Unit TR-3 is defined by a prominent reflector doublet, which is traceable across the section. Northwest of Inigok 1, horizon 1000 (top of the Triassic) is near the top of unit TR-3. Southeast of Inigok 1, the overlying J-1 unit is thin or absent and horizon 0900 (mid-Jurassic unconformity) is near the top of TR-3. Horizon 1040 ("basal Shublik"(?)) is near the base of TR-3.

5. Horizon 0900 downlaps onto and replaces horizon 1000 toward the southeast. The underlying J-1 unit thins to the southeast and is below the limit of seismic resolution.

6. Unit J-3, which overlies horizon 0900, is truncated by the Ka-1b unit northwest of South Simpson 1.

FIGURE 19

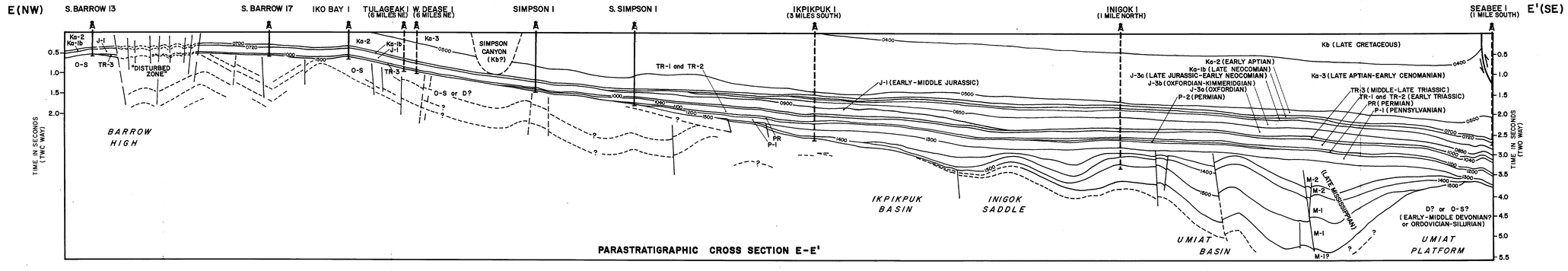
7. Unit Ka-1b is defined by horizon 0700, which is near the top of the unit, and horizon 0720, which is near its base. The 0700 and 0720 horizons form a prominent reflector couplet that is traceable across the section. From southeast to northwest, unit Ka-1b truncates progressively older rocks: units J-3c, J-3b, J-3a, and J-1.

8. Horizon 0500 (mid-Aptian(?)) is near the boundary between units Ka-2 and Ka-3. The horizon downlaps toward the northeast, away from the line of this section, onto horizon 0700. Horizon 0500 was not mapped in detail.

9. Horizon 0400 (mid-Cenomanian unconformity) is near the boundary between Ka-3 and Kb. This horizon is not as prominent as several stronger events within Ka-3, however, horizon 0400 is continuously traceable from just northwest of Seabee 1 to Ikpikpuk 1.

10. The Barrow High was uplifted in post-Early Cretaceous time. Progressively younger strata occur below surface beds from the crest of the Barrow High toward the southeast. Units subcropping beneath surface deposits are, northwest to southeast, Ka-2 in the Barrow area, Ka-3 southeast of Iko Bay 1 to Ikpikpuk 1 (except for the Dease Inlet), Kb from Ikpikpuk 1 to just northwest of Seabee 1, and Ka-3 at Seabee 1. Unit Ka-3 was pushed to the surface by thrust faulting. The Umiat field is located on top of a rollover produced by the thrust fault.

11. The South and East Barrow gas fields are located on the sides of the "Disturbed Zone," a prominent structure on the Barrow High. Because this chaotic feature has a complex internal structure, few seismic horizons can be traced confidently from one side of the "Disturbed Zone" to the other. The Simpson oil seeps emanate from the edge of Simpson canyon, a trough presumed to be a submarine canyon cut during mid-Cretaceous time; according to Robinson (1959), the canyon is filled with Late Cretaceous strata.



PARASTRATIGRAPHIC CROSS SECTION E-E'

TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA, 1974-1980 (FINAL REPORT)

PARASTRATIGRAPHIC CROSS SECTION E-E'
SOUTH BARROW 13 - SEABEE 1

NPR — ALASKA

FOR

ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. W. BRUNZEEL	PROJECT NO. TC-7174
INTERPRETATION BY: J. GALENDOPF	DATE / REVISION
DATE: JUNE, 1981	DATUM: SEA LEVEL
CONTOUR INT.	SCALE:
	DWG NO.

TETRA TECH REPORT NO. 8200

FIGURE 19

TG-2-0170

FIGURE 20

COMPRESSED SEISMIC CROSS SECTION E-E', SOUTH BARROW 13 TO SEABEE 1

Compressed seismic cross section E-E' is a northwest-to-southeast section starting at South Barrow 13 and ending at Seabee 1. This section ties the Barrow area and Simpson Peninsula to the Ikpikpuk and Umiat Basins and the Umiat Platform.

The seismic line segments form a "stair-step" pattern in map view (see index map, fig. 3). Abrupt changes in dip occur at seismic line intersections B10-78 and 657-79, B11-78 and B5-78, B5-78 and B12-78, B7-78 and B11-78, 42-74 and 41-74, 41-74 and 38-74, 38-74 and 36-74, 36-74 and 26-74, 26-74 and 3-74, 3X-75 and 58-75, 58-75 and 17X-75, 17X-75 and 59XW-75, 59XW-75 and 25X-75, 25X-75 and 81-77, and 81-77 and 79-77. A number of "pseudostructures" caused by line direction changes are shown on the right side of the section between 0.5 and 2.0 seconds. Features of interest are:

1. Indications of structure below "Acoustic basement" are good to poor. Faint indications of bedding and numerous refractions indicating probable faulting are beneath the Barrow High to the northwest. To the southeast, a series of good parallel reflectors below "Acoustic basement" are probably a continuation of the bedded sedimentary section above "Acoustic basement."

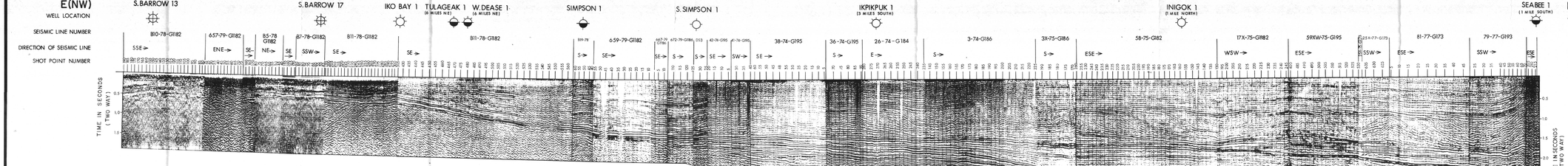
2. The "Disturbed Zone" is crossed just southeast of South Barrow 13, beginning on line B11-78. Very few reflectors can be traced across this feature.

3. Mud-gun data are represented by a "washed-out" zone near the right end of line B-11 over Dease Inlet. Even though the data are poor, some of the deeper continuous reflectors are more obvious on this compressed section than on conventional seismic sections. The higher reflectors are terminated on the flanks of the Simpson canyon.

4. The Umiat structure near Seabee 1 is a large anticlinal and thrust-fault complex that affects the post-Neocomian (Torok and younger) strata. The Umiat oil field is on the axis of this complex.

5. Basement tectonic elements on this section are the Barrow High, Ikpikpuk Basin southeast of Ikpikpuk 1, Inigok Saddle between Ikpikpuk 1 and Inigok 1, Umiat Basin between Inigok 1 and Seabee 1, and Umiat Platform near Seabee 1.

FIGURE 20



COMPRESSED SEISMIC CROSS SECTION E-E'

INDEX MAP

TETRA TECH, INC.
HOUSTON TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

COMPRESSED
SEISMIC CROSS SECTION E-E'
SOUTH BARROW 13 - SEABEE 1

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. W. BRIENZELL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GUDENZOFF, K. CLARY		REVISED DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

TG2-0170

FIGURE 20

FIGURE 21

CORRELATION CROSS SECTION F-F',
J. W. DALTON 1 TO SEABEE 1

Cross section F-F' includes J. W. Dalton 1, East Teshekpuk 1, North Inigok 1, Inigok 1, and Seabee 1. Datum is sea level. The main geologic features shown are:

1. Only one well, J. W. Dalton 1, reached the Ordovician-Silurian ("Argillite") unit or basement rock. The stratigraphic relationships shown below unit TR-3a (Shublik Formation) at North Inigok 1 and below unit Ka-1b ("Pebble Shale") at Seabee 1 are based on seismic-stratigraphic analysis.

2. The Late Mississippian M-1 (Endicott Group) and M-2 (Alapah Limestone) lap out against the Fish Creek Platform. M-1, as indicated by seismic data, overlies the basement at North Inigok 1 and Inigok 1, and laps out between North Inigok 1 and East Teshekpuk 1; an isolated erosional remnant of M-1 is preserved north of the Fish Creek Platform at J. W. Dalton 1. At East Teshekpuk 1, the basement is overlain by unit M-2, which laps out between East Teshekpuk 1 and J. W. Dalton 1.

3. Unit J-1 ("Lower Kingak") is thickest at East Teshekpuk 1. At J. W. Dalton 1, unit J-1 is absent because of truncation by the basal "Pebble Shale" unconformity. South of the Barrow Arch, the mid-Jurassic unconformity truncates the J-1. At North Inigok 1 and Inigok 1, only J-1a is present.

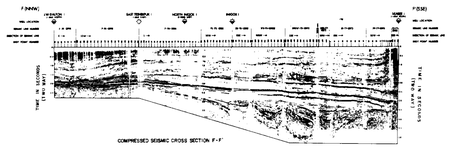
4. The basal "Pebble Shale" unconformity truncates J-3 ("Upper Kingak"). At North Inigok 1, Inigok 1, and Seabee 1, J-3c is below the unconformity. Ka-1a may be present below Ka-1b at Seabee 1; however, the quality of the log, paleontologic, and seismic data is insufficient to separate Ka-1a from J-3c. J-3b and J-3c are truncated completely across the Fish Creek Platform. At East Teshekpuk 1, J-3a lies just below the basal "Pebble Shale" unconformity.

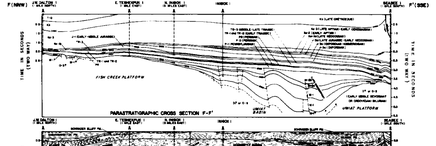
5. Torok fondothem (bottomset) beds, within the time-transgressive Ka-3 unit (Torok-Nanushuk), are just above the basal "Pebble Shale" unconformity at J. W. Dalton 1, East Teshekpuk 1, and North Inigok 1. At Inigok 1 and Seabee 1, Torok fondothem beds within Ka-2 are above the unconformity.

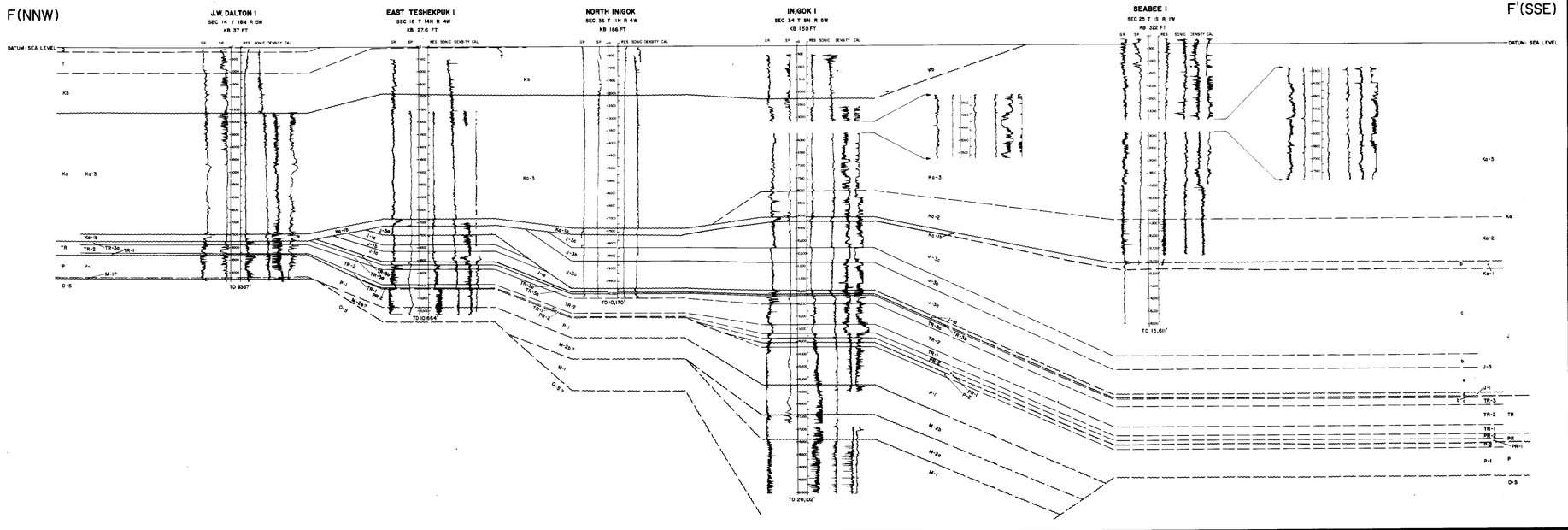
6. The mid-Cenomanian unconformity truncates unit Ka-3. Kb (Colville Group) strata are present above the mid-Cenomanian unconformity at J. W. Dalton 1, East Teshekpuk 1, North Inigok 1, and Inigok 1. The mid-Cenomanian unconformity is absent at Seabee 1 where Nanushuk nonmarine beds within Ka-3 are present at the surface.

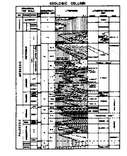
7. At J. W. Dalton 1, Quaternary surface beds overlie Tertiary beds. At East Teshekpuk 1, unit Q overlies unit Kb. At North Inigok 1 and Inigok 1, Kb is near the surface.

FIGURE 21









NO HORIZONTAL SCALE

TETRA TECH, INC.
ENERGY MANAGEMENT DIVISION
PETROLEUM EXPLORATION OF NPRA 1976-1981 FINAL REPORT

CORRELATION CROSS SECTION F-F'
J.W. DALTON I - SEABEE I

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. A. SPUTHCORL		PROJECT NO. 10-1174	
INTERPRETATION BY: L. BERNER, C. HOBBS		DATE: 1981	SCALE: NONE
DATE: JUNE, 1981	DATUM: SEA LEVEL		
DRAFTING BY: BERNIE LANG		DRAWN BY:	

TETRA TECH REPORT NO. 5200

FIGURE 21

TT-0130

FIGURE 22

FIGURE 22

LITHOSTRATIGRAPHIC CROSS SECTION F-F',
J. W. DALTON 1 TO SEABEE 1

Features of interest, starting at the bottom of the section upward and from the northwest (left) to the southeast (right), are:

1. Only J. W. Dalton 1 penetrated the "Argillite." Inigok 1 was drilled into the Endicott Group. North Inigok 1, East Teshekpuk 1, and Seabee 1 bottomed above the projected basement.

2. The Endicott Group in Inigok 1 consists of a relatively thin shale and thick sandstone, coal, and siltstone sequence. At J. W. Dalton 1, conformably interbedded red siltstones and sandstones (Pennsylvanian) underlie the Wahoo Limestone of the Lisburne Group. This Endicott sequence is probably part of a time-transgressive, basal clastic facies of the Lisburne that may be continuous with the Endicott Group in the Umiat Basin.

3. The Wahoo truncates the Alapah Limestone and the Endicott Group with a low-angle unconformity. The Alapah is probably much thicker in the Umiat Basin. A part of the added section may correlate with the Wachsmuth Limestone, which has not yet been identified in any well drilled in the NPRA. The sub-Wahoo unconformity is not obvious in the seismic section because the Wahoo and Alapah have similar carbonate properties.

4. North of the Fish Creek Platform, the Ivishak Formation overlies the Echooka Formation and the upper part of the Wahoo Limestone. The "Ivishak sandstone" member of the Ivishak Formation becomes siltier toward the south and probably grades into siltstone south of Inigok 1.

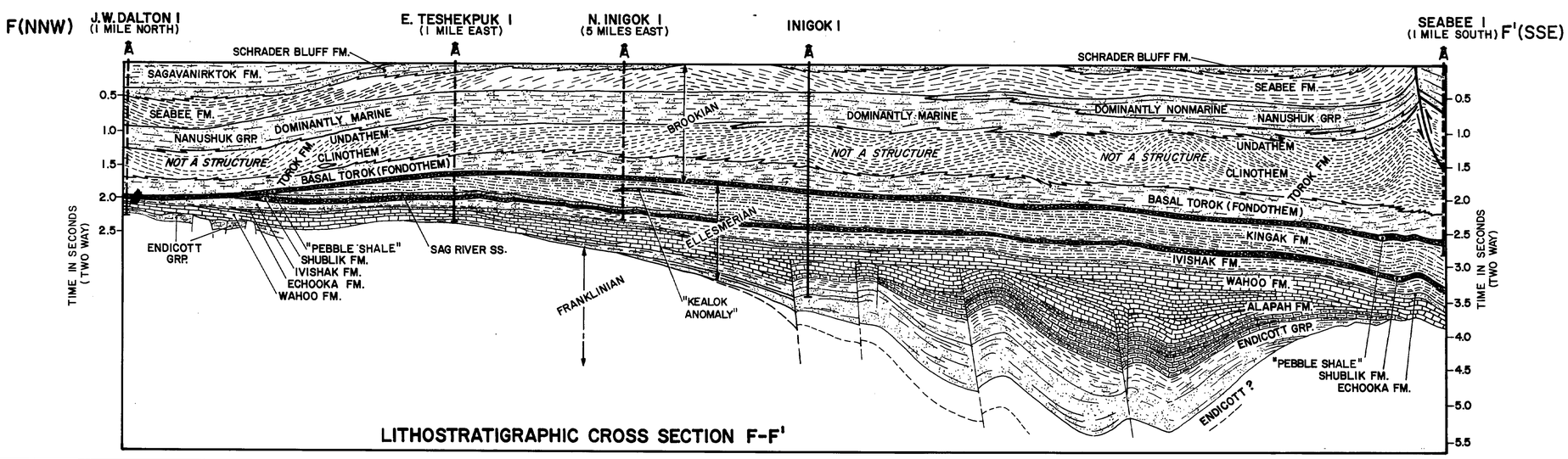
5. The Sag River Sandstone and underlying Shublik Formation are truncated toward the north by the "Pebble Shale." The Sag River grades into shale toward the south.

6. The Kingak Formation consists mainly of shale and siltstone, both the "Upper Kingak" and "Lower Kingak."

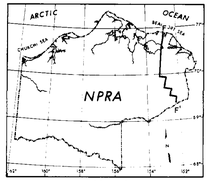
7. The "Pebble Shale" contains the distinctive "Gamma Ray Shale" zone in all wells in the cross section. The basal "Pebble Shale" sandstone is present at J. W. Dalton 1, East Teshekpuk 1, and Inigok 1. The "Pebble Shale" truncates progressively older formations toward the north.

8. The Torok Formation is a prograding shelf-slope-basin sequence that is progressively older toward the source area to the south. The shelf (undathem) and slope (clinothem) intervals are composed mostly of shale. The basin (fondothem), or "basal Torok," sequence consists of interbedded shale, siltstone, and silty sandstone. Several of the interbedded sandstones are probably turbidites.

9. The Nanushuk Group consists of the mostly nonmarine Grandstand Formation in all of the wells except Seabee 1. The mostly nonmarine Chandler Formation may be present between Inigok 1 and Seabee 1, according to Molenaar (1981).



LITHOSTRATIGRAPHIC CROSS SECTION F-F'



INDEX MAP

TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

LITHOSTRATIGRAPHIC CROSS SECTION F-F'
J.W. DALTON 1 - SEABEE I

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUYNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULDENZOPF		REVISED DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200 — FIGURE 22

TG 2-0170

FIGURE 23

FIGURE 23

PARASTRATIGRAPHIC CROSS SECTION F-F',
J. W. DALTON 1 TO SEABEE 1

Features of interest, starting at the bottom of the section upward and from the north (left) of the section to the south (right), are:

1. Horizon 1500 is "Acoustic basement." On the Fish Creek Platform, unit O-S underlies horizon 1500. A series of discontinuous reflectors between J. W. Dalton 1 and East Teshekpuk 1 may be down-faulted remnants of a formerly more extensive M-1 unit. South of East Teshekpuk 1, horizon 1500 is probably within the M-1 unit.

2. Horizon 1100 is near the top of the P or PR units across the section. Horizon 1300, which underlies the P-1 unit, is a regional angular unconformity that is not clearly defined seismically.

3. Unit TR-3 is defined by a prominent reflector doublet that is traceable across the section. North of Inigok 1, horizon 1000 (top of the Triassic) is near the top of unit TR-3. South of Inigok 1, the overlying J-1 unit is thin or absent, and horizon 0900 (mid-Jurassic unconformity) is near the top of TR-3. Horizon 0740 (Basal Shublik(?)) is near the base of TR-3.

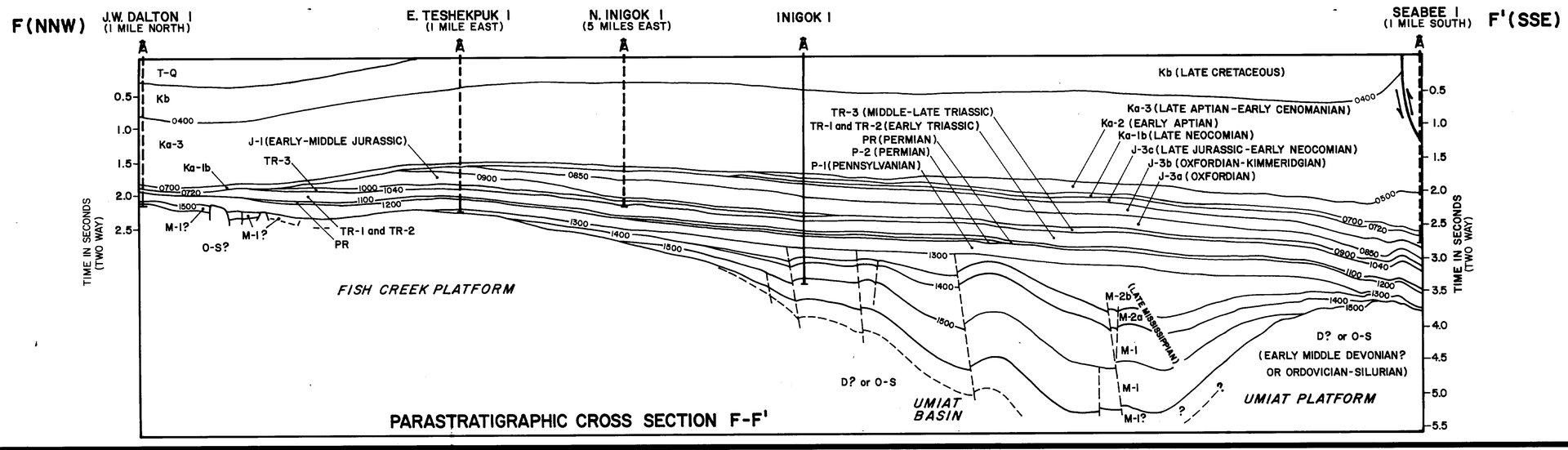
4. Horizon 0900 downlaps onto and replaces horizon 1000 toward the south (left to right). The underlying J-1 unit thins to the south and is below the limit of seismic resolution south of Inigok 1.

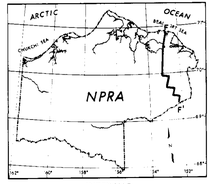
5. The 0700 and 0720 reflectors form a prominent doublet that is traceable across the section. Horizon 0720 truncates progressively older beds toward the north.

6. Horizon 0700 ("Gamma Ray Shale") is near the top of the Ka-1b unit that includes the "Pebble Shale." Horizon 0720 (basal "Pebble Shale" unconformity) is near the bottom of the unit.

7. Horizon 0500 (mid-Aptian(?)) downlaps northward onto horizon 0700 (top of the Ka-1b).

8. Horizon 0400 (mid-Cenomanian unconformity) is near the boundary between the Kb and Ka-3 units. This horizon is not as prominent as several stronger events within Ka-3. Horizon 0400 is traceable continuously from one end of the section to the other.





TETRA TECH, INC.
HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974 - 1981 (FINAL REPORT)

PARASTRATIGRAPHIC CROSS SECTION F-F'
J.W. DALTON I - SEABEE I

NPR — ALASKA

FOR
ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BRUYNZEEL		PROJECT NO. TC-7174
INTERPRETATION BY: C. GULDENZOPF		REVISED: DATE / INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL	
CONTOUR INT:	SCALE:	DWG NO.

TETRA TECH REPORT NO. 8200

TGZ-0170

FIGURE 23

FIGURE 24

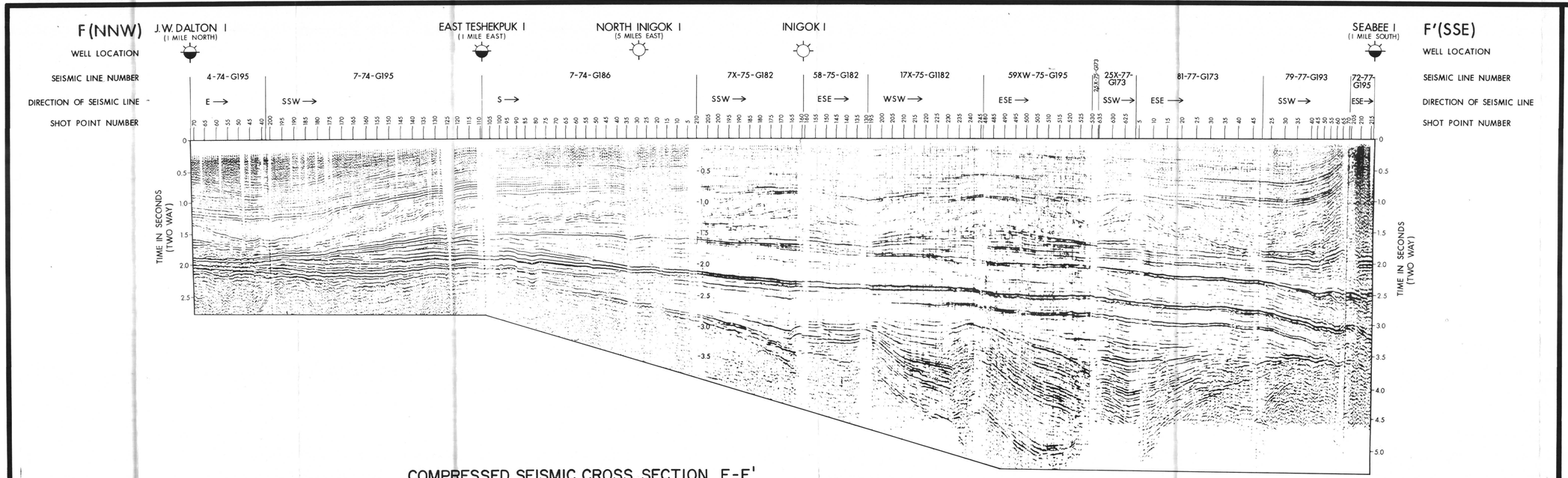
COMPRESSED SEISMIC CROSS SECTION F-F', J. W. DALTON 1 TO SEABEE 1

Cross section F-F' consists of an east-west segment of line 4-74 and north-south portions of lines 7-74 and 7X-75 between J. W. Dalton 1 and Inigok 1. From Inigok 1 to Seabee 1, a series of east-west and north-south segments form a "stair-step" pattern in map view. The lines involved are 58-75, 17X-75, 59XW-75, 25X-77, 81-77, 79-77, and 72-77 (see index map, fig. 3). Right-angle seismic line intersections cause several "pseudostructures" within the Torok clinothem and the Lisburne and Endicott Groups. Features of interest are:

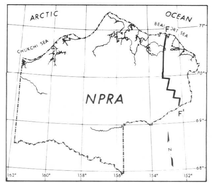
1. The Umiat structure near Seabee 1 is a large anticlinal and thrust-fault complex that affects the post-Neocomian (Torok and younger) strata. The Umiat oil field is on the axis of this complex.

2. Basement tectonic elements shown in this section are the Fish Creek Platform at East Teshekpuk 1, Umiat Basin south of Inigok 1, and Umiat Platform just north of Seabee 1.

FIGURE 24



COMPRESSED SEISMIC CROSS SECTION F-F'



INDEX MAP

TETRA TECH, INC

HOUSTON, TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

COMPRESSED SEISMIC CROSS SECTION F-F'

J.W. DALTON 1 - SEABEE 1

NPR — ALASKA

FOR

ONPRA

HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. W. BRUYNZEEL		PROJECT NO. TC-7174	
INTERPRETATION BY: C. GULDENZOPF, K. CLARY		REVISED	
		DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

FIGURE 24

TG2-0170

FIGURE 25

CORRELATION CROSS SECTION H-H', TUNALIK 1 TO ARCO ITKILLIK RIVER 1

Cross section H-H' includes Tunalik 1, Kaolak 1, Oumalik 1, Koluktak 1, Inigok 1, and Arco Itkillik River 1. Datum is sea level. The main geologic features shown are:

1. Arco Itkillik River 1 is the only well that reached unit O-S ("Argillite") or basement rock. At Kaolak 1 and Koluktak 1, stratigraphic relationships shown below unit Ka-2 are based on seismic-stratigraphic analysis.

2. Unit M-1 (Endicott Group) overlies unit O-S at Arco Itkillik River 1. M-1 laps out against the Oumalik High west of Inigok 1.

3. Unit M-2 (Alapah Limestone) unconformably overlies M-1 at Inigok 1 and Arco Itkillik River 1. Seismic stratigraphy indicates that unit M-2a (Lower Alapah) was truncated by unit M-2b (Upper Alapah). M-2 laps out against the Oumalik High.

4. Unit P-1 (Wahoo Limestone) overlies the basement at Tunalik 1 and laps out against the Oumalik High between Kaolak 1 and Oumalik 1. In the east, P-1 unconformably overlies M-2 at Koluktak 1, Inigok 1, and Arco Itkillik River 1. P-1 and P-2 ("Transition Zone") lap out against the Oumalik High west of Koluktak 1.

5. P-2 and PR-1 (Joe Creek Member of Echooka Formation) lap out to the east against the Colville High.

6. A 745-ft (229-m) thick basalt contained within P-2 at Tunalik 1 is believed to be an extrusive, because the core samples indicate an andesitic flow.

7. At Arco Itkillik River 1, unit PR-2 (Ikiakpaurak Member of Echooka Formation) unconformably overlies P-1.

8. The mid-Jurassic unconformity truncates unit J-1 ("Lower Kingak").

9. Unit J-3 ("Upper Kingak") is truncated by the mid-Neocomian unconformity at Tunalik 1 and Kaolak 1, and by the basal "Pebble Shale" unconformity at Oumalik 1, Koluktak 1, Inigok 1, and Arco Itkillik River 1. At Tunalik 1, the Ka-1a (Valanginian-Hauterivian) part of the "Upper Kingak" unconformably overlies J-3.

10. Unit Ka-1b ("Pebble Shale") unconformably overlies unit Ka-1a at Tunalik 1 and Kaolak 1. In all other wells, Ka-1a unconformably overlies the J-3c part of the "Upper Kingak."

11. The time-transgressive Ka-2 and Ka-3 units lie above the "basal Torok" unconformity. The original regional dip was toward the northeast where the Torok-Nanushuk rocks are younger. At Arco Itkillik River 1, Torok fondothem (bottomset) beds, within Ka-3, probably are present and, in all other wells, Torok fondothem beds within Ka-2 are present.

12. Nanushuk nonmarine beds within Ka-3 are present below the Quaternary surface beds at Tunalik 1 and Kaolak 1. At Oumalik 1, Nanushuk marine beds within Ka-3 are present below unit Q. At Koluktak 1, Nanushuk nonmarine beds within Ka-3 are near the surface. At Inigok 1, unit Kb (Colville Group) is at the surface. Tertiary (unit T) strata are near the surface at Arco Itkillik River 1.

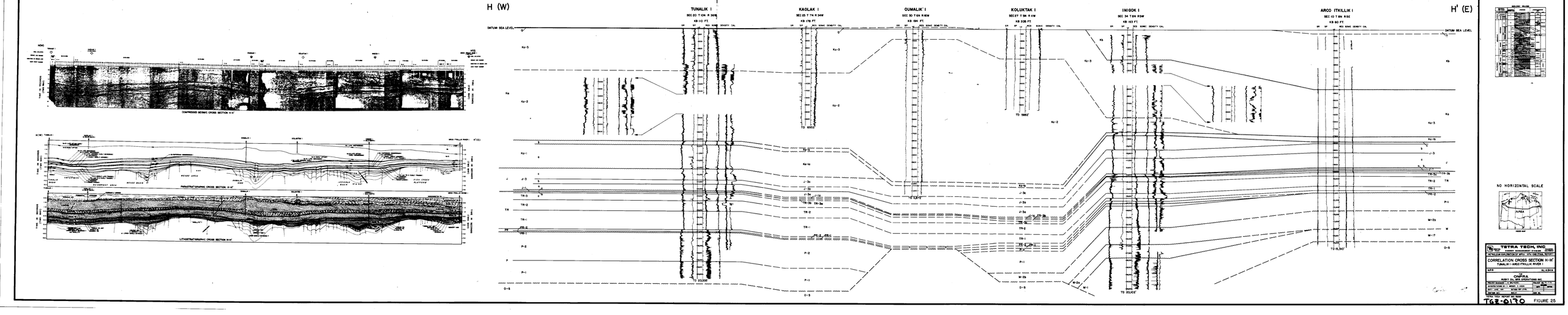

H (W)
H' (E)
TUNALIK I
SEC 20 T 10N R 36W
KB 110 FT.
KAOLAK I
SEC 25 T 7N R 34W
KB 178 FT.
OUMALIK I
SEC 30 T 6N R 16W
KB 194 FT.
KOLUKTAK I
SEC 27 T 5N R 11W
KB 205 FT.
INIGOK I
SEC 34 T 8N R 5W
KB 163 FT.
ARCO ITKILLIK I
SEC 10 T 8N R 5E
KB 60 FT.
DATUM SEA LEVEL
COMPRESSED SEISMIC CROSS SECTION H-H'
PARALETRATIGRAPHIC CROSS SECTION H-H'
LITHOSTRATIGRAPHIC CROSS SECTION H-H'
NO HORIZONTAL SCALE
NPRA
TETRA TECH, INC.
CORRELATION CROSS SECTION H-H'
TUNALIK I-ARCO ITKILLIK RIVER I
NPR
ALASKA
CNPRA
RUSSY-ALASKA OPERATIONS INC.
TETRA TECH REPORT NO. 0130
TG2-0130
FIGURE 25

FIGURE 26

LITHOSTRATIGRAPHIC CROSS SECTION H-H',
TUNALIK 1 TO ARCO ITKILLIK RIVER 1

Features of interest, from the bottom upward and from the left (west) to the right (east), are:

1. In cross section H-H', the only well that reached "Argillite" was Arco Itkillik River 1. The only other well drilled below horizon 1500 was Inigok 1, which bottomed in Endicott Group clastics consisting of a relatively thin shale and thick sandstone, coal, and siltstone sequence.

2. West of the Meade Arch, the Wahoo Limestone of the Lisburne Group probably overlies "Acoustic basement." The Mississippian Alapah Limestone and the Endicott Group were not reached by any of the western wells; however, the Alapah and Endicott may be present in the deeper parts of the Meade and Tunalik Basins west of the Meade Arch as a part of the "Acoustic basement." If complexly folded, faulted, or metamorphosed, the Alapah and Endicott are indistinguishable from the "Argillite" or the Lower-Middle Devonian rocks.

3. A low-angle unconformity that occurs below the Wahoo Limestone truncates the Alapah Limestone and the Endicott Group to the west of Inigok 1. The sub-Wahoo unconformity is not obvious in the seismic section, because the Wahoo and Alapah are both carbonates with similar physical properties.

4. A "Transition Zone," consisting of argillaceous limestone and shale, occurs between the top of the Wahoo Limestone and the overlying Echooka Formation. It is relatively thick west of the Meade Arch, but thins toward the east. The "Transition Zone" and the upper part of the Wahoo Limestone are truncated and overlain by the Echooka Formation toward the east and north.

5. The "Kavik shale" member of the Ivishak Formation is much thicker at Tunalik 1 than at any other location. The "Ivishak sandstone" member of the Ivishak Formation becomes siltier to the west of Inigok 1; at Tunalik 1, the unit is nearly all siltstone.

6. The Shublik Formation is a distinctive marker across the Reserve.

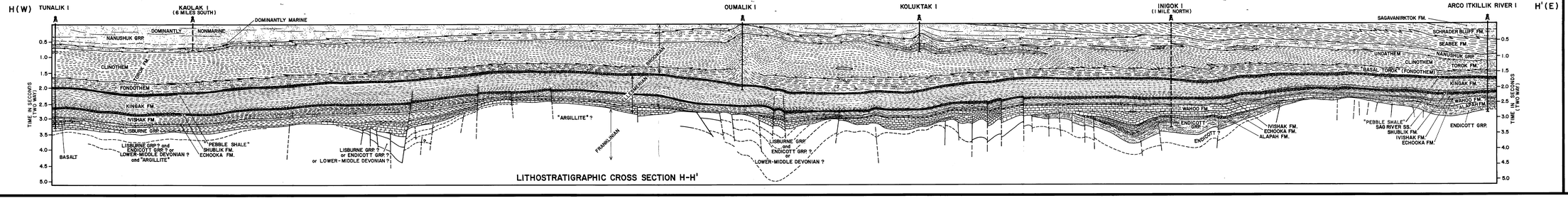
7. The Sag River Sandstone grades into shale to the south and west of the Fish Creek Platform.

8. Potential sandstone reservoirs that probably are present within the Kingak Formation west of the Meade Arch include silty sands below the "Pebble Shale" at Tunalik 1, and several similar lens-like turbidite(?) bodies. East of the Meade Arch, the "Kealok anomaly" on the south flank of the Fish Creek Platform may represent a potential sandstone reservoir. Other sands may be present around the edges of basins.

9. The "Pebble Shale," a distinctive marker all across the section, is composed of gray-to-black organic shale or siltstone. The basal "Pebble Shale" sandstone was absent in the wells included in this cross section.

10. The Torok-Nanushuk sequence progrades toward the east. In a vertical sequence west of the Meade Arch, the Torok fondothem, clinothem, and undathem and the Nanushuk marine and nonmarine beds succeed one another upward. The Nanushuk nonmarine Chandler Formation is absent on the Fish Creek Platform; the Nanushuk marine Grandstand Formation is overlain by shales of the Seabee Formation of the Colville Group.

11. The Colville Group (Seabee and Schrader Bluff Formations) is restricted to the north and east of Koluktak 1 and progrades toward the east. The depositional pattern of the Colville Group is similar to that of the Torok-Nanushuk sequence. The Seabee Formation is similar to the Torok clinothem and undathem, whereas the Schrader Bluff Formation is similar to Nanushuk nonmarine beds.



LITHOSTRATIGRAPHIC CROSS SECTION H-H'

TETRA TECH, INC.

TETRA ENERGY MANAGEMENT DIVISION PASADENA CALIFORNIA

PETROLEUM EXPLORATION OF NPRA, 1974-1985 (7 FIELD REPORTS)

LITHOSTRATIGRAPHIC CROSS SECTION H-H'

TUNALIK I - ARCO ITKILLIK RIVER I

NPR ALASKA

FOR

ONPRA

HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. R. ZILLITTO | PROJECT NO. TC-7776

INTERPRETATION BY: C. GOLDENDORF | DATE REVISED

DATE: JUL 16, 1985 | DATUM: SEA LEVEL

DRAFTER: M.T. | SCALE: 1 INCH = MILE

TETRA TECH REPORT NO. 8200 | FIGURE 26

TG-0140

FIGURE 27

PARASTRATIGRAPHIC CROSS SECTION H-H',
TUNALIK 1 TO ARCO ITKILLIK RIVER 1

Features of interest, from the bottom upward and from the west (left) to the east (right), are:

1. Reflectors below "Acoustic basement" (horizon 1500), probably generated from sedimentary or metasedimentary rocks, are shown at Tunalik 1 and in the Meade Basin, Oumalik High, and Ikpikpuk Basin. At Inigok 1, the rocks that generate the seismic reflectors from "Acoustic basement" are of the same age and composition as the overlying M-1 unit. Elsewhere, parallel reflectors from the "Acoustic basement" may be from rocks in the O-S, D, or M-1 and M-2 units.

2. The Oumalik High may be a synclinorium that is the axis of a pre-Pennsylvanian geosyncline. It is not known whether these rocks were deformed at the same time as unit O-S (Franklinian Orogeny) or later in a separate orogeny. Geologic studies in the Brooks Range suggest that these rocks were deformed during Devonian time.

3. The Meade Basin is shown especially well in this section. The eastern margin of the basin is defined by a high-angle fault dipping to the west. Estimates of the amount of throw of the fault depend on the correlation of seismic events across the Meade Arch. As defined here, horizon 1500 was displaced by about 0.5 seconds. If poor reflectors below horizon 1500 on the east side of the fault are correlative to reflectors in the basin, as is suggested in the section, the displacement is relatively small.

4. Horizon 1400 is near the boundary between units M-1 and M-2. The M-1 unit onlaps the Oumalik High and Fish Creek Platform to the west and east of Inigok 1, respectively.

5. Horizon 1300, which is near the boundary between units M-2 and P-1, is a regional angular unconformity that is not clearly defined seismically. P-1 truncates M-2 on the Oumalik High and on the Fish Creek Platform. M-2 or M-1 may be preserved in the deepest part of the Meade Basin; elsewhere, M-1 and M-2 are not identified west of the Meade Arch-Oumalik High trend, either by drilling or by seismic stratigraphy. M-1 is truncated by M-2, and both are truncated by P-1. This indicates continued uplift of the arches and subsidence of the basins into Late Mississippian time, and probably represents epeirogenic uplift that followed an earlier orogeny. Geologic studies in the Brooks Range suggest the orogeny took place during Devonian time.

6. West of the Meade Arch, the oldest rocks identified above "Acoustic basement" are units P-1 and P-2 (Pennsylvanian to Permian). The P-2 unit overlaps P-1 and is continuous over both positive elements. P-2 is relatively thinner over the Meade Arch. To the east of the Meade Arch, P-2 thins and laps out against the Oumalik High. On the Fish Creek Platform, the PR unit directly overlies P-1. Horizon 1100 is near the top of units P or PR across the section.

7. Units PR, TR-1, TR-2, and TR-3 are continuous across the section.

8. Unit TR-3 is defined by a prominent reflector doublet that is traceable across the section. Horizon 1040 (Basal Shublik(?)) is near the base of TR-3, and horizon 1000 is mainly near the top of TR-3. However, near Inigok 1, the top of TR-3 is defined by horizon 0900 (mid-Jurassic unconformity) that downlaps onto the TR-3 unit from the north, behind the plane of the section. The J-1 unit that normally overlies TR-3 is thin or absent where horizon 0900 is near the top of TR-3, and the J-3 unit either may directly overlie TR-3 or a very thin J-1 interval.

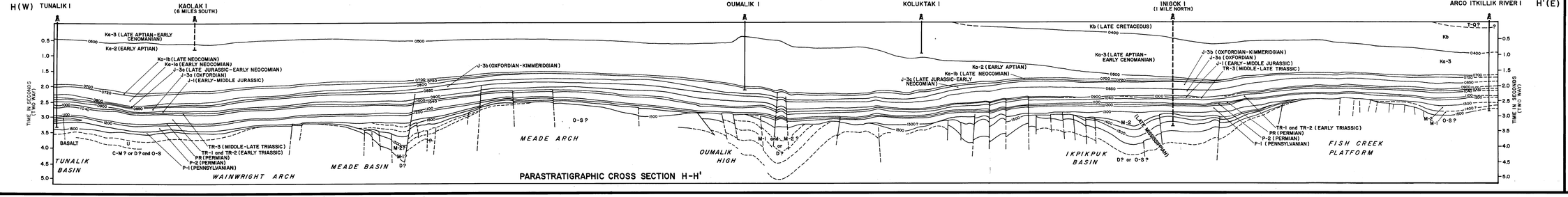
9. Unit J-1 is relatively thin to absent over the length of the section. Horizon 0900 downlaps from north to south until J-1 cannot be identified seismically.

10. Units J-3 and Ka-1a are truncated by horizon 0720. From the west toward the east, the horizon truncates progressively older rocks. At Tunalik 1, unit Ka-1a is overlain by horizon 0720 and underlain by horizon 0800. West of the Meade Arch, Ka-1a is truncated; J-3c pinches out just east of Inigok 1; and J-3b becomes thinner because of truncation between Inigok 1 and Arco Itkillik River 1.

11. Unit Ka-1b is defined by horizon 0700, which is near the top of the unit, and by horizon 0720, which is near the base. These horizons form a prominent reflector couplet that is traceable across the section. Toward the east, Ka-1b truncates progressively older rocks.

12. Horizon 0500 (mid-Aptian(?)), near the boundary between units Ka-2 and Ka-3, downlaps toward the east and joins horizon 0700 east of Inigok 1. East of Inigok 1, unit Ka-3 lies directly on unit Ka-1b.

13. Horizon 0400 (mid-Cenomanian unconformity) is near the boundary of units Ka-3 and Kb. The Kb thins and is absent just to the north and east of Koluktak 1, but thickens to the east.



PARASTRATIGRAPHIC CROSS SECTION H-H'

INDEX MAP

TETRA TECH, INC

TETRA TECH ENERGY MANAGEMENT DIVISION PASADENA, CALIFORNIA

PETROLEUM EXPLORATION OF NPRA 1974-1981 (FINAL REPORT)

PARASTRATIGRAPHIC CROSS SECTION H-H'
TUNALIK I-ARCO ITKILLIK RIVER I

NPR ALASKA

ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J.W. BROYLES		PROJECT NO. 80-1774	
INTERPRETATION BY: C. GLADENZOFF		DATE	REVISED
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	SHEET NO.	

TETRA TECH REPORT NO. 8200

FIGURE 27

TGR-0170

FIGURE 28

COMPRESSED SEISMIC CROSS SECTION H-H',
TUNALIK 1 TO ARCO ITKILLIK RIVER 1

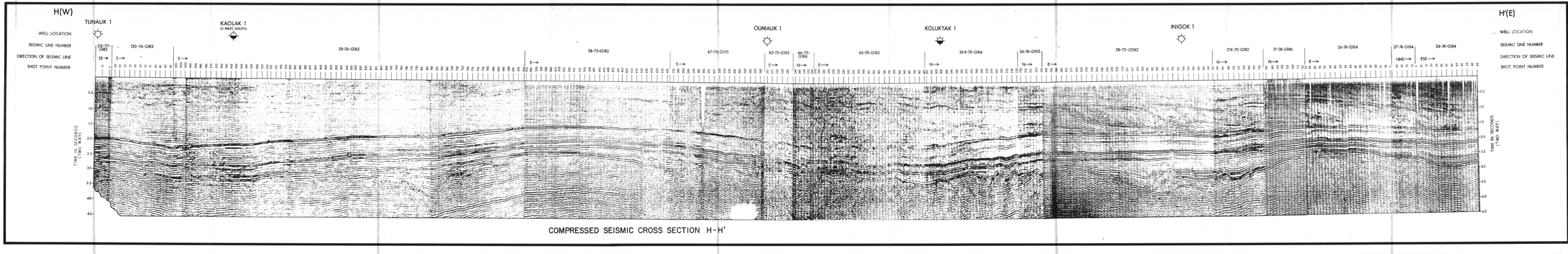
Compressed seismic cross section H-H' crosses the width of the NPRA and ties Tunalik 1 and Inigok 1, which are two of the deepest wells drilled in the Arctic. The section begins at Tunalik 1 and ends on the Colville River about 3 miles west of Arco Itkillik River 1. The quality of the seismic data is good to fair, except in the middle of the section between Oumalik 1 and Koluktak 1 where it is poor. Features of interest are:

1. Dip reversals are seen at seismic line intersections 130-76 and 58-76, 58-75 and 47-75, 47-75 and 62-75, 62-75 and 46-75, and 46-75 and 63-75.

2. Below "Acoustic basement," there is some indication of structure along line 58-76 near Oumalik 1 and between Koluktak 1 and Inigok 1. Most of the basement reflectors in these areas probably are from sedimentary or metasedimentary rocks. Apparent features below "Acoustic basement" in the rest of the section are refractions that probably originate from faults or multiples derived from higher units.

3. At Tunalik 1, a high-velocity basalt layer at about 3.0 seconds masks the strata below it, making it difficult to identify "Acoustic basement" in this area.

4. Basement tectonic elements shown in this section are the Tunalik Basin at Tunalik 1 (on line D2-77 only), Wainwright Arch between Kaolak 1 and Oumalik 1, Meade Arch, Oumalik High at Oumalik 1, Ikpikpuk Basin to the west of Ikpikpuk 1, and Fish Creek Platform between Inigok 1 and Arco Itkillik River 1.



COMPRESSED SEISMIC CROSS SECTION H-H'

TETRA TECH, INC.

REGISTERED TEXAS — ENERGY MANAGEMENT DIVISION — PASADENA CALIFORNIA

PETROLEUM EXPLORATION OF NPR-A (1974-1981 FINAL REPORT)

COMPRESSED
SEISMIC CROSS SECTION H-H'
TUNALIK 1-ARCO ITKILLIK RIVER 1

NPR — ALASKA

ONPRA
HUSKY OIL NPR OPERATIONS INC.

PROJECT MANAGER: J. R. BOUTWELL		PROJECT NO. TC-1174	
INTERPRETATION BY: C. GLIDENZORF, K. GLAPP		REVISED	
		DATE	INITIAL
DATE: JUNE, 1981	DATUM: SEA LEVEL		
CONTOUR INT:	SCALE:	DWG NO.	

TETRA TECH REPORT NO. 8200

T82-0170

FIGURE 28