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Reconnaissance Geology of the Chukchi Platform -

West-Central Chukchi Shelf, Offshore Alaska

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Donald David Jessup

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RECONNAISSANCE GEOLOGY OF THE CHUKCHI PLATFORM - WEST-CENTRAL CHUKCHI SHELF, OFFSHORE ALASKA

by

Donald David Jessup

A THESIS

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DEDICATION

To my parents, Dave and Mary Jessup; without them this project would not have been possible.

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ABSTRACT

RECONNAISSANCE GEOLOGY OF THE CHUKCHI PLATFORM - WEST-CENTRAL CHUKCHI SHELF, OFFSHORE ALASKA

BY

DONALD DAVID JESSUP

Stratigraphic and structural information interpreted from 24-fold seismic reflection data indicate that the Chukchi platform is covered by significantly thinned Eo-Ellesmerian, Ellesmerian, and Lower Brookian strata. Upper Brookian sediment are found in structurally controlled grabens and half grabens. Eo-Ellesmerian and Ellesmerian strata, derived from local sediment sources, fill fault blocks and form localized ponds of sediment in topographic depressions. Ellesmerian strata reach a thickness of 1.5 km west of 171° W. Lower Brookian strata form a 0.3 km. veneer of sediment east of 171° W, but thicken to 3 km in a trough west of 171° W.

Three major episodes of structural activity are recognized on the platform. Pre-Cretaceous normal faults are overprinted by the Herald-Wrangel arch thrust system which ramped onto the Chukchi Platform in mid to late Cretaceous. Regional extension created the latest Cretaceous to late "Paleogene" normal faults (1 km offsets) on the platform.

INTRODUCTION

The Chukchi Shelf, between Wrangel Island and Alaska (Figure 1), forms a remarkably flat surface with broad bathymeteric undulations. Water depths vary from 30 to 50 meters, and reach 90 meters in two isolated depressions east of Herald Island (Figures 2 and 3; Hill et al., in press). Grantz and May (1984b) identify seven major structural provinces on the Chukchi Shelf. These provinces are subsurface features with only slight bathymeteric expressions, with the exception of Herald arch. The Chukchi platform lies on the west-central Chukchi Shelf between North Chukchi basin and Hope basin (Figure 3). The most striking subsurface characteristics of the Chukchi platform are a decrease in thickness of the sedimentary cover, and regionally extensive high angle normal faults with basement offsets of up to 0.9 km.

This study describes the Devonian to Recent depositional history and structural development of the Chukchi platform as interpreted from 24-fold CDP and single-channel seismic reflection data. Emphasis is placed on Cenozoic faulting and sedimentation. Single channel data were

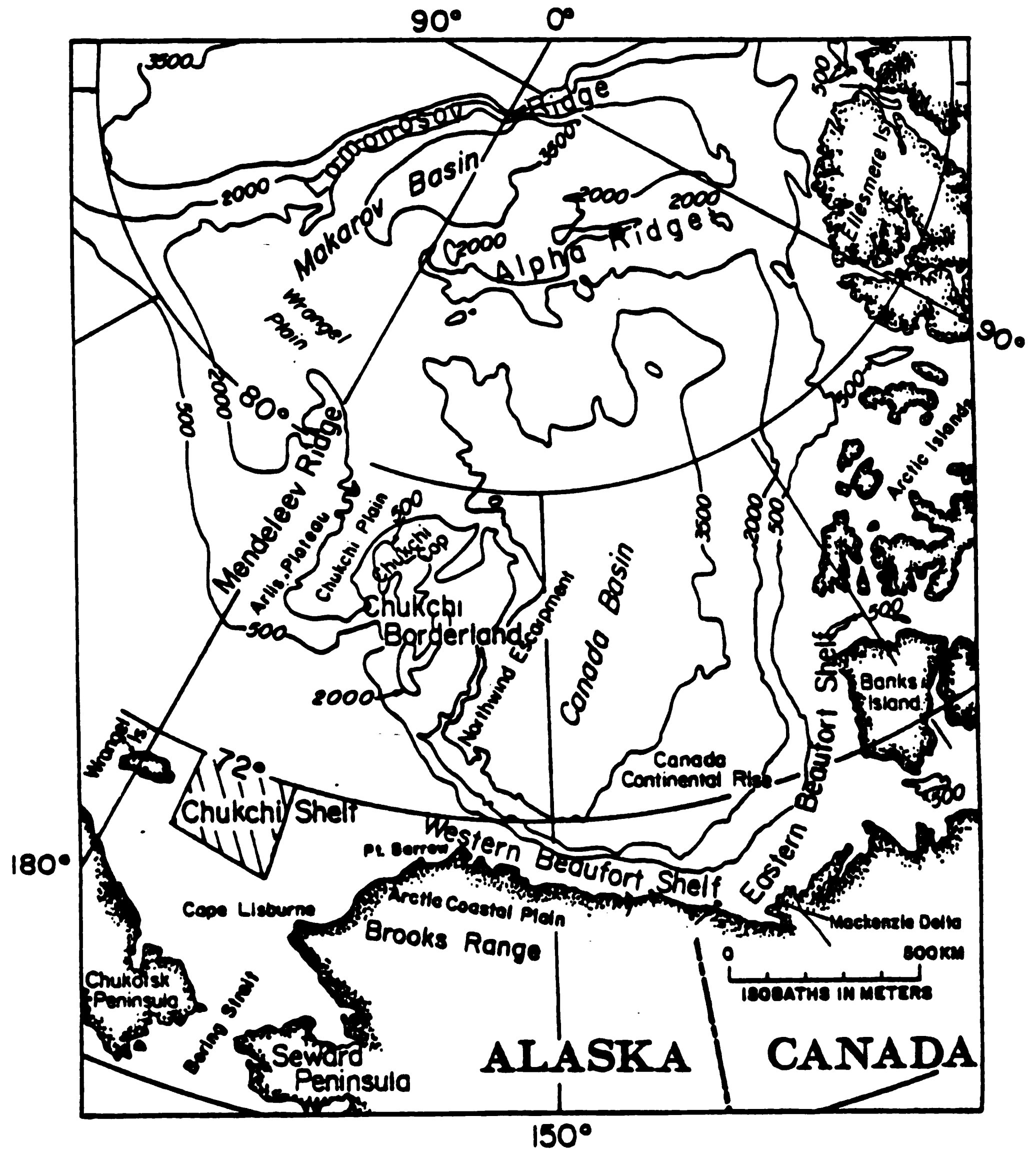

Figure 1 Continental margin north of Alaska and major features of the Arctic Ocean (from Grantz and May, 1983). Hachures identify the approximate boundaries of the study area.

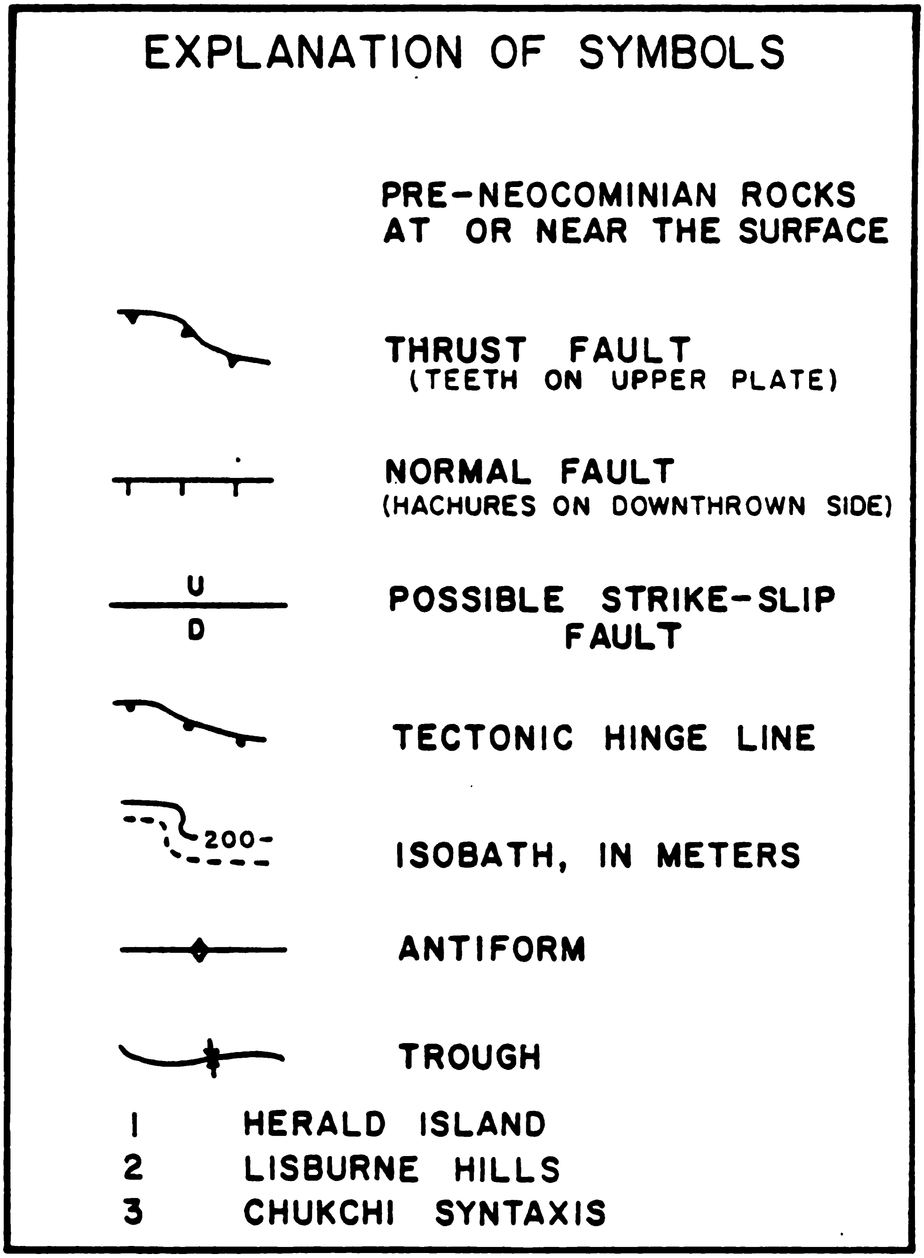

Figure 2 Explanation of map symbols for Figure 3.

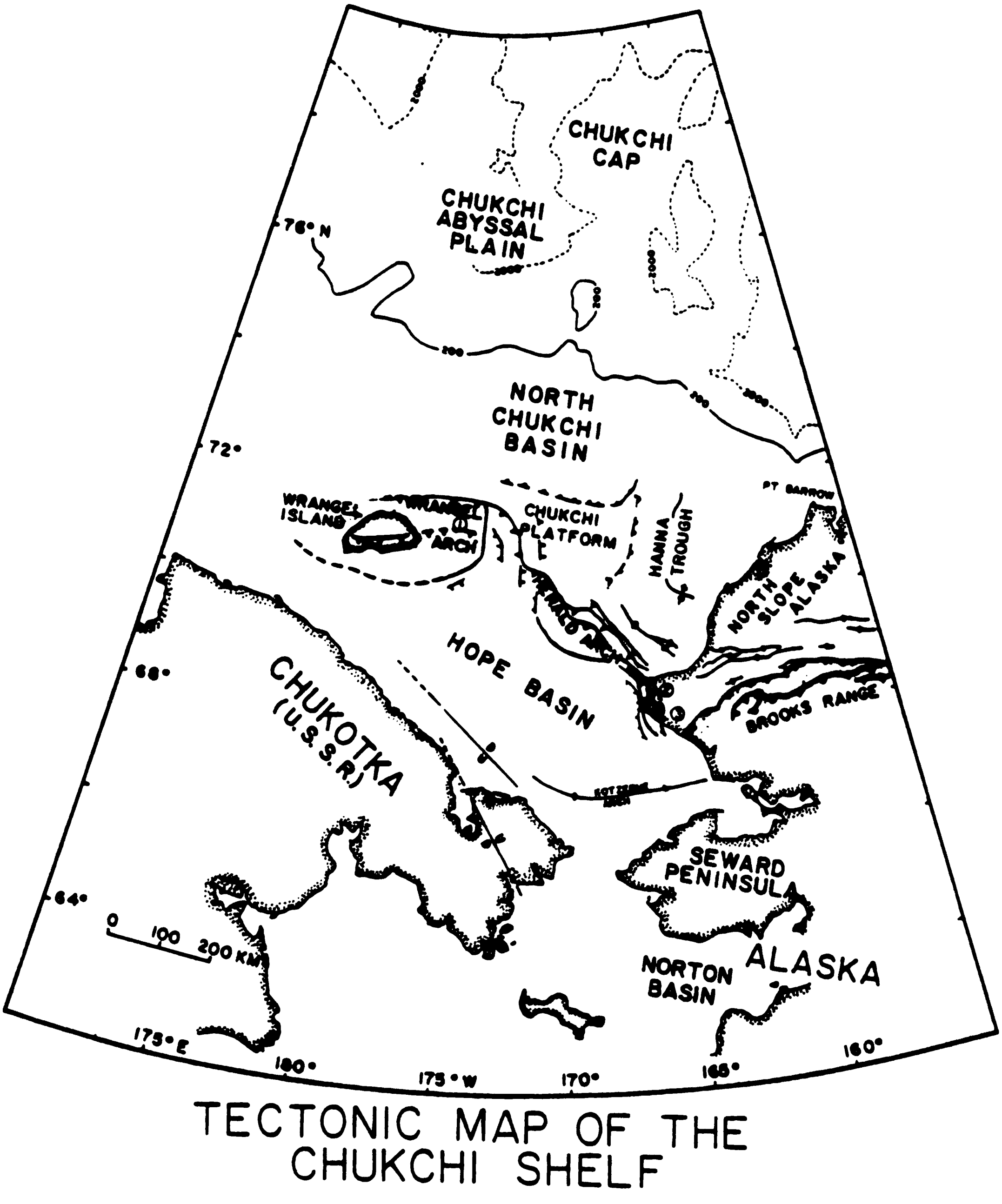

Figure 3 Tectonic map of the Chukchi Shelf and adjacent land areas (modified from Grantz and May, 1984b, and others). 1 - Herald Island, 2 - Lisburne Hills, 3 - Chukchi Syntaxis

collected by the U. S. Geological Survey during the 1969 to 1972 field seasons, and are available as U. S. Geological Survey open-file reports (Grantz and others, 1970, 1971, and 1972). Preliminary processed, 24-fold CDP, seismic reflection data were obtained from the U. S. Geological Survey R/V S. P. Lee during 1978, 1981, and 1982, and are not yet available as a publication. Multichannel data over the study area form a 25 km by 50 km grid of lines west of 171° W, and a 25 km by 25 km grid of lines east of 171° W. When single channel data are included, the grid spacing is essentially cut in half (Figure 4).

Figure 3 illustrates the location of the Chukchi platform in relation to Alaska, Chukotka, and the adjoining geologic features on the Chukchi Shelf. The Chukchi platform is covered by approximately 50 meters of water and is seasonally ice free. Ostenso (1968) refers to the bathymeterically shallowest portion of the later-identified Chukchi platform as "Herald Reef". Herald Reef is marked by a gravity low, which Ostenso (1968) attributes to a granitic pluton at depth. Grantz et al. (1981), refer to the same bathymeteric feature as Herald Shoal. Grantz and May (1984b) note the westward shoaling of pre-Franklinian basement, westward thinning of Ellesmerian and Lower Brookian strata, and numerous high angle normal faults as being a separate geologic province

Figure 4 Map showing the data base of single-channel (dotted lines) and 24-fold CDP (solid lines) seismic reflection profiles over the Chukchi platform region of the Chukchi Shelf.

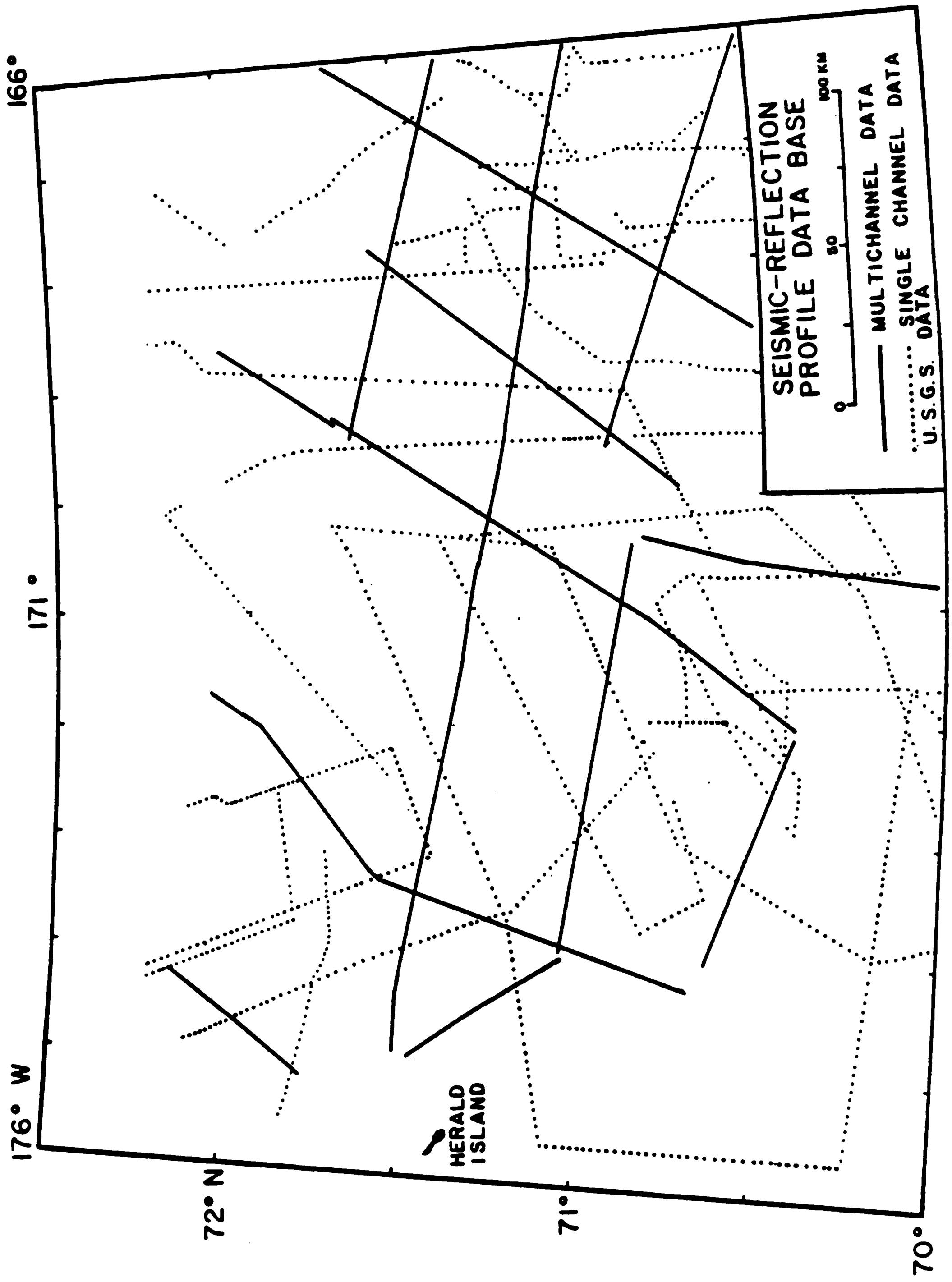
166°
171°
176° W
72° N
71°
70°
HERALD ISLAND
SEISMIC-REFLECTION PROFILE DATA BASE
0
50
100 KM
MULTICHANNEL DATA
SINGLE CHANNEL DATA
U.S.G.S. DATA

Figure 4

on the Chukchi Shelf, which they name the Chukchi platform. The data, observations, and interpretations presented in this study define, in greater detail, the structure and sediment distribution on the Chukchi platform.

REGIONAL GEOLOGIC SETTING

Regional Stratigraphic Framework

The regional stratigraphy currently used on the Chukchi Shelf is best described on the North Slope of Alaska where three major units of differing tectonic significance are identified; the Franklinian, Ellesmerian, and Brookian sequences. These units were first described by Lerand (1973) in the Canadian Arctic Islands, and modified by Grantz et al. (1981, 1982) for use in northern and western Alaska, and the Chukchi Shelf. Figure 5 outlines the stratigraphy used in the North Slope and adjacent Chukchi Shelf.

The Franklinian sequence was originally named for its occurence in the Franklinian geosyncline of the Queen Elizabeth Islands, Canada. In northwestern Alaska the Franklinian sequence consists of strongly deformed and mildly metamorphosed to unmetamorphosed Middle Cambrain to Upper Devonian marine and nonmarine eugeosynclinal sedimentary rocks (Grantz and May, 1983). Grantz and May (1984a) detected seismic reflectors indicating the presence of undeformed

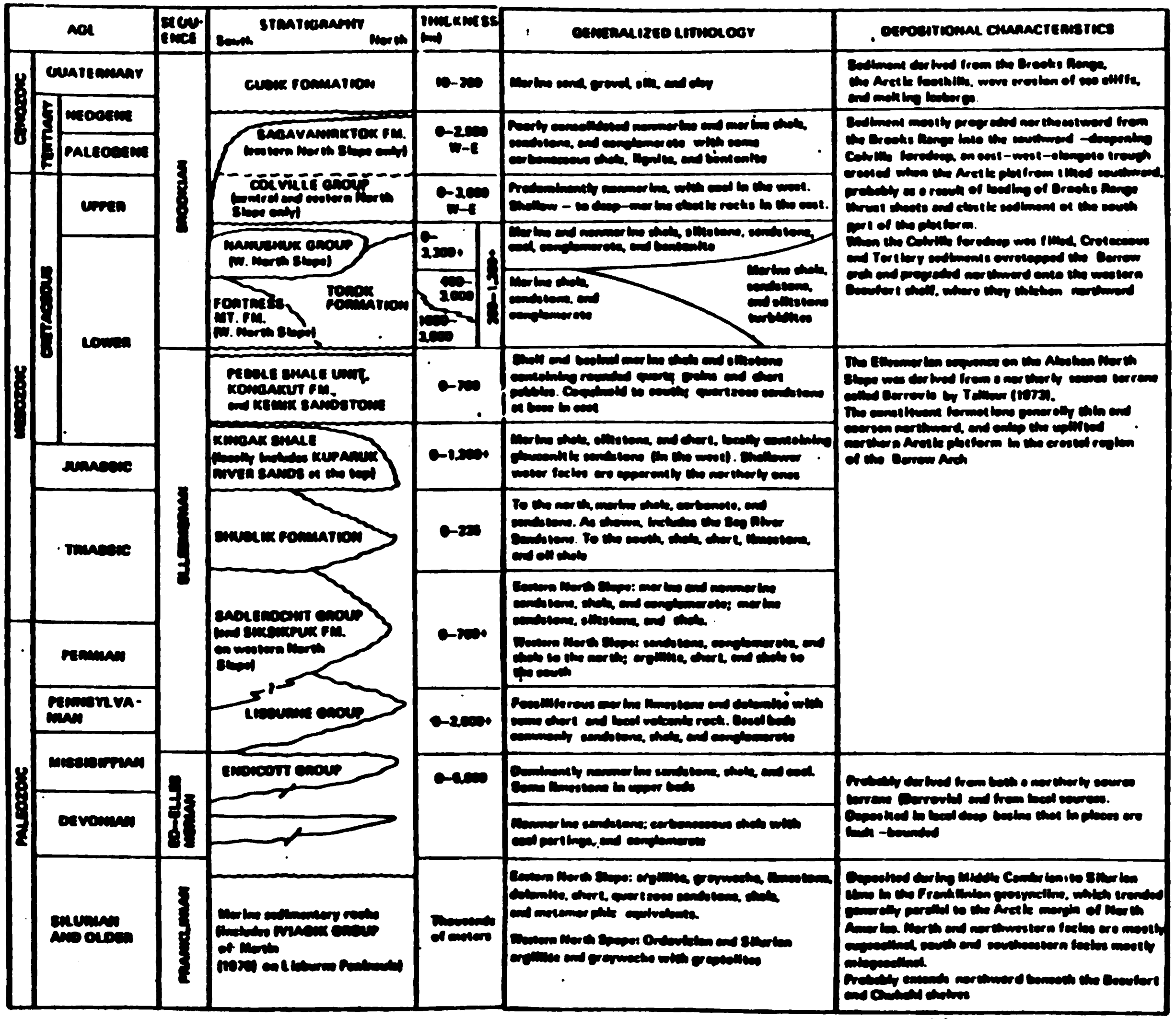

Figure 5   Generalized stratigraphy of northern Alaska and adjacent Continental shelves (from Grantz and May, 1984a).

detected seismic reflectors indicating the presence of undeformed Franklinian rocks on the northern Chukchi Shelf, which project onshore to correlate with Ordovician and Silurian argillites identified by Carter and Laufield (1975) in test wells in northern Alaska. During Late Devonian time the Franklinian sequence was uplifted and exposed to extensive erosion to form the Arctic Platform which is the foundation for all later sediment accumulation in Alaska and the adjacent Chukchi Shelf.

The Mississippian to Neocomian stable shelf clastic and carbonate Ellesmerian sequence was deposited directly on the Franklinian Arctic Platform. Locally, the Ellesmerian sequence is separated from the Franklinian by the so-called Eo-Ellesmerian sequence, which is deposited in structural depressions and downwarps in the Arctic Platform. The Eo-Ellesmerian is dominantly nonmarine and may correlate with rocks of the Endicott group in Alaska (Grantz and May, 1984b). The Ellesmerian sequence overlies the Eo-Ellesmerian sequence with slight unconformity. Rocks younger than the Endicott group, and older than and including the Pebble shale Unit, are generally placed in the Ellesmerian sequence (Grantz and May, 1984b). These rocks are separated from the Brookian sequence because they are derived form a northerly sedimentary source terrane which Tailleur (1973) called Barrovia and is presumed to have occupied the location of the present day Canada Basin. Grantz and May (1984a and b) suggest that the westward thinning of Ellesmerian strata onto the Chukchi platform indicates that an Ellesmerian source may exist to the west, significantly altering the stratigraphy in the Chukchi Platform region.

The onset of uplift and later thrusting in the Brooks Range in Mid-Jurassic (Tailleur and Brosgé, 1970), and the separation of Barrovia from what is now the North Slope of Alaska in Early Jurassic (Grantz and May, 1983), shifted sedimentary provenances to the south, establishing the Brookian tectonic regime (Grantz and May, 1984a). In northern Alaska, the Brookian sequence refers to sediments that are deposited in front of the Brooks Range orogenic belt. Grantz et al. (1982) divide the Brookian sequence into the Lower Brookian and the Upper Brookian sequences. The Upper Brookian sequence is found on the western Chukchi Shelf and beneath the Beaufort Sea. The Lower Brookian sequence consists of latest Jurassic to mid-Cretaceous marine deltaic sediments of the Fortress Mountain and Torok Formations, and nonmarine to shallow marine intradelta deposits of the Nanushuk Group (Grantz et al., 1982). The Lower Brookian Sequence observed in seismic data, beneath the Chukchi Sea, exhibits reflection characteristics generally associated with deltaic deposits (Grantz et al., 1982). Comparision with onshore data suggest ages between Aptian and earliest Upper Cretaceous for this unit (Grantz and May, 1984b). The Upper Brookian sequence found in the western Chukchi Shelf is similar to the Lower Brookian, but is interpreted to be a more regressive unit in North Chukchi basin (Grantz and May, 1984b). The boundary between the Lower and Upper Brookian is an unconformity which marks the constriction of the Brookian depositional area in Laramide (Late Cretaceous) time. These rocks are thought to correlate in time with the Hope basin sequence of Grantz et al. (1981) and Grantz and May (1984b). In general, the Lower Brookian refers to rocks of dominantly Cretaceous age while the Upper Brookian refers to rocks of largely Tertiary age. Since no rocks of Upper Brookian age have been found in northwestern Alaska the age of the Upper Brookian is constrained by its stratigraphic position and relativly low average acoustic velocity, and is therefore tentative (Grantz et al., 1982).

Structural Provinces of the Chukchi Shelf

Four major structural provinces lie adjacent to the Chukchi platform; Hanna trough, North Chukchi basin, Herald arch, and Hope basin (Figure 3) (Grantz et al., 1982). The major structural and sedimentary features of each province will be reviewed as they relate to the Chukchi platform.

For more detailed discussions see Grantz and May (1984a and b) and Grantz et al. (1981,1982). The following summarizes important portions of these works.

East of the Chukchi platform is a major north-trending faulted depression in the Arctic Platform called Hanna trough. Sedimentation began in Early Mississippian time with the accumulation of approximately 1 km of Eo-Ellesmerian strata followed by deposition of 7 to 8 km of Ellesmerian strata (Grantz and May, 1984b). Compared to surrounding areas, the trough contains increased thicknesses of Lower Brookian rocks. West of Hanna Trough, Eo-Ellesmerian, Ellesmerian, and Brookian strata thin by onlap and erosional truncation onto the Chukchi platform (Grantz and May, 1984b). Thick accumulations of Mississippian to Tertiary age strata suggest that Hanna trough has been a major active feature on the Chukchi Shelf since its formation in Middle to Late Devonian time (Grantz and May, 1984b).

The northern edge of the Chukchi platform is outlined by a marked increase in dip of Ellesmerian and Brookian strata, accompanied by a dramatic thickening of Lower and Upper Brookian Sequences into the North Chukchi basin (Grantz and May, 1984b). Models for the formation of North Chukchi basin are dependent on tectonic reconstructions of the Canada

Basin and the origin of the Chukchi Borderland. The most popular models for the origin of the Canada Basin include rifting of Alaska from the Canadian Arctic Islands (Carey, 1958, Tailleur, 1973) around a pole located in the McKenzie Delta (Sweeney, 1981, Grantz and May, 1983) and left-lateral strike-slip along the northern margin of Alaska (Vogt et al., 1982, Jackson and Johnson, 1984, Rowley et al., 1985).

Grantz and May (1983, 1984b, 1985) propose that the North Chukchi basin formed on thinned continental crust by two stages of crustal extension. The first stage of proposed extension may correlate with the Late Neocomian rifting episode which is related to opening of the Canada Basin in this region. A second stage of latest Cretaceous to Tertiary rifting is proposed to explain numerous listric normal faults in the eastern portion of the basin and thickening of Upper Brookian strata (Grantz and May, 1984b). In this model, the North Chukchi basin formed as the Chukchi Borderland rifted northward out of the present location of North Chukchi basin.

Left-lateral movement of the Chukchi Borderland out of the present site of the Beaufort Sea as proposed by Vogt et al. (1982; and others) would force the North Chukchi basin to have pull-apart affinities. The data to prove either model do not exist at this time.

Herald arch is a narrow basement high trending across the Chukchi Shelf from Cape Lisburne to a point west of Wrangel Island (Ostrov Vrangelya) where it is named Wrangel arch (Grantz et al., 1973). The arch connects outcrops of similar Ellesmerian and Franklinian rocks in the Lisburne Hills (Martin, 1970) and on Wrangel Island (Bogdanov and Til'man, 1964, and Kameneva, 1977). This basement high is interpreted to be the upper plate of a large overthrust system that thrusts Lower Brookian, Ellesmerian, and Franklinian rocks northeastward over Lower Brookian rocks of the Colville Foredeep (Grantz and May, 1984b). Motion along the fault is largely reverse slip, but may change from shallow dipping reverse slip near Cape Lisburne to moderate to high angle reverse slip with a strike-slip component west of 169° W (Grantz et al., 1981). Stratigraphic relationships constrain the end of thrusting to be younger than Albian, but older than undisturbed Paleogene strata east of the the Lisburne Hills. Grantz et al. (1981) suggest that Wrangel arch, the possible westward continuation of Herald arch, may cut Paleogene strata. However, evaluation of multichannel seismic data in this study found no indication that thrusting in this region cuts the unconformity at the top of the Lower Brookian Sequence.

Two models exist relating Herald arch to structures in the Brooks

Range. Briefly, the Brooks Range thrust sheets are thought to be formed by southward underthrusting (subduction) of the Arctic Alaska plate (Box, 1983) and detachment of the upper parts of the subducting continental shelf which ended by Albian time (Mayfield et al., 1983). One model, proposed by Tailleur and Brosgé (1970), suggests that the truncation of Brooks Range structures by the northwest-striking Lisburne Hills structures resulted from simple oroclinal bending at the Chukchi Syntaxis (Tailleur and Brosgé, 1970; Figure 3) to its present position. The oroclinal bending model proposes that Herald arch is a westward continuation of the Brooks Range thrusts. A second model proposed by Grantz et al. (1970) suggests that Herald arch may be the leading edge of an easterly directed, younger thrust fault system that crosscuts the Brooks Range thrusts. Both models explain the observed orocline, but the Grantz et al. (1970) model explains structural relations observed in Hope basin and allows features on the Chukchi Shelf to be compared to tectonic interactions in northeast Asia as described Fujita and Newberry (1983).

Resting unconformably on the southward-dipping flank of Herald arch is the latest Cretaceous to Tertiary Hope basin (Grantz et al., 1976). The structure of Hope basin is dominated by high angle normal faulting, irregular basement topography, and a few high angle reverse faults

(Grantz and May, 1984b). Structures forming Hope basin overprint structures forming Herald arch and the Brooks Range, suggesting that the basin developed after the formation of these features (Grantz et al., 1975). The sediment distribution in the eastern portion of Hope basin is controlled by three east to northeast striking basement ridges, the largest being Kotzebue arch. Moving west, across Hope basin, the strike of Kotzebue arch changes gradually from northeast to northwest and becomes less pronounced (Eittreim et al., 1979). The sediment fill is mainly Tertiary in age and overlies acoustic basement of Lower Brookian and Ellesmerian (north) to Precambrian (south) age (Grantz et al., 1975). The sedimentary sequence (time correlative with the Upper Brookian sequence; Grantz et al., 1981) is broken into northward overlapping units of possibly nonmarine rocks with low average acoustic velocities which are separated by a strong regional reflector (Eittreim et al., 1979). The age of this reflector is uncertain, but it is thought to represent the "Paleogene"-"Neogene" boundary. This age is used for discussion purposes only (Eittreim et al., 1979). The combined thickness of "Paleogene" and "Neogene" sediment thin to the west from a maxium of 3.5 km and onlap Herald and Kotzebue arches on the north and south respectively (Eittreim et. al., 1978, 1979).

Seismicity

Very little seismicity has been recorded teleseismically on the Chukchi Shelf. Earthquake activity is more prevelant to the south on Chukotka and Seward Peninsula. The few seismic events which have occured appear to be centered at 68° N, 173° W on the Chukchi Shelf. The best studied event has epicentral coordinates of 67.38° N, 172.57° W, and has a body wave magnitude of 5.2 (Coley, 1983, Fujita et al., 1983). Fujita et al. (1983) propose a left-lateral strike-slip or normal mechanism with the southern block down. The fault plane chosen from the focal mechanism strikes approximately 285°, and is parallel to the major structural trend in Chukotka. The event is interpreted to represent current activity on Kotzebue arch (Fujita et al., 1983).

Wrangel Island

Wrangel Island lies approximately 250 kilometers west of the study area (Figures 1 and 3). Precambrian to Triassic rocks form a central mountain range bounded by relatively flat coastal plains to the north and south. The stratigraphy described on the island is summarized in Figure 6, and in the following paragraphs

The oldest formation on the island is the Gromovian Suite. The Gromovian Suite consists of 2000 meters of amphibolite, epidote-amphibolite, amphibolite-biotite-chlorite, and quartz-biotite-chlorite schist. Intrusive granite porphyry and gabbro diabase are also found in the suite (Kameneva, 1975). Acritarchs and microphytoliths of Middle to Late Riphean age have been identified in the suite (Kameneva and Il'chenko, 1976).

Unconformably overlying the Gromovian suite is the Inkalinskian suite. This suite contains basal metaconglomerates beneath arkosic and quartzo-feldspathic metasandstone, actinolite-epidote-chlorite and quartz-albite-sericite schist metamorphosed to the greenschist facies (Kameneva, 1975). The suite reaches a thickness of up to 800 meters (Kameneva and Il'chenko, 1976). Vendian acritarchs were identified in the suite by Kameneva and Il'chenko (1976).

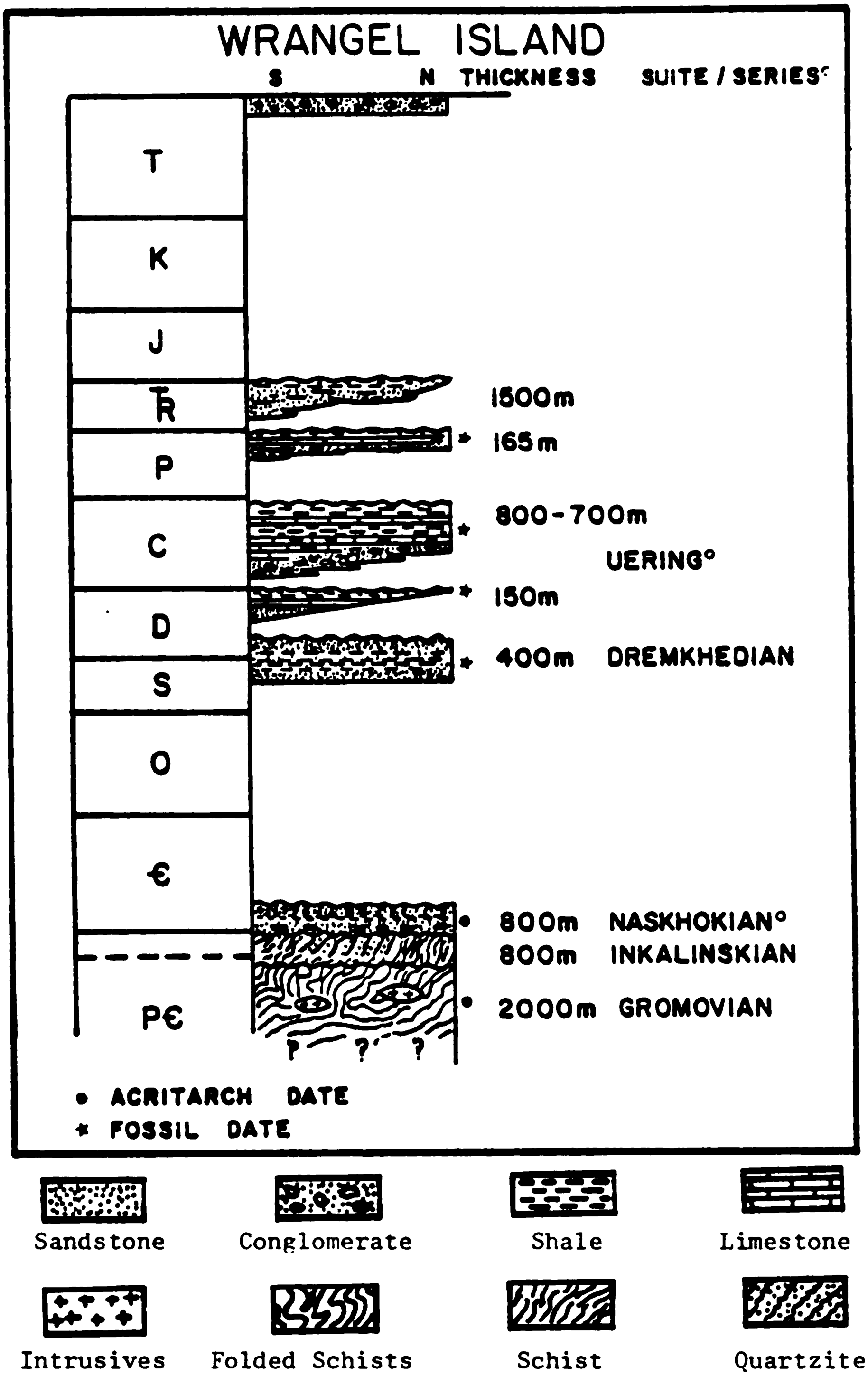

Figure 6 Generalized stratigraphy of Wrangel Island (modified from Churkin et al., 1981).

The Naskhokian series unconformably overlies the Inkalinskian suite. The series is reported to contain 800 meters of conglomerate, phyllite, and quartzite. Kameneva and Il'chenko (1976) identified acritarchs, microphyloliths, and algae of Early Cambrian age within the series.

Unconformably overlying the Naskhokian series is 400 meters of Upper Silurian to Lower Devonian argillite, siltstone, and sandstone (Dremkhedian suite) overlain conformably by Upper Devonian limestone and shale with gypsum seams. The Upper Devonian unit is 150 meters thick (Kameneva, 1975). Numerous Lower Devonian brachiopod, ostracod, byrozoan, coral, and pelecypod fossils are found near the base of this series (Kameneva, 1977). The Silurian to Devonian faunal age and their lower degree of metamorphism, relative to the underlying schists in this outcrop suggest that the sequence may be equivalent to Franklinian deposits on Barrow arch (Grantz et al., 1981) and extrapolated in seismic data beneath the Chukchi Shelf (Grantz and May,1984a and b).

Overlying the Upper Devonian (south) and Lower Cambrian rocks (north) are trangressive interbedded limestones and shales of Carboniferous age (Bogdanov and Til'man, 1964, Kameneva, 1975, 1977). Brachiopods, bryozoans, corals, goniatites, gastropods, chrinoids, nautiloids, trilobites, and pelecypods in algae bioherms, common in the northern part of the island, allow the strata to be assigned an Early Carboniferous age (Kameneva, 1977). The Carboniferous (Bashkirian to early Moscovian) suite is thought to be a conformable and continuous episode of limestone and shale deposition (Bogdanov and Til'man, 1964, Chernyak and Kameneva, 1975, Kameneva, 1977). The entire Carboniferous sequence is 700 meters (north) to 800 meters (south) thick (Kameneva, 1975).

75 meters of Permian conglomerate with quartz-sericite-schist and chert pebbles separate Carboniferous and Permian rocks near the Neizvestnaya River valley. In the Permian sequence, conglomerate underlies interbedded shale and limestone which becomes predominantly shale higher in the suite (Chernyak and Kameneva, 1975).

Triassic sediment overlies older strata of various ages (Kameneva, 1977) with a 10 to 20° angular unconformity (Ivanov, 1973). 1 to 1.5 kilometers of Triassic strata in the southern part of the island (Kameneva, 1975). These strata represent a trangressive unit with basal shales, intermediate shale and sandstone, and a sandstone cap (Ivanov, 1973, Bogdanov and Til'man, 1964, Kameneva, 1977). Sedimentary rocks overlying the metamorphic complex are very similar, in both lithology and age, to rocks found on the Lisburne Peninsula, Alaska (Bogdanov and

Til'man, 1964).

Structurally, Wrangel Island forms a large nappe-like structure (Fujita and Cook, in preparation) divided into northern and southern sections by the nature of folded structures exhibited in the sedimentary column (Chernyak and Kameneva, 1975). Paleozoic deposits in the southern section are contorted into a system of northward tilted linear folds. Folding is described as "intermediate, closer to holomorphic, with block elements" (Kameneva, 1977). Structures in the northern part of the island are less complicated forming a series of "brachyform" synclines. Folding is described as "close to idiomorphic" (Kameneva, 1977). Separating the northern and southern regions is a large southward imbricated thrust fault, dipping 40 to 50°, to the south thrusting Precambrian crystalline rocks northward over Carboniferous sedimentary rocks (Bogdanov and Til'man, 1964). On the east shore of the island Triassic sediments with steep, commonly overturned, dips are observed near fault zones (Bogdanov and Til'man, 1964). Thus, thrusting is younger than Triassic. A large unconformity separates Triassic and Quaternary alluvial deposits.

Herald Island (Ostrov Geral'd) lies 60 km east of Wrangel Island (Figure 3). The island is composed of leucocratic granite, mylonite, sandstone, phyllite, and quartzose sandstone (Egiazarov, 1970). These rocks are thought to correlate with nearly identical rocks of Precambrian age on Wrangel Island (Egiazarov, 1970). Grantz et al. (1981) report that the granite on the island may be of Jurassic age.

GEOLOGY OF THE CHUKCHI PLATFORM

The Chukchi platform (Figure 3) identified by Grantz and May (1984b) is distinguished by westward shallowing of pre-Franklinian basement, westward overlap of older by younger Ellesmerian and Lower Brookian sequences, and extensive high angle normal faulting. The stratigraphy identified on the platform is directly correlated on seismic sections with the regional stratigraphy used by Grantz and others (Grantz et al., 1981; Grantz and May, 1984) in the North Slope of Alaska, the eastern Chukchi Shelf, and the North Chukchi basin regions. The following discussion of the seismic stratigraphy on the Chukchi platform outlines the geometry of sedimentary accumulations and the potential lithologies suggested by the reflection characteristics observed in the seismic data.

Seismic Stratigraphy

The stratigraphy of the Chukchi platform consists of Franklinian basement overlain by significantly thinned Ellesmerian and Lower Brookian sequences, and a variable thickness of Upper Brookian sequence. These sequences are most likely shallow marine to nonmarine clastic sedimentary rocks, similar to their eastern counterparts. Sediment thicknesses range from 0.2 kilometers up to a maximum of 4.5 kilometers. in grabens and half grabens formed by numerous high angle normal faults crossing the Chukchi platform.

Two major problems are encountered in defining and correlating the stratigraphy across the study area. First, the nearest direct control of the stratigraphy lies 500 kilometers away in test wells near Point Barrow. Grantz et al. (1982) and Grantz and May (1984b, and personal communication) trace seismic reflectors, representing the major stratigraphic subdivisions encountered in these wells (Figure 5), across the eastern Chukchi Shelf onto the Chukchi platform where they are directly adopted for use in this study. The large distances over which these reflectors have been extrapolated force the stratigraphy in the study area to be greatly generalized. Only those units which are recognized in seismic data and separated by pronounced unconformities with tectonic significance are identified. An attempt is made to correlate the pre-Triassic stratigraphy to Wrangel Island whenever possible.

Second, large fault offsets, extensive erosion, and the loose grid of seismic lines prevent direct correlation of individual seismic units across the Chukchi platform. In cases where direct correlation of seismic sequences is not possible the sequence is identified solely on the basis of the internal reflection character, its relation to structure, and interval velocity.

Seismic velocities used in this study are derived from coherency plots of normal moveout curves (velocity spectra) and are converted to interval velocities using Dix equation (Dix, 1955). This procedure is most accurate when thick sequences of continuous reflectors are encountered. Since this is clearly not the case on the Chukchi platform, velocities are often poorly constrained. Velocities mentioned in this report represent an average value obtained by averaging only the most confident velocity picks from the velocity spectra data. Thicknesses and depths reported in seconds in this study are given in seconds two-way travel time.

Variations in seismic character, sediment geometry, and structural trend make it convenient to divide the study area into east and west halves. The study area is divided along a large normal fault which trends along 171° W. This fault (Figures 7, 9, 12, 18, and 19) will be refered to as fault 171° W in discussions of the stratigraphy and structure in this report.

Franklinian sequence

Tentative correlation of Silurian argillites between Wrangel Island and Alaska (Bogdanov and Til'man, 1964, Grantz et al., 1981) suggests that the Franklinian sequence may extend beneath the Chukchi Shelf from northern Alaska to Wrangel Island. On the Chukchi platform, the Franklinian sequence is inferred to form acoustic basement in the east half of the study area, but due to the increasing structural complexity, acoustic basement may lie on Ellesmerian or even Lower Brookian strata west of 172° W. The upper contact is identified by a well-defined high-amplitude continuous reflector below which little reflection coherency is achieved. Where significant accumulations of Eo-Ellesmerian strata overlie Franklinian rocks, the boundary becomes poorly defined.

Sonobuoy refraction data (Houtz et al., 1981, and A. Grantz and S. May personal communication) correlated with reflection data, yield acoustic velocities of approximately 5.5 to 5.9 km/sec. below the Franklinian boundary. In two cases, refraction velocities of 6.4 and 6.5 km/sec. are observed along an intra-acoustic basement interface. The change in velocity required to return a refraction event suggest that a velocity interface exists beneath seismic reflection penetration. Velocities of 5.5

and 5.9 km/sec are obtained within the interval, and velocities of 6.4 and 6.5 km/sec. are observed below the refracting interface. The base of the unit lies 1.3 km and 2.2 km (.5 sec @ 5.5 and 5.9 km/sec) beneath the top of the Franklinian sequence. The combined thickness of the Inkalinskian suite and Naskhokian series is 1.6 km on Wrangel Island. The refraction may represent the boundary between the Inkalinskian suite and the Gromovian suite as observed on Wrangel Island.

Eo-Ellesmerian sequence

The Eo-Ellesmerian sequence is deposited directly on Franklinian basement rocks on the Chukchi platform. Figure 7 shows the distribution of the combined thicknesses of Eo-Ellesmerian and Ellesmerian strata. On the Chukchi platform, the sequence is characterized by poorly defined prograded reflectors. Reflectors have higher continuity where they appear to be prograded and low continunity where the prograded nature is not identified (Figure 8). Toplap is observed near the hinge of the half grabens, and the sequence thickens by offlap towards the fault scarp. The footwall of fault 171° W contains up to 1.0 second (2.5 kilometers @ 5 km/sec) of Eo-Ellesmerian strata along the fault scarp, but erosion and internal thinning decrease the total thickness to less than 0.1 second (0.25 kilometers @ 5.0 km/sec.) 20 kilometers east of the fault scarp

Figure 7 Isopachs, in seconds of two-way reflection time, of the Eo-Ellesmerian and Ellesmerian sequences (combined thickness) on the Chukchi platform.

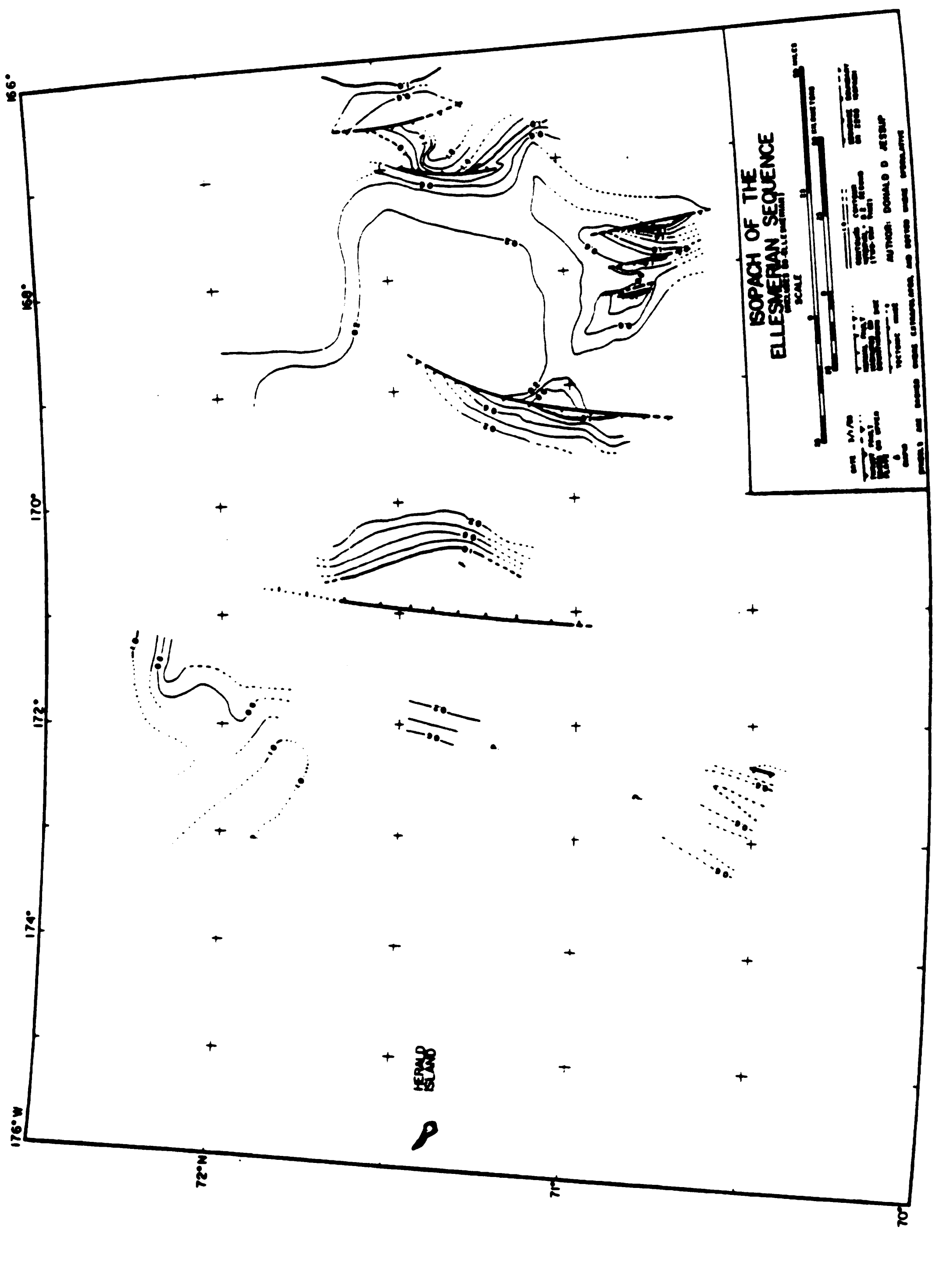
ISOPACH OF THE
ELLESMERIAN SEQUENCE
HERALD ISLAND
166°
168°
170°
172°
174°
176° W
72° N
71°
70°

Figure 7

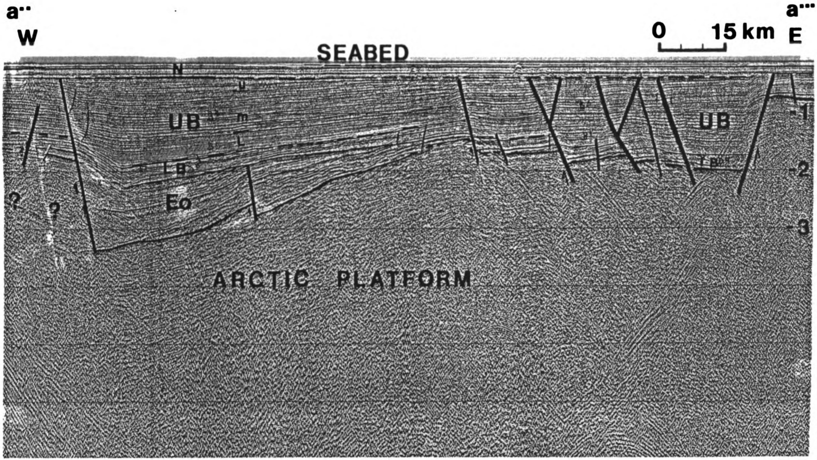

Figure 8 CDP seismic profile a'' - a''' (Figure 14), showing the reflection character and faulting relationships of Eo-Ellesmerian (Eo), Lower Brookian (LB), and Upper Brookian (UB) strata. The vertical scale is in seconds of two-way travel time. Note the prograded character of Eo-Ellesmerian reflectors. Upper Brookian reflectors are observed to pile-up against the fault scarp (west), and are completely truncated to the east. N- "Neogene"

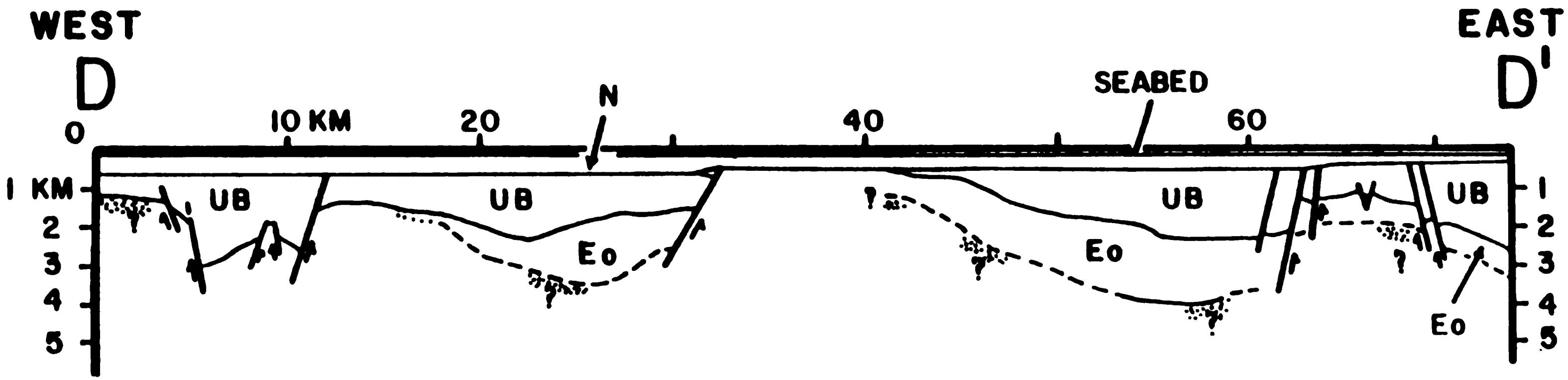

Figure 9 Depth converted structural cross section D - D' (Figure 14). Note the lack of Lower Brookian (LB) strata. Eo - Eo-Ellesmerian, UB - Upper Brookian, N - "Neogene"

(Figure 8). The second accumulation, along 169° W , exhibits a similar character.

Along cross section D - D' (Figure 9), a unit 0.6 second (1.15 km @ 5 km/sec) thick is identified as Eo-Ellesmerian based on its similarity in reflection characteristics to better constrained Eo-Ellesmerian strata. The reflector package has poorly constrained interval velocities of 4.5 km/sec which fals into the range of expected for Eo-Ellesmerian strata.

The localized accumulations and prograded character of the Eo-Ellesmerian sequence suggest that the unit was deposited from neighboring sources into existing depressions on the Franklinian Arctic Platform. This is similar to its character east of the study area as described by Grantz and May (1984b). The offlap character suggests that the influx of sediment was rapid and consists of coarse clastic rocks (Sheriff, 1980).

Ellesmerian sequence

A thin veneer of the regionally extensive Ellesmerian sequence exists over most of the Chukchi platform. Grantz and May (1984b) identify two units within the Ellesmerian sequence, but only the lower unit is identified west of 168° W. The variation in thickness of Ellesmerian (and Eo-Ellesmerian) sediment is shown in Figure 7 by isopachs in time.

Figure 10 Isochrons on the base of Lower Brookain strata, top of Ellesmerian strata, on the Chukchi platform.

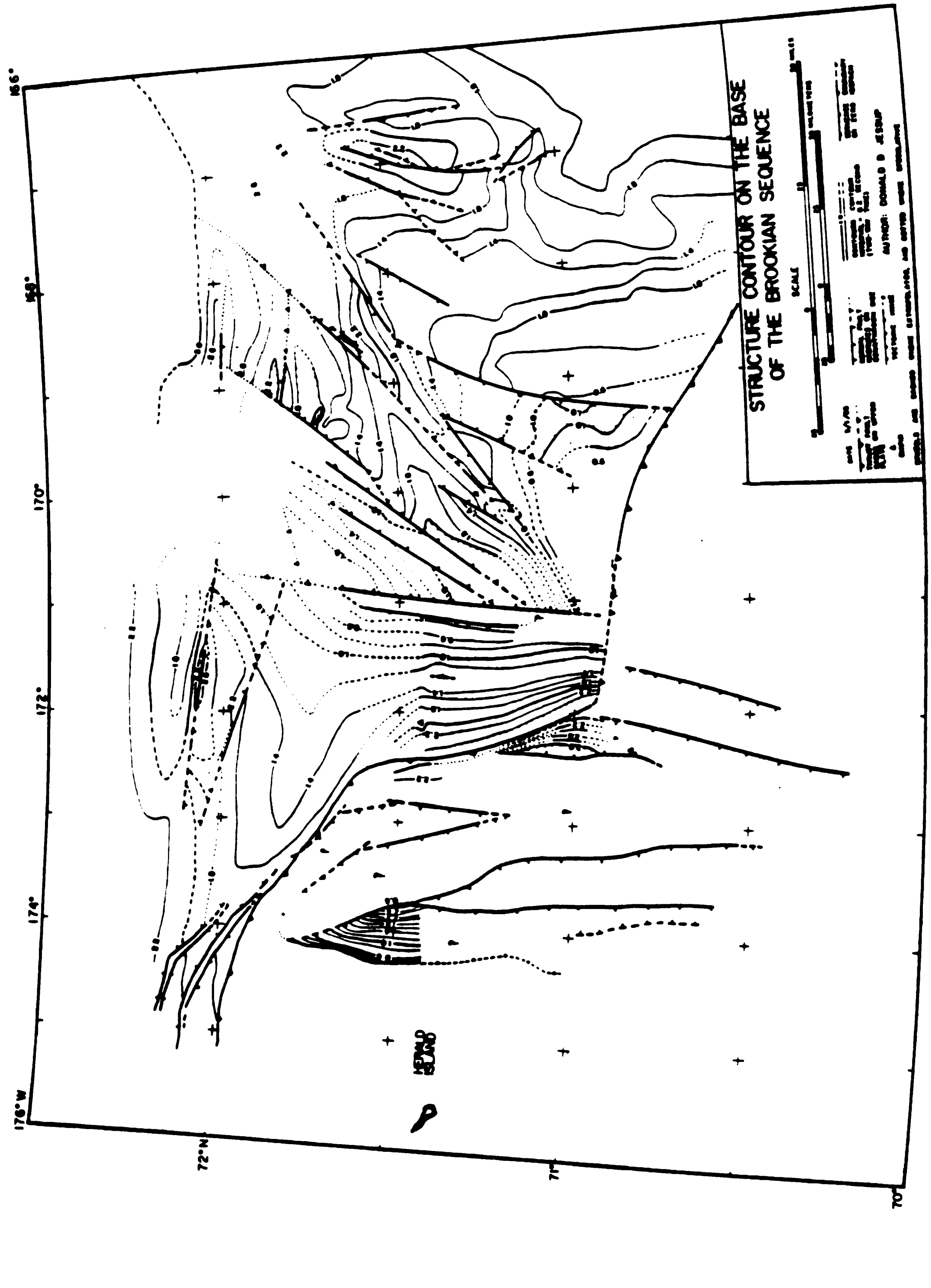
STRUCTURE CONTOUR ON THE BASE
OF THE BROOKIAN SEQUENCE
SCALE
AUTHOR: DONALD B. JESSUP
HERALD
ISLAND
166°
168°
170°
172°
174°
176° W
72° N
71°
70°

Figure 10

Figure 10 is a structure contour on the top of the Ellesmerian sequence (base of the Brookian sequence). The base of the Ellesmerian forms a high amplitude continuous reflection where it is in contact with Franklinian basement rocks. A marked change in reflection character occurs when Eo-Ellesmerian strata underlie the Ellesmerian sequence. East of 168° W, the top of the Ellesmerian sequence is identified by a strong reflector with few internal reflectors beneath it. West of 168° W, the upper contact is recognized by a strong reflector which truncates underlying reflectors. Ellesmerian strata pinch out locally near 170° W.

In the eastern half of the study area, in topographic depressions in the Franklinian unconformity, Ellesmerian strata form thin sediment ponds generally less than 0.2 seconds thick. In the western half of the study area 0.6 second (1.5 km @ 5 km/sec) of Ellesmerian strata is identified by its stratigraphic position. The unit thins by onlap and erosion to less than 0.1 second on the upthrown side of fault 171° W (Figure 11).

In the eastern part of the study area two units are identified within the Ellesmerian Sequence (Grantz and May, 1984b). The lower unit has a significantly greater areal extent, and is interpreted to exist in localized depressions throughout the study area, whereas the upper unit pinches out

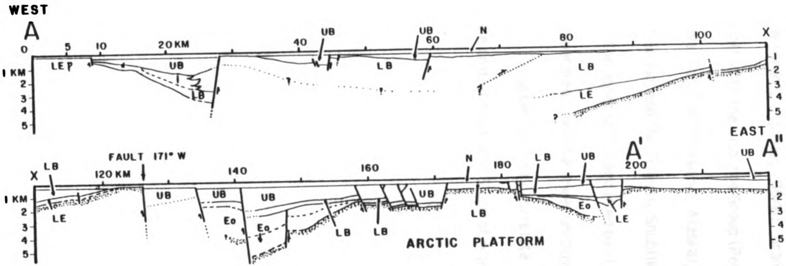

Figure 11 Depth converted structural cross section A - A' (Figure 14). Notice the dramatic increase in thickness of Lower Brookian (LB) and Ellesmerian (LE) strata west of fault 171 W. The regional thrust forming Herald arch is interpreted to cross this profile at kilometer 78. Eo - Eo-Ellesmerian, UB - Upper Brookian, N - "Neogene", Stipples mark the top of Franklinian Basement.

near 168° W (Grantz and May, 1984b). Grantz and May (1984b) correlate the lower unit with the Lisburne Group (Pennsylvanian and Permian in the western Naval Petroleum Reserve, Alaska), the Permian and Triassic Sadlerochit Group, and the Triassic Shublik Formation and Sag River Sandstone. The upper unit, identified by its lack of internal reflectors, is generally separated from the lower unit by a strong reflector (Grantz and May, 1984b). The upper unit may correlate with the Kingak shale and Pebble shale unit of the North Slope of Alaska (Grantz and May, 1984b).

Lower Brookian sequence

Unconformably overlying the Ellesmerian, and locally the Franklinian, sequence throughout the study area is the Lower Brookian sequence. The sequence correlates with the extensive deltaic system of the Colville basin beneath the North Slope of Alaska (Grantz and May, 1984b). On the Chukchi platform the sequence is identified by variable amplitude discontinuous reflectors which generally downlap onto the Ellesmerian , and locally, the Franklinian unconformity. Figures 10 and 12 are contour maps showing the depth, in seconds, to the base of the Lower Brookian, and the variations in its thickness.

The Lower Brookian Sequence displays a great deal of variation in the geometry of its deposits. In the west half of the study area, Lower Brookian strata fill a north-striking trough bounded by basement highs to the east, west, and south, with a constricted opening to the north. The trough is best defined in two east-west seismic profiles shown as depth converted line drawings in Figures 11, 13, and 14. Between the north striking segment of the thrust fault near 172° W and fault 171° W, 1.8 seconds (3.5 km @ 3.5 km/sec) of Lower Brookian strata are identified (Figures 11 and 13). In cross section A-A' (Figure 11), the unit is thickest near the thrust fault and thins by onlap and erosional truncation

Figure 12 Isopachs, in seconds of two-way travel time, of the Lower Brookain sequence, on the Chukchi platform.

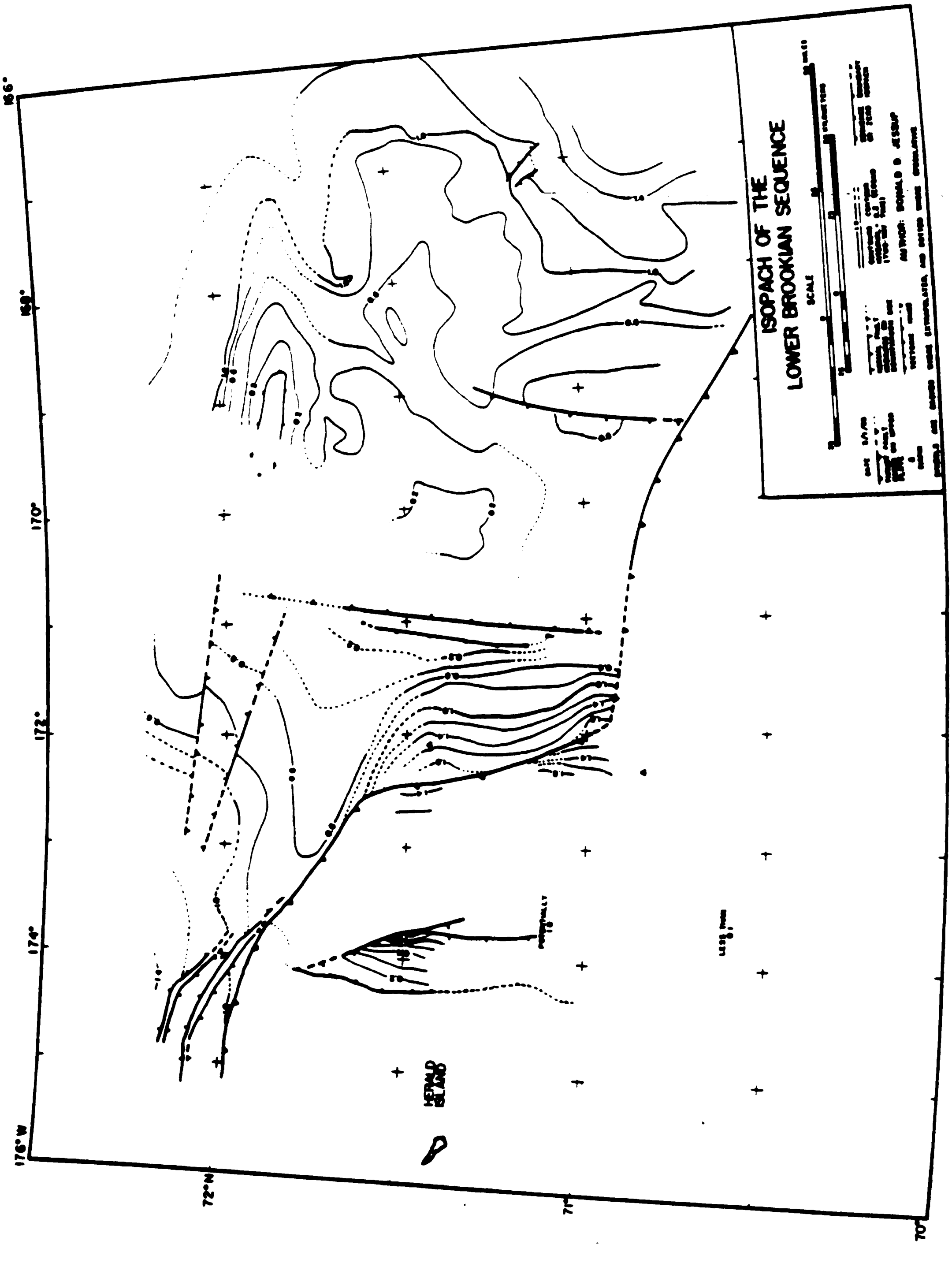
ISOPACH OF THE
LOWER BROOKIAN SEQUENCE
SCALE
HERALD ISLAND
166°
168°
170°
172°
174°
176°W
72°N
71°
70°

Figure 12

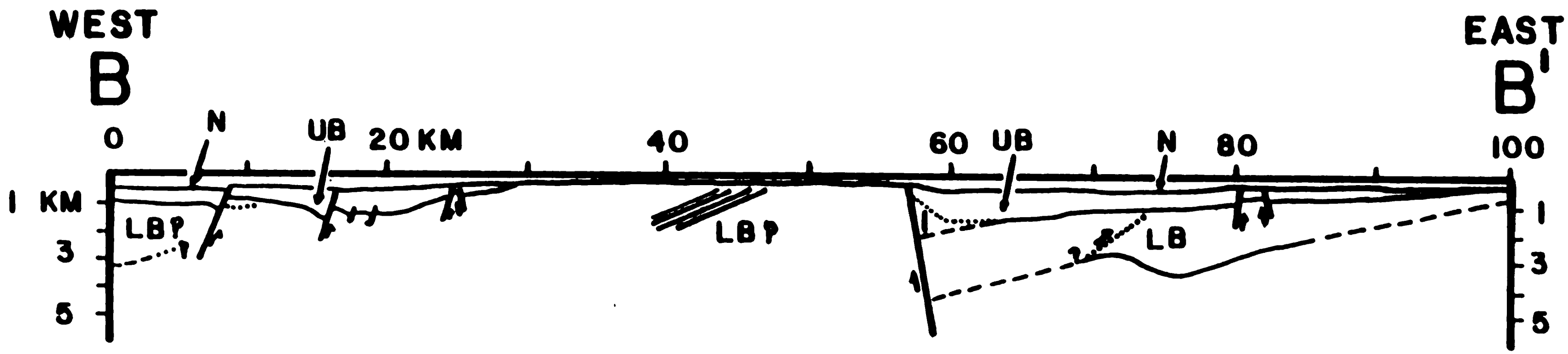

Figure 13 Depth converted structural cross section B - B' (Figure 14). Notice potential rotation of Lower Brookian reflectors west of kilometer 72. LB - Lower Brookian, UB - Upper Brookian, N - Neogene

Figure 14 Map showing the major structural features and locations of structural cross sections.

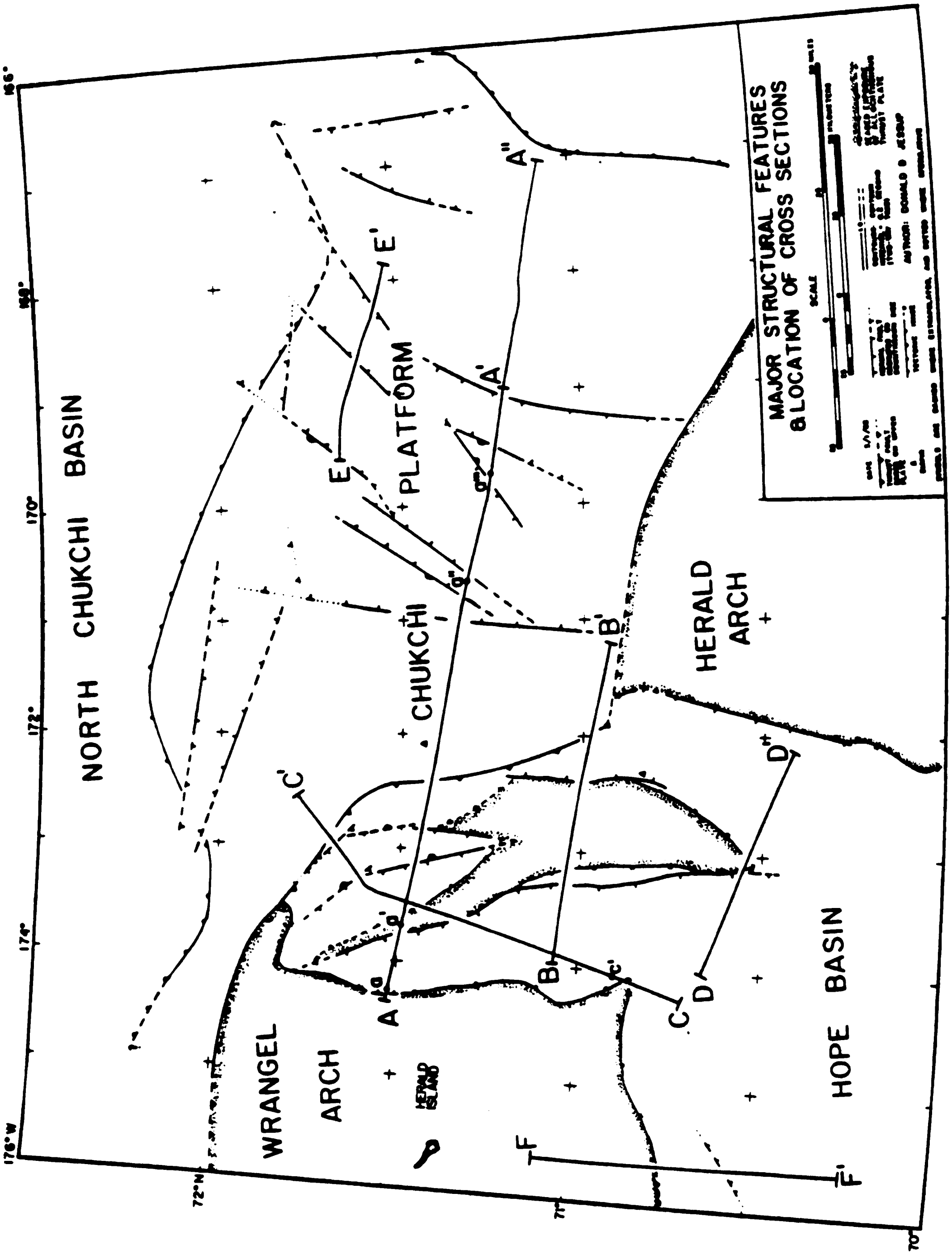
NORTH CHUKCHI BASIN
CHUKCHI PLATFORM
WRANGEL ARCH
HERALD ARCH
HOPE BASIN
HERALD ISLAND
MAJOR STRUCTURAL FEATURES
& LOCATION OF CROSS SECTIONS
SCALE
A
A'
A''
B
B'
C
C'
D
D''
E
E'
F
F'
176°W
174°
172°
170°
168°
166°
72°N
71°
70°

Figure 14

on the west dipping flank of fault 171° W. West of the thrust fault seismic definition of the unit decreases sharply. However, directly west of the fault, reflectors thought to represent the base of the Lower Brookian are included in Figures 10 and 12. Lower Brookian strata in cross section A - A' are infered to thin westward, and correlate with Lower Brookian reflectors in the hanging wall of the half graben near 172° W, 71° 30' N (Figures 11 and 17).

In cross section B-B' (Figures 13 and 14), 1.2 seconds (2.1 km @ 3.5 km/sec) of Lower Brookian strata are observed. The strata are partially overlain by the Upper Brookian sequence, and are truncated by a large normal fault (Figure 13). West of the normal fault, reflectors tentatively identified as dipping Lower Brookian strata occur in the footwall of the normal fault (Figure 11, 14). Although these reflectors cannot be traced in seismic data to the west, they are may correlate with structurally complex Lower Brookian reflectors in cross section C-C' (Figures 14 and 15). Poorly defined reflectors rise towards the surface indicating that the Lower Brookian sequence wedges out near 174° W.

No Lower Brookian strata are recognized in cross section D-D' (Figures 9 and 14), thus the southern boundary of the trough lies north of this line. A regional Free-air gravity anomaly map (May, in press) shows

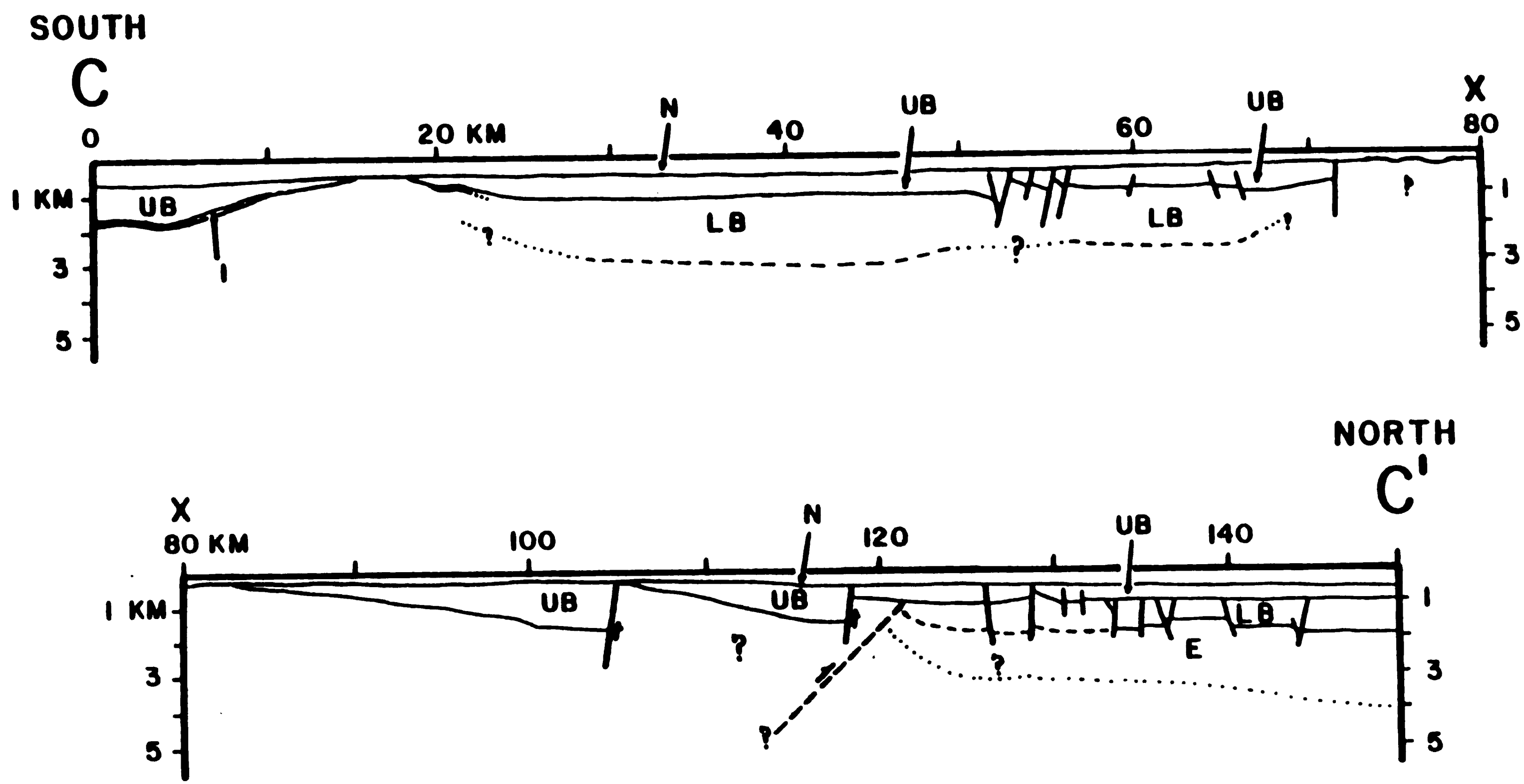

Figure 15 Depth converted structural cross section C - C' (Figure 14). E - Ellesmerian, LB - Lower Brookain, UB - Upper Brookian, N - "Neogene"

an increase of 20 mgals (-20 to 0 mgals) between the thickest part of the trough (71° N 172° W) and the location of D-D' (Figures 9 and 14). The increasing anomaly is interpreted to be caused by shoaling of Franklinian basement accompained by southward thinning of Lower Brookian strata.

In summary, up to 1.8 seconds (3.1 km @ 3.5 km/sec) of Lower Brookian strata, west of fault 171° W, fill a north-striking trough. Seismic data show reflectors onlapping the west flank of fault 171° W. The reflectors are infered to onlap basement highs to the west and south. The north end of the trough forms a constricted opening into North Chukchi basin. The trough shows no indication of having been fault controlled.

On Herald arch, in the southeastern corner of the study area, resonant seabed multiples prevent satisfactory identification of any seismic stratigraphic units. However, several lines of evidence suggest that the Lower Brookian Sequence does exist in this region. First, no pinch-out of Lower Brookian strata is observed as reflectors are traced southward onto Herald arch. Second, folded strata identified east of 170° W in one high resolution seismic profile correlate to the west, down dip, with reflectors identified as Lower Brookian in multichannel data. Third, Grantz and May (1984b) attribute refraction velocities of 3.1 to 4.0

km/sec, located on Herald arch, to the Lower Brookian sequence. These observations suggest that the Lower Brookian sequence does exist on Herald arch.

In the eastern half of the study area, north of Herald arch, the Lower Brookian sequence forms three wedges (subunits) thickening from 0.2 seconds (0.3 km @ 3.5 km/sec) on the Chukchi platform to more than 3 seconds in Hanna Trough and to 6 seconds in North Chukchi basin (Grantz and May, 1984b). Each subunit contains discontinuous low- to moderate-amplitude reflectors near the base and discontinuous high-amplitude reflectors toward the top. East of 171° W three repetitions of this reflection pattern are recognized. The lowest subunit has concordant reflectors (south) and thins by downlap to the north where it is overstepped by the middle subunit.

Westward thinning and truncation of stratigraphically higher Lower Brookian strata, accompanied with a 0.5 km/sec increase (2.2 km/sec to 2.7 km/sec) in interval velocity at similar depths beneath the Upper Brookian sequence, suggest that only the lower (oldest) subunit exists on the Chukchi platform west of 170° W. Grantz et al. (1975, 1981) noticed this on a much larger scale on the Chukchi Shelf.

The poor continuity and low-amplitude reflectors underlying high- to variable-amplitude discontinuous reflectors may be interpreted, following Sheriff (1980), as deltaic sediments overlain by fluvial to marginal-marine, and nonmarine clastic sedimentary rocks. The northward overstepping and reflection character of the subunits suggest that three successive episodes of deltaic sedimentation occurred with a southern source. The middle subunit pinches-out towards the west implying that one delta lobe migrated to the west, as well as to the north. This also suggests that at least one delta lobe had a source east of the Chukchi platform. In the west half of the study area, subunits were not be identified in the Lower Brookian sequence, but the variable-amplitude discontinuous reflectors suggest that deltaic processes may also be involved in this area.

Unit I

Separating the Lower and Upper Brookian sequences in the half graben along 174° W, and near 172° W, 71° N is a package of reflectors identified as Unit I in this report. Unit I is a 0.2 second thick package of undeformed reflectors overlying highly warped Lower Brookian reflectors. A latest Cretaceous age is assigned to this unit because it is stratigraphically higher than the Lower Brookian sequence (mid to late Cretaceous) and is onlapped by the Upper Brookian sequence (latest Cretaceous to earliest

Figure 16 CDP seismic profile a - a' (Figure 14), showing:

1. Alluvial fan (F) shed off the fault scarp prior to the deposition of Upper Brookian strata in latest Createceous time.
2. The onlapping character of the lower Upper Brookian subunit (L) onto the fan.
3. The large offset of Upper Brookain reflectors above the fan deposit.

LB - Lower Brookain, 1 - Unit I, UB - Upper Brookian, L -, m -, u -, Lower, middle, upper subunits of Upper Brookian strata respectively, N - "Neogene"

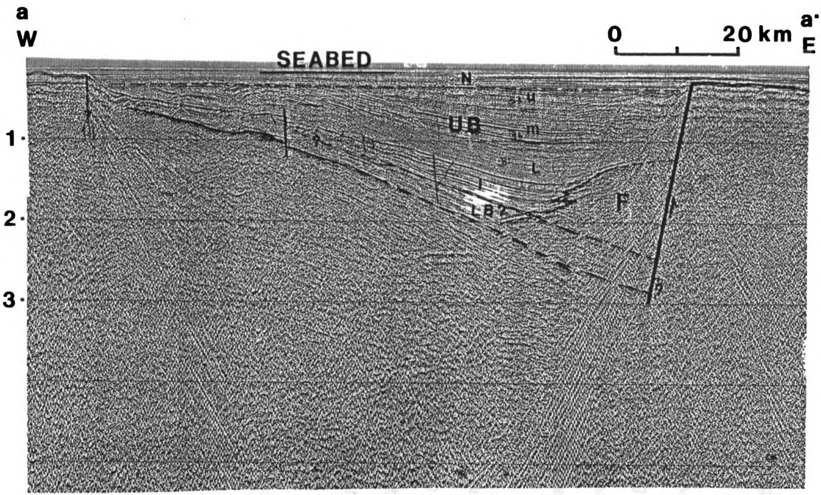

Figure 16

Paleogene; Figure 16 and 17).

Unit I is traced northward and correlated with reflectors having similar stratigraphic position near 174° W, 71° 30' N. At this location, Unit I thickens by divergence towards the fault plane bounding the half graben and merges with a wedge shaped packet of reflectors angling down from the fault plane shown in Figure 17. Based on the location of these reflectors in the hanging wall, and their wedge shaped geometry, they are interpreted as alluvial fan deposits interfingering with Unit I.

Unit I is traced to the southern edge of multichannel data coverage and is not identified in single channel data to the south. It is possible that these reflectors may be similar to a package of supra-basement reflectors identified by Grantz et al. (1976) in the eastern portion of Hope Basin. However, approximately 400 kilometers separate these observations, making this correlation highly speculative. Lithologically, the unit may consist of volcanic tuff, volcaniclastic debris, and crystalline volcanic rocks which are penetrated in two test wells in the eastern part of Hope Basin (Fisher et al., 1982). The thickness of Unit I is included in the thickness of the Lower Brookian sequence reported in Figure 12.

Figure 17 CDP seismic profile showing the relationship between the stratigraphy and an erosional terrace. An intermediate unit (Unit I) is identified to overlie acoustic basement. The unit is onlapped by Upper Brookian strata. The vertical scale is in seconds of two-way travel time. 1 - Unit I, UB - Upper Brookian, L -, m -, lower and middle Upper Brookian subunits respectively, N - "Neogene"

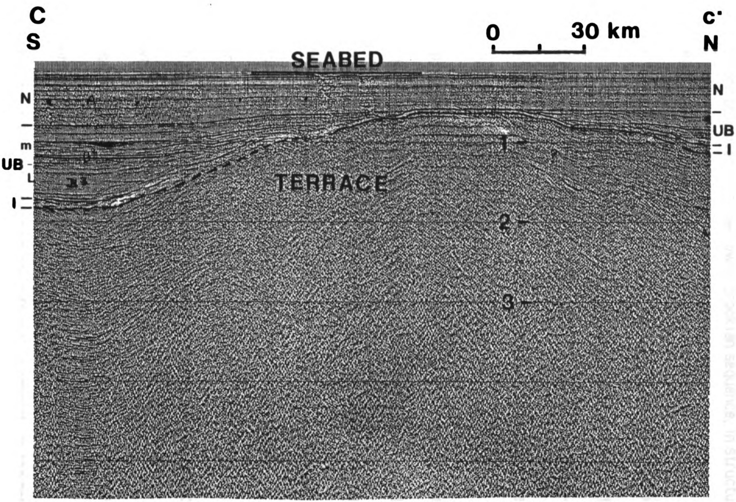

Figure 17

Upper Brookian sequence

Unconformably overlying the Lower Brookian sequence, in structurally controlled grabens and half grabens, is the Upper Brookian sequence. The sequence forms the youngest stratigraphic unit on the Chukchi platform. Grantz et al. (1982) identify the unit as Tertiary (mainly Paleogene) by its stratigraphic position, relatively low acoustic velocity, and lateral correlation with Tertiary strata beneath the Beaufort Sea. The sequence forms a continuous sedimentary unit thickening from a saddle on the Chukchi platform into North Chukchi basin and Hope basin. The sequence thickens by divergence of reflectors and addition of onlapping reflectors into Hope basin. In the east half of the study area, Upper Brookian strata are primarily isolated in a large graben west of 169° W. In the west half of the study area, Upper Brookian strata are concentrated in two north-striking troughs, separated by a fault-bounded high. Contours drawn on the base of the sequence are shown on Figure 18, and isopachs are shown in Figure 19.

The sequence is divided into three subunits with different reflection characters. Each subunit is best defined in the west-central portion of the study area; definite boundaries are difficult to identify in the rest of the study area. Reflectors in the lower unit, in the central part of the

Figure 18 Isochrons, in seconds of two-way travel time, on the base of the Upper Brookian sequence, on the Chukchi platform.

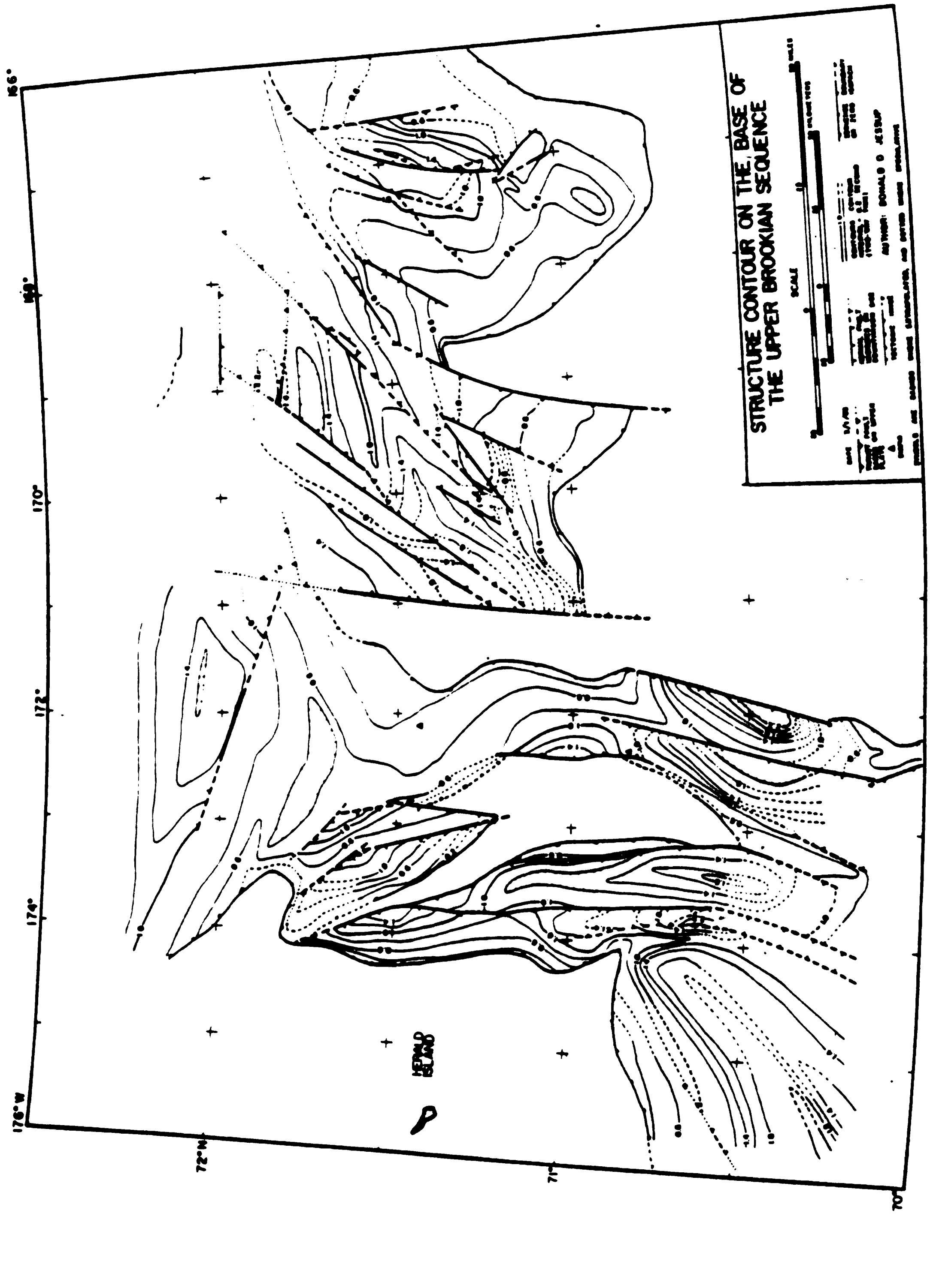
STRUCTURE CONTOUR ON THE BASE OF
THE UPPER BROOKIAN SEQUENCE
SCALE
HERALD ISLAND
176° W
174°
172°
170°
166°
72° N
71°
70°

Figure 18

Figure 19 Isopachs, in seconds of two-way travel time, of the Upper Brookian sequence, on the Chukchi platform.

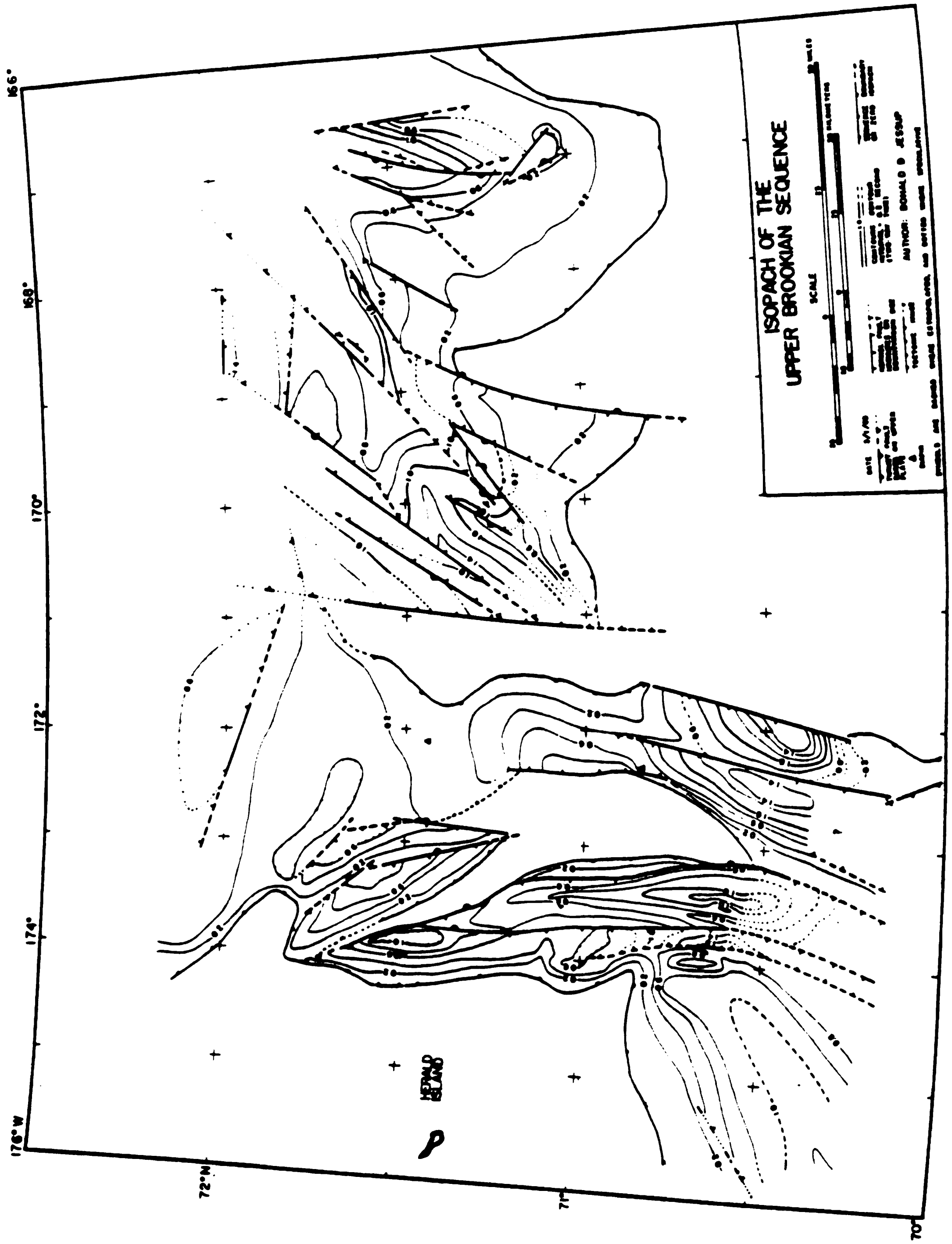
ISOPACH OF THE
UPPER BROOKIAN SEQUENCE
SCALE
HERALD ISLAND
166°
168°
170°
172°
174°
176°W
72°N
71°
70°

Figure 19

study area, form weak continuous reflections, concordant with the basal unconformity. The unit is associated with faults, and reflectors "pile up" against the fault scarp (Figure 8). In the two locations where alluvial deposits are identified, the lower unit thins onto the alluvium by onlap and convergence of reflectors (Figure 9). In the southern portion of the study area the reflection character becomes chaotic, but the infilling character appears to be similar. In several depressions, beneath the chaotic reflectors, onlapping fill is observed. The chaotic character is interpreted to represent a high energy depositional enviroment, while the onlapping fill suggest low energy enviroments (Sheriff, 1980). It is possible that the initial stages of sediment deposition occurred in relatively quiet enviroments, and the depositional energy increased during deposition of the lower subunit.

The boundary between the lower and middle subunits is gradational. The middle subunit contains locally continuous high-amplitude reflectors interspersed with discontinuous low-amplitude reflectors. Reflectors of the middle subunit in the eastern half of the study area tend to display greater continuity then reflectors in the same unit to the southwest. This suggests that the eastern portion of the study area was the site of marine sedimentation, whereas nonmarine conditions prevailed in the west. The upper subunit is identified in two cross sections and contains moderately weak reflectors in gradational, and occasional erosional, contact with the middle unit. The middle, and locally the upper, subunits thicken by divergence and addition of truncated reflectors towards the controlling fault of the grabens. When the middle subunit overlies alluvial deposits, reflectors thin by convergence, step over the wedge, and are abruptly truncated at the fault.

Reflectors are abruptly truncated at a pronounced unconformity, generally less than 0.3 seconds (285 meters @ 1.9 km/sec) beneath the seabed. Approximately 1.0 second (1.2 km @ 2.4 km/sec) of erosion can be measured as thickness variations between the hanging wall and footwall of several half grabens. Extensive channels gouge the unconformity in the southwest and central portions of the study area. Reflectors representing the unconformity are traced in widely spaced single-channel seismic data across the west portion of Hope basin and can be correlated with the regional reflector identified by Eittreim et al. (1978), and Eittreim et al. (1979). A "Neogene" age is assigned to this reflector by Eittreim et al. (1979) for "discussion purposes only". The unconformity is refered to as the "Neogene" unconformity in this report.

Along the southwest edge of the study area, on basement highs, and on several fault scarps, terracing is observed. Stratigraphic relations of the terraces are shown in profile C-C' (Figures 14 and 17). The middle unit is observed to overstep the lower unit, onlap the basement high, and fill the terrace. The terracing is interpreted to represent erosion along a paleo-shoreline during deposition of the middle subunit of the Upper Brookian sequence in mid-Paleogene.

The lower subunit correlates with the infilling unit at the base of the Upper Brookian sequence identified by Grantz and May (1984b) in North Chukchi basin. Grantz and May (1984b) also suggest that Tertiary sediment overlying the infilling unit in North Chukchi basin and Hanna trough are largely marine, grading into nonmarine, rocks on the Chukchi platform. Eittriem et al. (1979) suggest that Hope basin is filled with nonmarine sediments. These interpretations coincide with lithologies associated with erosional terraces and the reflection character observed in the middle and upper subunits on the Chukchi platform. The well-delineated subunits of Upper Brookian strata in the central part of the study area are interpreted to represent a shallow depositional enviroment which is more sensitive to tectonic and eustatic changes.

Overlying the "Neogene" unconformity throughout the Chukchi platform is a thin (generally less than 0.3 second including water depth), veneer of

"Neogene" sediment. The unit is included as part of the Upper Brookian sequence defined by Grantz et al. (1982) and Grantz and May (1984b). High resolution seismic data show numerous channels with prograded fill within the unit. The unit thickens into the west portion of Hope basin by divergence of reflectors and reaches a thickness of 0.8 second in an apparently isolated depression near 173° W 69° 30' N.

Structure

The Chukchi platform constitutes a regional basement high transected by three overprinting structural events. Structural activity recognized in seismic data began following the consolidation and metamorphism of the Arctic Platform in Middle Devonian to Early Mississippian time (Grantz and May, 1984a), and ended prior to Neogene sedimentation. Three major episodes of faulting are recorded on the platform. Two periods of extension created normal displacements of up to 1 kilometer, and an intervening regional thrusting episode dislocated portions of the western Chukchi Shelf by 25 to 60 kilometers. Figures 9, 11, 13, 14, 15, 20, and 21 show regional cross sections across the platform. Each cross section is constructed along a seismic profile with a vertical scale in kilometers. Figures 8, 16, and 21 show detailed portions of these cross sections. Figure 14 shows the location of the cross sections in relation to major structural features on the Chukchi platform.

Early Normal Faulting

The first episode of deformation on the Chukchi platform formed widely spaced, north striking, normal faults identified by increased thicknesses of Eo-Ellesmerian strata. Numerous diffractions prevent measurement of the offset near the fault plane, but the thicknesses of the infilling unit reach 1 second (2.5 km @ 5 km/sec), and the displacement is thought to have a similar magnitude. Fault planes tend to be nearly vertical with normal slip. The age and prograded character of the of the infilling units (see stratigraphic discussion) suggest that these faults formed prior to the deposition of Eo-Ellesmerian strata in Late Devonian to Early Mississippian time.

The second episode of deformation appears to have been minor in comparision to the previous one. Nearly vertical normal faults, observed in two seismic lines, offset Eo-Ellesmerian and Ellesmerian strata by a maximum of 0.35 seconds. Along the eastern edge of the study area, the base of the upper Ellesmerian subunit is offset while the top of the unit remains undisturbed. This suggests that faulting occured during deposition of the upper subunit in Late Jurassic to Early Cretaceous time. It is possible that faulting was more extensive at that time, but is not visible seismically due to the lack of bedded sediment rocks on the Chukchi platform throughout the late Paleozoic and early Mesozoic.

Thrust Faulting

The thrust faults which form Herald arch intersect the Chukchi platform near 169° W 70° N, and make a "Z" shaped curve on the basement high (Figures 10 and 12). West of the study area the continuation of the thrust strikes east north of Herald and possibly Wrangel Islands (Grantz et al., 1975). Thrusting is identified on the Chukchi platform by the loss of seismic resolution in Lower Brookian strata caused by complex structures and high seabed velocities south of the thrust. The approximate location of the thrusts on Figures 10 and 12 represent the leading edge of significant compressional deformation, marked by the loss of resolution in Lower Brookian strata, and is therefore tentative. The loss of resolution in Lower Brookian strata is gradual in the eastern part of the study area, but becomes sharp to the west.

In two seismic lines, a sharp decrease in data quality caused by numerous diffractions above an apparent anticline is interpreted to represent the thrust across its north striking segment (Figures 10, 11, 12, and 13). The fault plane is not identified in the seismic data due to the dominance of diffractions. The anticline is interpreted to be a velocity pull-up caused by allochthonous, higher velocity rocks, which have been tectonically juxtaposed against younger, lower velocity rocks. The thrust can be traced to within 30 km of cross section C-C' (Figure 15) and is projected along strike to cross it. However, a gap in the data coverage obscures any thrust-related features that may exist. The only evidence of thrusting is a sharp up-turn of lower Brookian reflectors and a decrease in the number of minor high angle normal (possibly reverse) faults north of the projected trace. West of the platform the thrust is identified in seismic data by allochthonous acoustic basement overlying bedded rocks which return coherent reflections. The surface expression of the dip of the fault plane is steep (30°). I suspect that the 30° dip measured from the seismic data has been significantly steepened by post-thrusting structural activity.

The major component of movement is thought to be northeast-directed thrusting (Grantz et al., 1975). However, Grantz et al. (1981) suggest that near 169° W motion along the fault may have a strike-slip componet.

Due to the poor seismic resolution on Herald arch, the amount of displacement along the thrusts could not be calculated. East of the study area a throw of at least 60 km is suspected (Grantz and May, 1984b), but it may decrease towards the Chukchi platform (Grantz et al., 1981). Kameneva (1975) proposes that 10 km of shortening is observed on Wrangel island. However, evaluation of the geometry between the klippen zones and the main thrust mapped on the island (Kameneva, 1975) suggest that at least 25 km of shortening is more likely. Since the leading thrust may be located 25 km north of Wrangel Island (Grantz et al., 1975), the entire island may be an exposed portion of the allochthonous plate. Therefore, the proposed 25 km shortening on Wrangel Island may be attributed to a thrust fault bifurcated from the main thrust.

Thrusting along Herald arch is proposed to be Aptian to Paleogene in age (Grantz et al., 1981). Since no reverse faults or folds are observed above the unconformity separating deformed Lower Brookian and the undeformed Unit I, a post-Lower Brookian (Aptian) to pre-Unit I (latest Cretaceous) age is consistent with observations made in this study. Geologic data are insufficent to determine when thrusting ended on Wrangel Island. However, Bogdanov and Til'man (1964) describe overturned Triassic rocks on Wrangel Island that suggest thrusting is younger than Triassic. No evidence is observed on the Chukchi platform to suggest that Wrangel arch and Herald arch are separate structures.

Late Normal Faulting

The most characteristic structural features on the Chukchi platform are large high angle normal faults. Basement offsets of up to 0.8 sec (1 km) with dips ranging from 40° to 80° (average dip is 67°) are common. The fault distribution, shown in Figures 18 and 19, reveal two dominant trends, one striking north to northwest, and the other striking northeast. Figures 9, 11 and 13 show the geometry of faulted structures in the west, while Figures 9 and 20 show structural features east of 171° W. Notice that structures west of 171° W are generally half grabens, whereas both full and half grabens are present in the east. The grabens and half grabens contain thick (1.5 km) accumulations of Upper Brookian strata. Complete truncation of the Lower Brookian sequence, and rotation of thrust related features suggests that faulting occured after deposition and thrusting of Lower Brookian strata in "Paleogene" time.

Two generations of normal faulting can be identified by differences in the reflection character of Upper Brookian strata close to the fault plane. The earliest episode of faulting is shown in the west side of Figure 8, while the second generation of faults dominate the east end of Figure 8. Development attributed to the first generation of faulting is best defined where alluvial fans are deposited in the hanging wall of the faults. Alluvial deposits are not observed in the east part of the study area, but Upper Brookian reflectors pile-up against the fault scarps. Figures 8 and 9 compare two different reflection characters observed at the base of numerous fault scarps. Alluvial deposits, and the piling-up character of reflectors along the fault scarps, suggest that faulting began during deposition of Unit I in latest Cretaceous time. The presence of alluvial material suggests that at the onset of normal faulting the rate of faulting

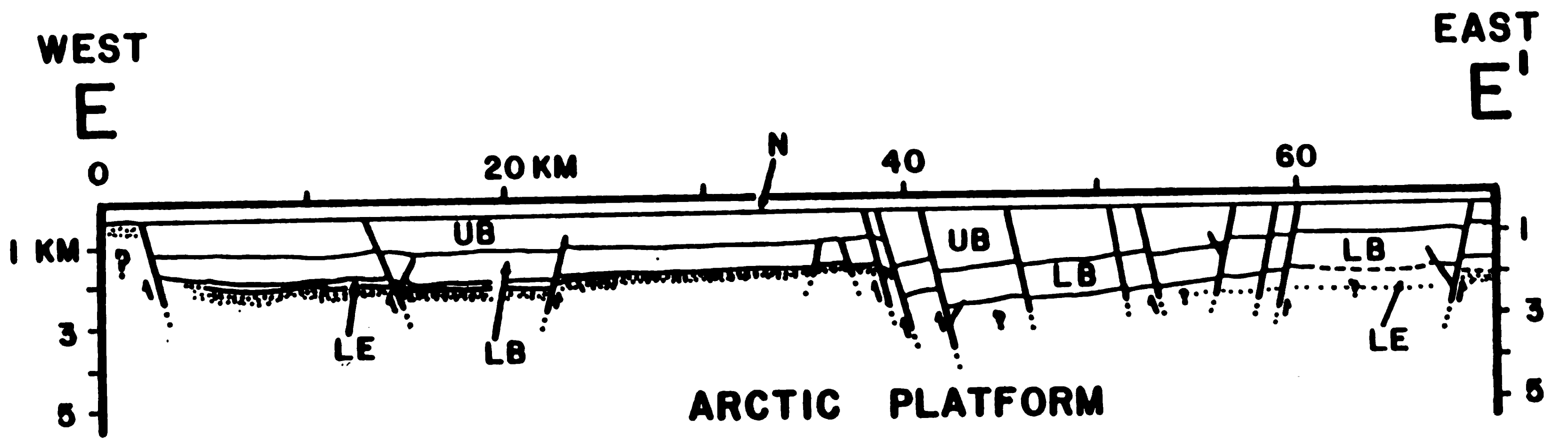

Figure 20 Depth converted structural cross section E - E' (Figure 14). LE - lower Ellesmerian subunit, LB - Lower Brookian, UB - Upper Brookian, N - Neogene

exceded the rate of sedmentation. Based on the thickness of the alluvium, 0.5 to 1.3 seconds (0.6 to 1.5 km) of displacement occurred during this time. In several locations faults cause major basement offsets, but the offset is barely preceptible in strata that lie over the faults.

In the Upper Brookian sequence, first generation faults show decreasing offset between successivly higher reflectors (younger stratigraphy). Reflector dips of stratigraphically higher units decrease upwards from as much as 6 degrees to 1 degree in several half grabens (Figure 16). These observations indicate that faulting continued contemporaneously with Upper Brookian sedimentation. It appears that the rate of sedimentation increased during the Upper Brookian regime.

The second episode of faulting is expressed by the abrupt truncation of the entire Upper Brookian sequence (Figures 8 and 11) in late "Paleogene" time. Up to 0.8 second (1 km) of displacement is observed. Truncated Upper Brookian strata above the alluvial deposits suggest that faults of the first generation were reactivated (or continuously active) during late generation faulting. The symbol  in Figures 18 and 19 identifies faults which show no evidence of infilling prior to the deposition of the Upper Brookian sequence.

No relationship between the strike of the faults and their proposed ages is identified. However, the younger episode of faulting is expressed by reactivation of early Paleogene faults west of 171° W, and by reactivation of older faults and the formation of new faults east of 171° W.

Fault 171° W, and faults bounding Hope basin to the north, deserve special mention. Fault 171° W brings Franklinian Basement rocks within 300 meters of the sea bed (Figure 11). The observed westward dip of onlapping reflectors indicate that the west flank of fault 171° W is rotated up to 5 degrees. The increased thickness of Eo-Ellesmerian and Upper Brookian strata (Figure 8) in the footwall suggest that this fault formed in Late Devonian to Mississippian time and was active until late "Paleogene" time. At least 2.8 seconds of cummulative offset is demonstrated by the thickness of Eo-Ellesmerian, Ellesmerian, and Lower and Upper Brookian sedimentary rocks in the hanging wall of the fault. It is possible that a splay off of the main thrust near 71° 45' N (Figures 10 and 12) may connect to this fault, but the lack of data near 171° W 72° N prevent delineation of structures in that area. If this speculation is correct, fault 171° W would have had a strike-slip component in mid to Late Cretaceous time.

In the southwestern corner of the study area, nearly vertical normal faults, cut by erosional terraces, separate the Chukchi platform and Hope basin. In cross section F - F' (Figure 21) terracing is observed above and below the "Neogene" unconformity. Since the terraced fault scarps along F -F' are only observed in single-channel data, precise stratigraphic relations between the fault, the terrace, and the sedimentary column cannot be determined. However, a terrace identified on a basement high in the multichannel data suggests that terracing occurred during deposition of the middle Upper Brookian subunit (mid-"Paleogene"; Figure 17). This would account for the accumulation of sediment below the terrace (probably the lowest Upper Brookian subunit and Unit I), and the necessary exposure of the fault required for terracing.

Diapirs

Immediately in front of the thrust along 172° W, two diapiric structures are identified (Figure 10). The diapirs rise are truncated at the "Neogene" unconformity 300 meters beneath the seabed. The diapirs are probably rooted in Lower Brookian strata, due to its greater thickness in the area. The best studied diapir in the region is thought to be composed of shale on the basis of low acoustic velocities, small gravity and magnetic signature, and the dominance of shale over other diapir forming materials in the stratigraphic column (Grantz et al., 1975).

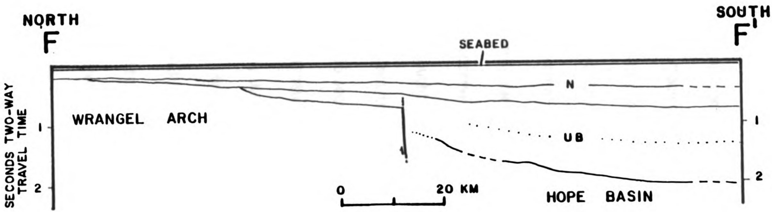

Figure 21 Depth converted structural cross section F - F' (Figure 14), showing the terraced fault scarp facing Hope basin. UB - Upper Brookian, N - Neogene

Structural Summary

Following the formation of the Artic Platform in mid-Devonian to early Mississippian time (Grantz et al., 1981), normal faults cut the Franklinian erosional surface. Devonian to Mississippian structures on the Chukchi platform strike north, parallel to Hanna trough (Grantz and May, 1984b). The largest structure on the Chukchi platform, fault 171° W, exhibits 1.0 second of normal displacement during this time.

From Mississippian to Early Cretaceous time, only minor faulting and extensive erosion are observed in Eo-Ellesmerian and Ellesmerian strata. The minor faulting is thought to have occurred during Late Jurassic to Early Cretaceous time since the base of the youngest Ellesmerian unit is offset by as much as 0.35 second, while the top remains unbroken. This episode of faulting and erosion may have been in response to regional uplift caused by the Early Jurassic opening of the Canada Basin, north of Alaska (Grantz and May, 1983).

Following normal faulting, Aptian to latest Cretaceous compression thrusted Ellesmerian, and possibly Franklkinian, rocks northeastward over Lower Brookian rocks between Cape Lisburne and Wrangel Island (Grantz et al., 1981). On the Chukchi platform the thrust forms a "Z" shaped curve (Figures 10 and 12).

The "Z" shaped trace formed by the thrust formed in response to the irregular basement geometry near the Chukchi platform. The Arctic Platform is shallower between 170° W and 167° W than it is to the east or west (Figures 7 and 10). As a result, the allochthonous thrust sheet, moving along a decollement at or above the basement-sediment interface was forced to move higher, over the shallower Arctic Platform in the eastern part of the study area. Subsequent erosion through the thrust sheet in the east, exposed the thrust further south. An alternative explanation would involve a tear in the thrust, and strike-slip motion along the north striking segment of the thrust fault (Figures 12 and 18). In the second model, northeast directed thrusting was impeded by elevated basement in the eastern part of the study area. This allowed the allochthonous plate to slip along a tear fault, north of the eastern portion of the now segmented thrust sheet. Due to the possible barrier effect of the high standing basement, displacement along the thrust is probably less on the Chukchi platform than on other portions of the Chukchi Shelf.

Complete truncation of deformed (south) and undeformed (north) Lower Brookian strata north and south of the thrust mark the onset of large-scale normal faulting on the Chukchi platform in latest Cretaceous time. Decreasing offsets of successively younger stratigraphic sequences suggest that faulting occured along reactivated Devonian to Mississippian age normal faults, and by the formation of numerous new faults. Two episodes of normal faulting are recognized. The first episode of normal faulting is characterized by alluvial deposits, the "piling-up" character of Upper Brookian reflectors, and the decreasing offset and dip of stratigraphicaly higher (younger) Upper Brookian reflectors. These observations suggest that faulting began prior to, and continued contemporaneously with, the deposition of the Upper Brookian sequence in latest Cretaceous to "Paleogene" time. The final episode of normal faulting in late "Paleogene" completely offsets the Upper Brookian sequence.

The gross Late Cretaceous to late "Paleogene" structure of the eastern half of the study area (including fault 171° W) can be represented by one large graben with numerous intermediate faults (Figures 14, 18, and 19). The faults forming the graben can be traced along strike into the zone of numerous listric normal faults identified by Grantz and May (1984b) near the east edge of North Chukchi basin. The pattern of slightly diverging fault traces (Figures 18 and 19), assymetrical grabens, and rapid (1.5 km in 50 my.) rates of infilling suggest that these faults may have formed in response to oblique-slip motion. However, no through-going faults are identified, and negative flower structures characteristic of strike-slip regimes (Harding, 1985) are not observed in the seismic data to support this speculation. If these faults have a component of strike-slip motion, it is not large.

Grantz and May (1984b) suggest that these faults formed in response to the second rifting episode in North Chukchi basin. If this were the case, the strike of the faults would tend to be parallel, rather than oblique, to the hinge marking the southern edge of North Chukchi basin. Based on the time which these faults formed it is more likely that they formed in response to the same regional extension recorded in Norton and Hope basins (Figure 3; Fisher et al., 1982; Eittreim et al., 1979).

Faults east and west of 171° W formed in response to the same stress regime, however they have greatly different strikes. Faults west of 171° W lie on, or near, the allochthonous plate of Herald arch. These faults may have formed in existing zones of weakness as the allochthonous plate collapsed into the underlying young sediment. Similar explanations are proposed by Sales (1983) to explain features caused by the Laramide Orogeny in the western United States. Reverse activation on older thrust planes proposed by Smith et al. (1984) to explain structures in the Basin and Range Province of the western United States, could also explain these faults. However, unlike faults in the Basin and Range province, faults on the Chukchi platform have steep dips and do not appear to become listric at depth.

Following the end of "Paleogene" time all positive features were leveled by up to 1 km of erosion, marking the end of structural activity on the Chukchi platform.

GEOMETRY OF THE CHUKCHI PLATFORM

The current geometry of the Chukchi platform is defined by tectonic hinges to the north and east (Grantz and May, 1984b), and high angle normal faults to the south. The location of southern boundary is tentative since Herald arch strongly overprints any features which may have existed prior to its formation. No western boundary is identified.

Prior to the formation of Hope basin and Herald arch the southern boundary of the Chukchi platform is interpreted to have been the eastward extension of the south dipping monocline observed on Wrangel Island (Kameneva, 1977). The presence of the monocline is suggested by the northward transgression of Carboniferous to Triassic strata (Ellesmerian equivalents), the concentration of algal bioherms in the northern part of Wrangel island, and a 100 meter increase in thickness of Carboniferous strata on Wrangel Island (Kameneva, 1975). Increased thicknesses (up to 10 km) of Ordovician to Triassic strata on Chukotka (Oradovskaya, 1969, Shilo and Zagruzina, 1965, Rogozov et al., 1970 and Voyevodin et al., 1978) suggest that southward thickening of Ellesmerian equivalents beneath the western portion of Hope basin is quite likely. This monocline is interpreted to continue to the east and form the southern boundary of the Chukchi platform in the study area.

The northern boundary of the Chukchi platform is expressed by the northward thickening of Lower Brookian strata from a tectonic hinge into North Chukchi basin. Increased thickness of Ellesmerian strata reported in North Chukchi basin (Grantz and May, 1984b) suggest that the northern boundary may be expressed in Ellesmerian strata as well. If this is the case, the Chukchi platform may have been peninsular in shape, or possibly an isolated basement high, during deposition of the Ellesmerian sequence.

Figure 22 shows the proposed boundary of the Chukchi platform prior to the formation of Hope basin and Herald arch. The potential ages for hinge formation are listed along the corresponding boundary. The northern and eastern boundaries and their respective ages are according to Grantz and May (1984b). Figure 22 shows that the Chukchi platform obtained its present geometry in Mississippian time (south and east) and Neocomian time (north), and was overprinted by thrusting along Herald arch and subsidence of Hope basin in latest Cretaceous to late "Paleogene" time.

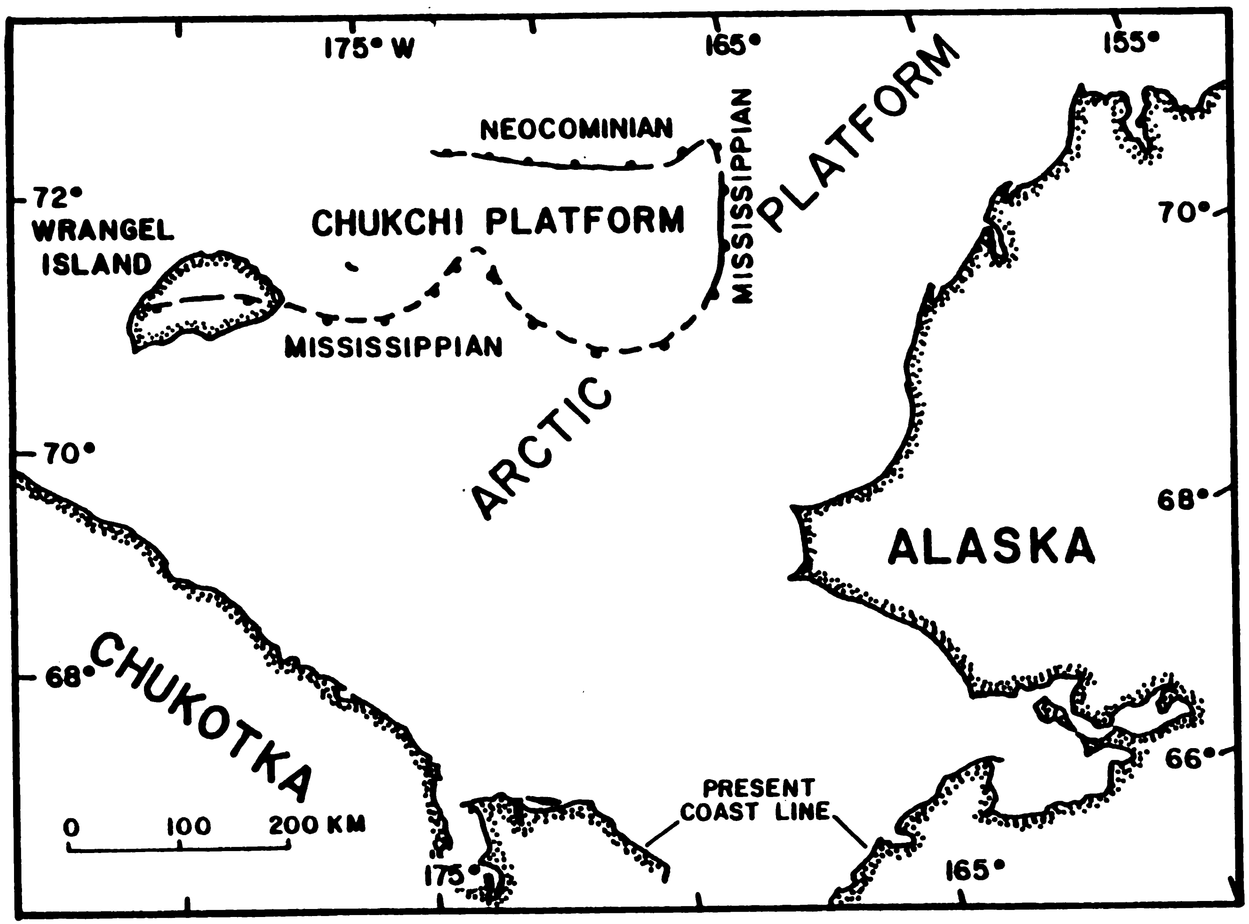

Figure 22 Map showing the geometry of the Chukchi platform in Cretaceous time, prior to the onset of thrusting along Herald arch.

GEOLOGIC HISTORY

Figure 23 through 27 illustrate the major faulting and depositional events recgonized on the Chukchi platform. Each successive diagram represents the change in cross section along 71° 30' N, centered on fault 171° W. Consolidation , metamorphism, uplift, and erosion of the Arctic Platform in mid-Devonian to early Mississippian time created a stable foundation upon which all subsequent sediment deposition occured (Grantz and May, 1984b). Figure 23 shows the morphology of the Chukchi platform in Late Devonian to Middle Mississippian time, as locally derived course clastic Eo-Ellesmerian strata prograded into existing faulted depressions on the Arctic Platform. On a larger scale, downwarping of the Arctic Platform in response the formation of an undescribed basin (south) and Hanna trough (east) created the south and east margins of the Chukchi platform in Mississippian time.

Following an undetermined amount of erosion on the newly formed Eo-Ellesmerian surface in Mississippian time (Grantz and May, 1984a) a thin veneer of Ellesmerian strata filled the remaining irregularities, on

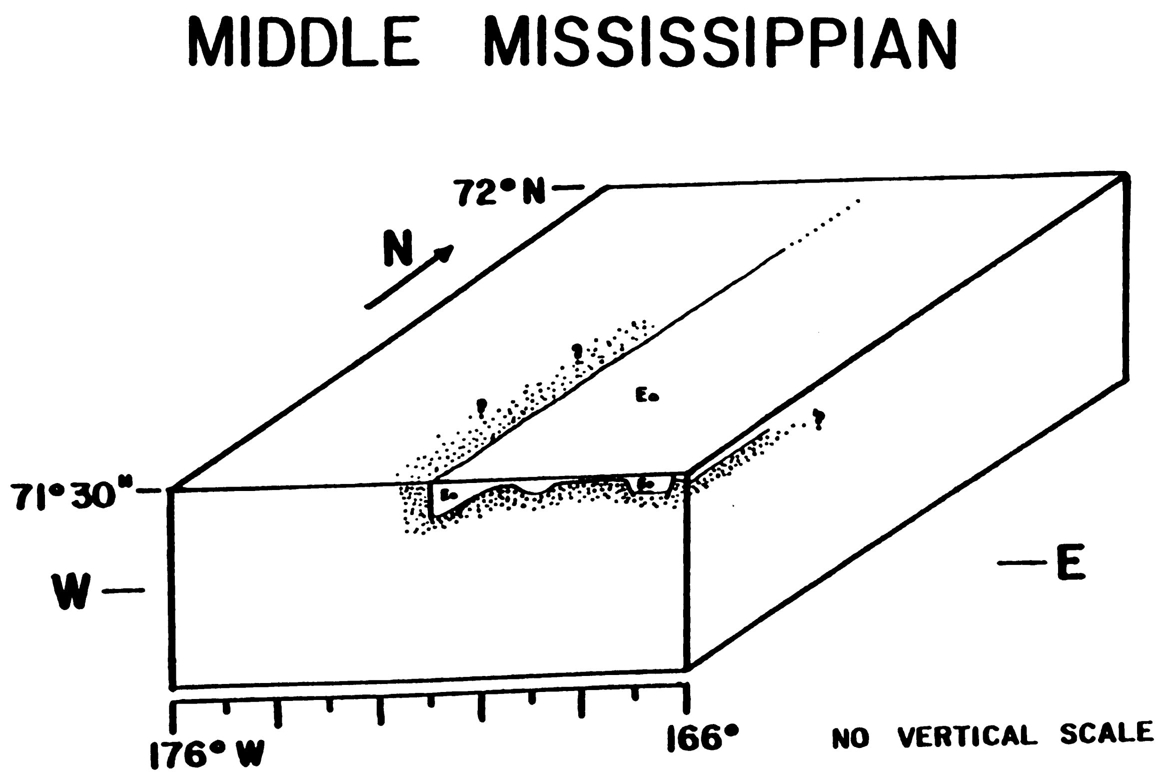

Figure 23 Middle Mississippian structural features and geometry of sedimentary accumulations on the Chukchi platform.
Eo - Eo-Ellesmerian, stipples mark the top of Franklinian basement.

the Chukchi platform. This sedimentary regime continued until the deposition of the Kingak and Pebble Shale units east of the study area in Jurassic to Early Cretaceous time (Figure 24; Grantz and May, 1984b). The lack of this unit over much of the study area suggests that the Chukchi platform was the site of extensive erosion during Jurassic to Early Cretaceous (Grantz and May, 1984a), shedding sediment south (this study), north, and east (Grantz and May, 1984b), where extensive Ellesmerian deposits are identified.

The onset of the Brookian tectonic regime in Jurassic (North Slope; Grantz and May, 1984a) and early Cretaceous time (Chukchi platform) shifted sedimentary provinces from locally exposed areas on the Chukchi platform to a major developing tectonic front to the south. Three episodes of Lower Brookian deltaic sedimentation, derived from exposed proto-Herald arch thrusts or larger subduction-related uplifts south of Chukotka (Box, 1983), prograded northward across the Chukchi platform throughout mid Cretaceous time (Figure 25).

Immediately following, and possibly contemporaneous with, the deposition of Lower Brookian strata in Aptian to Paleogene time, regional thrusting began along Herald arch (Grantz et al., 1970, 1981). The thrusts overprinted the proposed southern boundary of the Chukchi platform

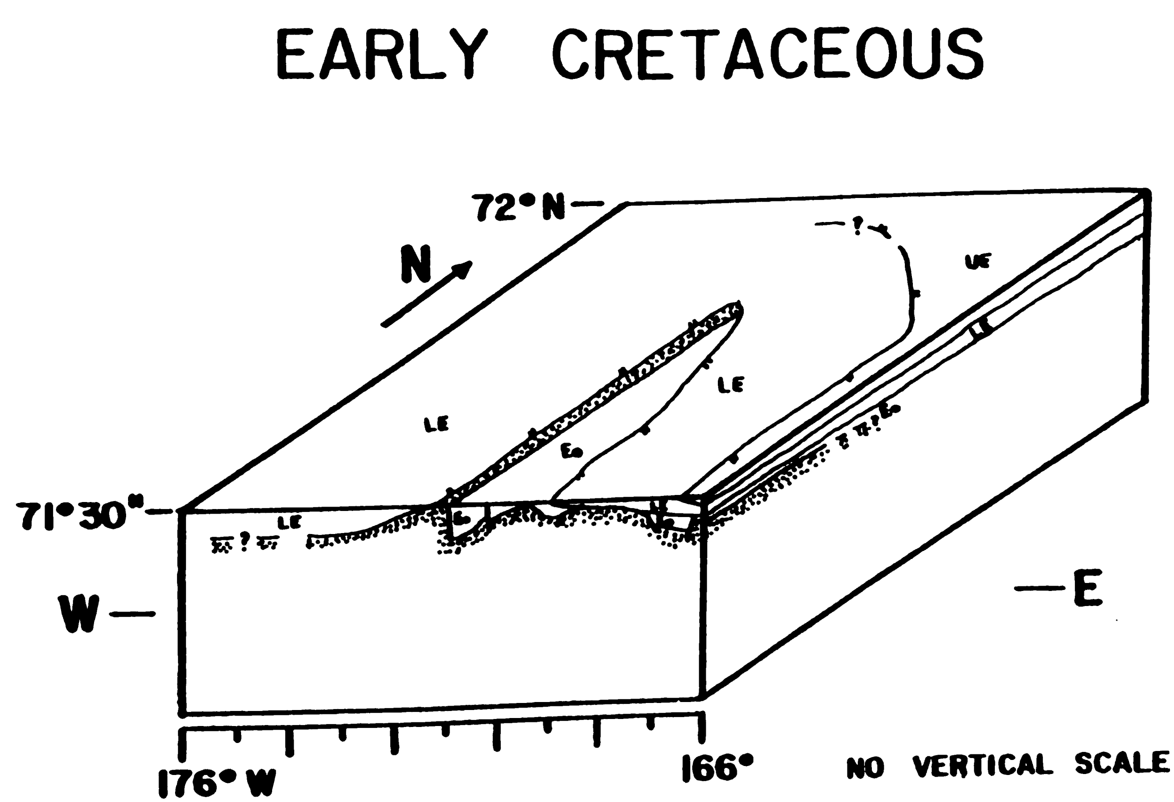

Figure 24 Early Cretaceous structural features and geometry of sedimentary accumulations on the Chukchi platform. Eo - Eo-Ellesmerian, LE - lower Ellesmerian subunit, UE - upper Ellesmerian subunit

MID-LATE CRETACEOUS

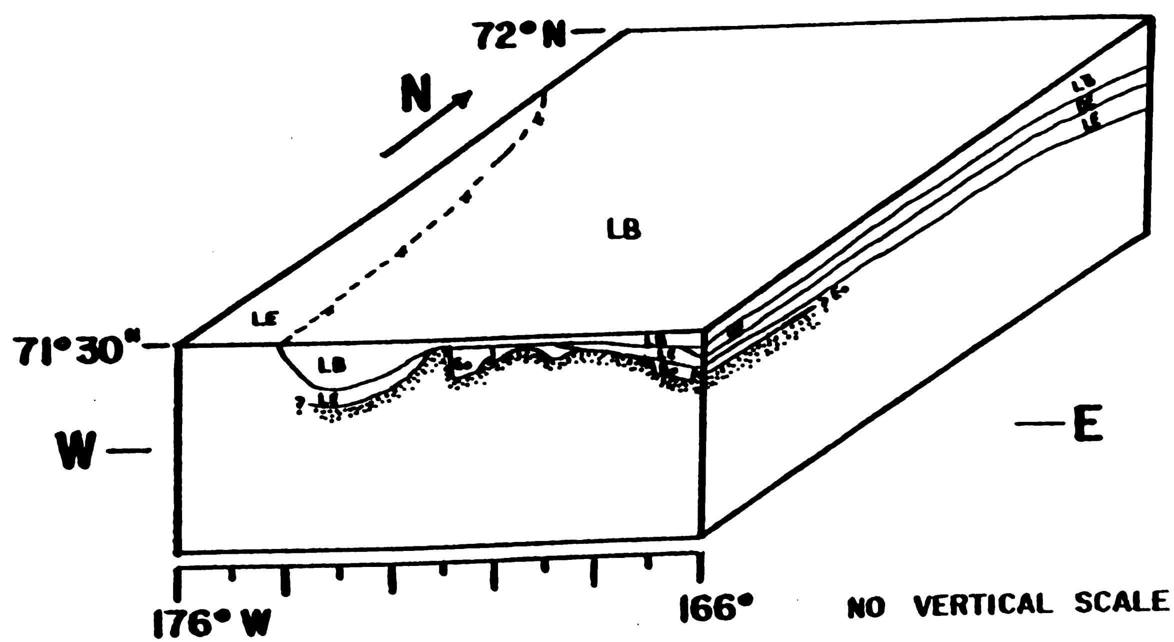

Figure 25 Mid to Late Cretaceous structural features and geometry of sedimentary accumulations on the Chukchi platform.
Eo - Eo-Ellesmerian, LE - lower Ellesmerian subunit, UE - upper Ellesmerian subunit, LB - Lower Brookian

(Figures 10 and 12). It is likely that the thrust sheet rode over the high-standing Chukchi platform and was either eroded to its present subcrop position, or a tear fault developed along 172° W (Figure 26).

Relaxation of northeast-directed compressive stress at the end of the Cretaceous allowed normal faults with offsets of up to 1 km to develop on the Chukchi platform. Normal faults may have formed in response to regional extension, which formed Norton and Hope basins during this period (Fisher et al., 1982, Eittreim et al., 1979). The early stages of normal faulting on the Chukchi platform are similar to the early development of Norton basin (Fisher et al., 1982). Initial faulting and alluvial fan deposition appear to have occurred during the same time periods. Minor wrenching could also affect the formation of faults on the Chukchi platform.

Deposition of shallow marine (east) to nonmarine (west) Upper Brookain sediments, continued from latest Cretaceous unitl late "Paleogene" time. The predominance of reflection characters associated with nonmarine rocks in the western portion of the study area suggest that a paleo-shoreline lay to the west during "Paleogene" time. Exposed fault blocks also provided numerous local sediment sources. The south-facing erosional terraces suggest that a paleo-shoreline flanked

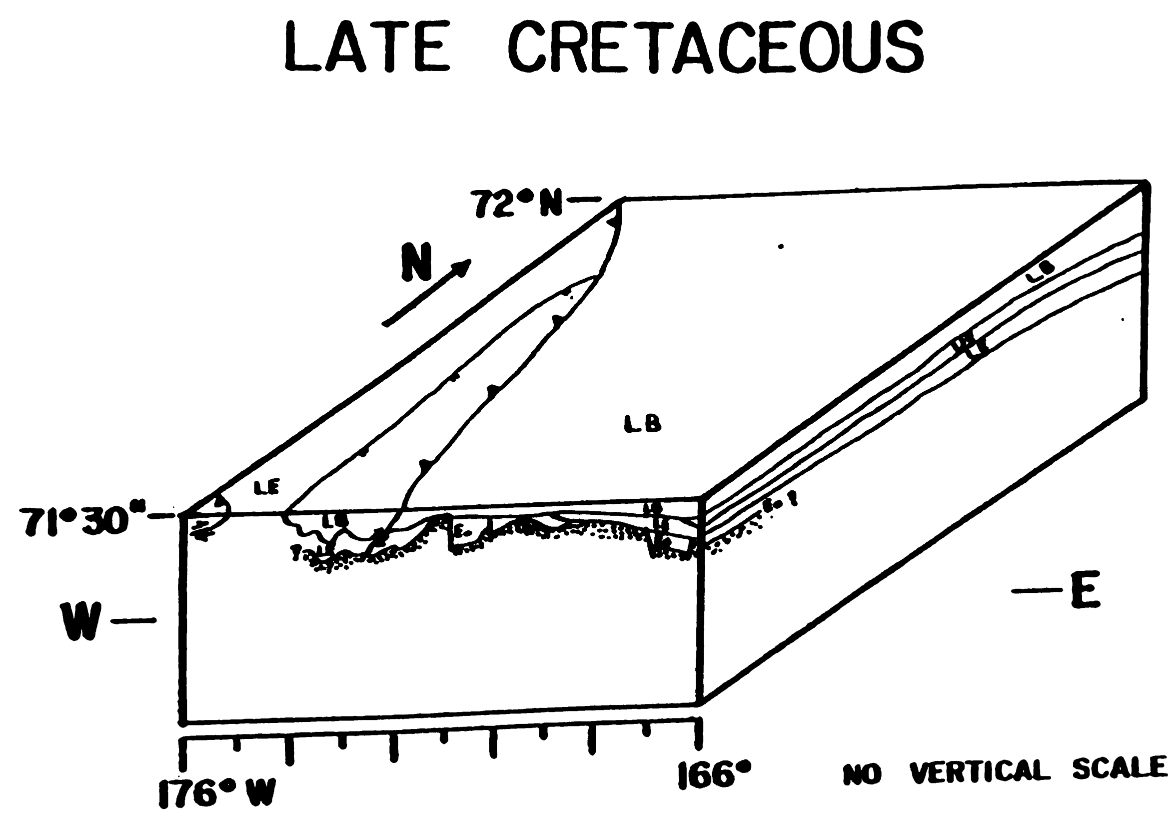

Figure 26 Latest Cretaceous structural features and geometry of sedimentary accumulations on the Chukchi platform. Eo - Ellesmerian, LE - lower Ellesmerian subunit, UE - upper Ellesmerian subunit, LB - Lower Brookian

the Chukchi platform to the south. The area was then uplifted, faulted, and subjected to as much as 1 km of erosion (Figure 27). Upper Brookian rocks probably covered a much more extensive region prior to uplift and erosion. The Chukchi platform is currently the site of marine sedimentation, undisturbed by structural activity.

Tectonic Implications

The Chukchi platform lies in an extremely complex tectonic zone which extends from eastern Siberia to eastern Alaska. Large fault dislocations and deep erosion obscure many features which would aid tectonic reconstructions of the region. Stratigraphic continuity between Alaska and Wrangel Island suggest that the Chukchi Shelf and the north Slope of Alaska have been part of one tectonic block since post-Carboniferous time.

If the Chukchi platform is viewed from the perspective of sedimentary provinces, it compares with Barrovia of Tailleur (1973). Sediment derived from the Chukchi platform during Mississippian to Neocominian (the Ellesmerian sequence) time fills basins to the south, east and possibly the north (Grantz and May, 1984a and b). Sediment sources shifted from the Chukchi platform, in Neocomian time, in response to the Brookian tectonic regime. This sequence of events on the

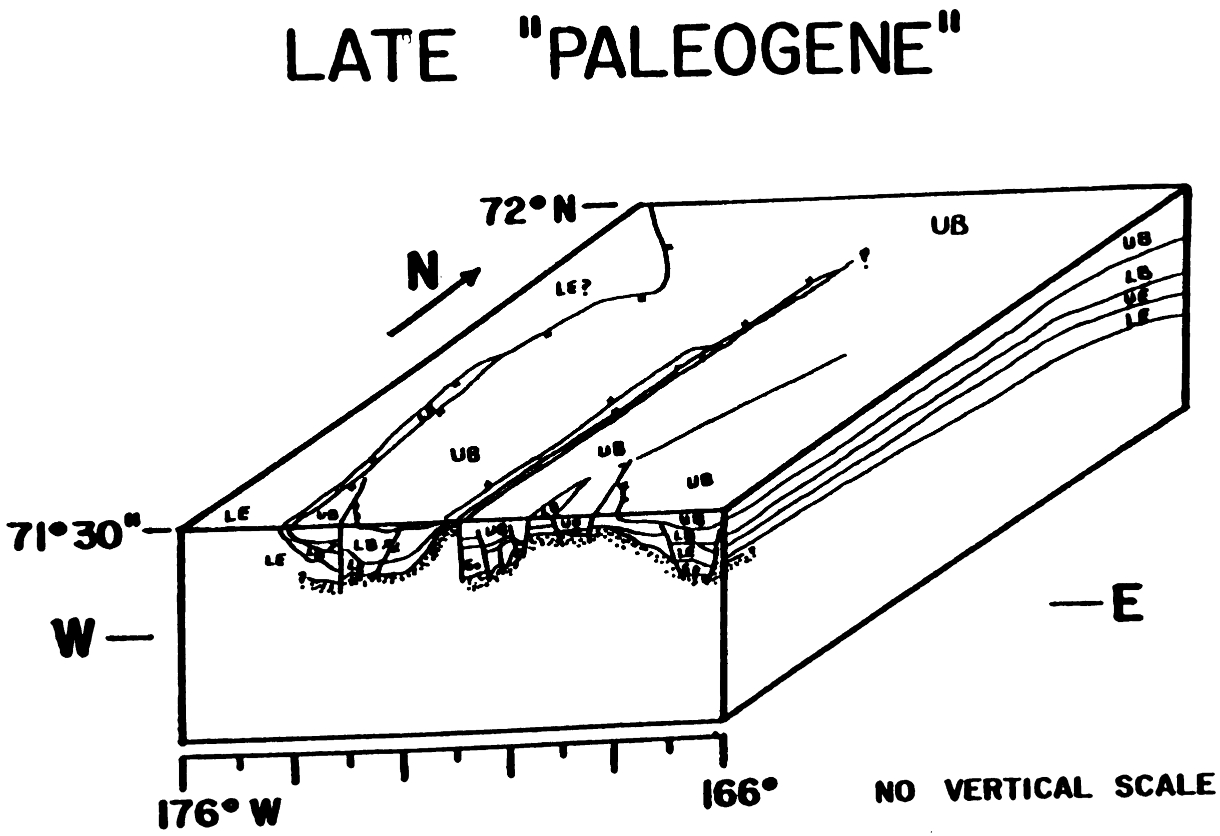

Figure 27 Late "Paleogene" structural features and geometry of sedimentary accumulations on the Chukchi platform. Eo - Eo-Ellesmerian, LE - lower Ellesmerian subunit, UE - upper Ellesmerian subunit, LB - Lower Brookian, UB - Upper Brookian

Chukchi platform is identical with events observed south of Barrow arch in the North Slope, Alaska. I propose that the tectonic hinge identified by the thinning of Ellesmerian strata onto the Chukchi platform and Barrow arch may be a continuous feature. However, the thinning of Ellesmerian to Lower Brookian strata is probably the result of different structures. In this interpretation the Chukchi platform represents a stranded remnant of Barrovia, isolated by Neocominian rifting (Grantz and May, 1983), or strike-slip motion (Vogt et al., 1983, and others).

Structural features on the Chukchi platform and Chukchi Shelf parallel major structural features on Chukotka. This suggests that the tectonic development of the Chukchi Shelf may be synchronous with the tectonic evolution of Chukotka and eastern Siberia.

The lack of precise geologic information on Chukotka and eastern Siberia make correlation of tectonic events to these regions difficult. Box (1983) proposes that southward-dipping subduction occured along a continuous zone from the Anyui suture to eastern Alaska in Late Cretaceous time. The plate boundary is located in central Chukotka in Box's study. If this interpretation is correct, and the age of suturing coincides with the age of thrusting on the Chukchi Shelf, Herald arch may have formed as a result of plate a collision south of Chukotka.

Relaxation of compression in the northern Bering and Chukchi Seas in latest Cretaceous time (Fisher et al., 1983) initiated a normal faulting regime. Regional extension, south of Herald arch, initiated normal faulting in the tectonically thickened region.

CONCLUSIONS

1. The southern and eastern boundaries of the Chukchi platform formed in Mississippian time during early stages of downwarping of the Arctic Platform in Hanna trough. The proposed southern boundary is overprinted by Herald arch and Hope basin. The northern boundary formed in response to deep subsidence in North Chukchi basin in Neocomian time. No western boundary has been identified.

2. The highstanding Chukchi platform shed sediment to the east and north in Mississippian to Neocomian time (Grantz and May, 1984a). This study proposes that sediment is also shed southward from Mississippian to Neocomian time. Isolated accumulations of Eo-Ellesmerian strata are identified in faulted and topographic depressions on the Chukchi platform.

3. Three episodes of prograded deltaic sedimentation of the Lower Brookian sequence form a 0.3 second veneer over much of the study area. However, 1.8 seconds (two-way time) of Lower Brookian strata fill a trough west of 171° W.

4. Regional thrusting ramped allochthonous Franklinian, Ellesmerian,

and Lower Brookian rocks onto the eastern flank of the Chukchi platform. in mid-Cretaceous time. Thrusting straddles the southern and western parts of the study area. At least 25 km of north to northeast directed displacement is probable.

5. Relaxation of compressive stress and the development of regional extension formed numerous normal faults, with offsets up to 1 km, on the Chukchi platform. These faults may have a component of oblique-slip motion. Alluvial fan development, intermediate in age between Lower and Upper Brookian, suggests that initial faulting rates exceeded sedimentation rates in latest Cretaceous time.

6. Normal faulting and deposition of Upper Brookian strata ended in late "Paleogene" time.

7. Erosional terraces, and reflection characters associated with marginal marine sedimentation, suggest that a paleo-shoreline lay along the southern edge of the Chukchi platform, facing Hope basin, in mid-"Paleogene" time. A corresponding paleo-shoreline must exist on the northern edge of the Chukchi platform. Terraces on fault scarps separating the Chukchi platform from Hope basin suggest that these faults, and Hope basin, form in latest Cretaceous.

8. A late stage of faulting in late "Paleogene" time, and at least 1 km of

erosion, significantly reduces the preserved depositional limits of the Upper Brookian sequence. No structures show activity post-dating the "Neogene" unconformity.

9. Recent sediment, 200 to 300 meters thick, overlies the "Neogene" unconformity throughout the study area.

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