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GEOLOGY OF THE BEAUFORT-MACKENZIE BASIN

F.G. YOUNG,
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CONTENTS

Illustrations

GEOLOGY OF THE BEAUFORT-MACKENZIE BASIN

Abstract

The pericratonic Beaufort-Mackenzie Basin is a structural depression resulting from extensional and wrench tectonics near the continental margin of the southern Beaufort Sea. Down-to-basin block faulting along the Aklavik Arch Complex forms its southeastern margin, while Columbian to Laramide uplifts of the eastern nose of the Brooks Range Geanticline and Romanzof Uplift flank the basin on the southwest.

Sedimentation in the basin began in Late Triassic time when marine waters flooded the northwestern corner of Yukon Territory. Following a hiatus at the end of the Triassic, continuous sedimentation commenced in Early Jurassic time when neritic sands were deposited adjacent to the Peel Landmass and pelitic equivalents were transported westward into Blow Trough and northeastward into Kugmallit Trough. Epicontinental sedimentation continued into Early Cretaceous time, and was followed by the development of fluviodeltaic systems along the flank of the Aklavik Arch Complex. Syndepositional and later Laramide faulting in the Complex formed structures which have yielded significant amounts of hydrocarbons near Parsons Lake.

During the Early Cretaceous, a major, right-lateral, strike-slip fault propagated across northern Alaska to the south side of Old Crow Stock (Kaltag Fault). Its presumed continuation, the Porcupine Fault, and the Yukon Fault to the southeast converge and veer northward immediately west of Richardson Mountains. Northward from this restraining bend, these faults splay into an array of near-vertical faults with both reverse and right-lateral displacements. This array continues offshore to the inner side of the uplifted rim of the continental margin. Within the Blow Trough, a depression exaggerated by movements along these faults, the Aptian-Albian flysch sediments were deposited, while immediately east of Cache Creek High, a condensed section of phosphatic iron carbonates developed. Coeval littoral and alluvial sandstones deposited near the crest of the Eskimo Lakes Arch of Tuktoyaktuk Peninsula contain oil near Atkinson Point.

Following a long interval during the Late Cretaceous of relative quiescence and slow mud accumulation, the Laramide Orogeny commenced in late Late Cretaceous time and continued into the late Cenozoic. Episodic uplift and erosion in northern Alaska and Yukon and along the entire Mackenzie Arc provided the detritus for a thick molassic succession which prograded seaward toward the continental margin in a series of progressively offlapping cycles. In the Richards Island Basin, prodeltaic muds were intruded into coeval and younger fluviodeltaic sediments to form diapiric structures that

Résumé

Le bassin de Beaufort-Mackenzie, établi en bordure d'un craton, est une dépression structurale due à une tectonique d'étirement et de basculement près de la marge continentale de la partie sud de la mer de Beaufort. Des blocs faillés en escalier descendant vers le centre du bassin, le long de l'arche complexe d'Aklavik, constituent sa bordure sud-est, alors que les soulèvements des orogenèses du Columbien et du Laramide de l'extrémité orientale du géanticlinal du chaînon Brooks et le soulèvement de Romanzof bordent le bassin au sud-ouest.

La sédimentation a commencé dans le bassin au Trias supérieur au moment où les eaux marines ont envahi la zone nord-ouest du Yukon actuel. Après une interruption au Trias supérieur, la sédimentation continue a commencé au Jurassique inférieur et des sables néritiques se sont déposés à côté de la masse continentale de Peel; les équivalents pélitiques ont été transportés vers l'ouest dans la dépressions de Kugmallit. La sédimentation épicontinentale s'est poursuivie au cours du Crétacé inférieur, et a été suivie par la formation de systèmes fluviodeltaïques le long du flanc de l'arche complexe d'Aklavik. Les failles contemporaines de la sédimentation, puis celles de l'orogenèse du Laramide qui découpent l'arche ont formé des structures qui ont fourni des quantités importantes d'hydrocarbures, près de Parsons Lake.

Au Crétacé inférieur, une faille de décrochement dextre importante s'est développée en travers du nord de l'Alaska jusqu'au sud de Old Crow Stock (faille de Kaltag). La faille de Porcupine et la faille du Yukon, qui en sont le prolongement supposé vers le sud-est, convergent puis s'orientent vers le nord juste à l'est des chaînons Richardson. A partir de cette courbe, en direction du nord, ces failles se disposent en un faisceau de failles quaise-verticales: failles inverses ou décrochements dextres. Cette disposition se poursuit en mer jusqu'au côté intérieur de la bordure soulevée de la marge continentale. Dans la dépression de Blow, qui a été accentuée par les mouvements survenus le long de ces failles, se sont déposés les sédiments de type flysch de l'Albien et de l'Aptien, alors qu'immédiatement à l'est de Cache Creek High, s'est formée une série condensée de roches carbonatées phosphatées ferrifères. Les grès de la même époque, littoraux et alluviaux, qui se sont déposés près de la crête de l'arche d'Eskimo Lakes, dans la péninsule de Tuktoyaktuk, contiennent du pétrole près de la pointe Aktinson.

Après un long intervalle de calme relatif et de lente accumulation de boues au Crétacé supérieur, l'orogenèse du Laramide commença à la fin du Crétacé supérieur et se poursuivit jusqu'à la fin du Cénozoïque.

are hydrocarbon-bearing. This region is defined as the "lutokinetic diapir field". Northwest of the Kaltag-Rapid Fault Array, continued right-lateral movements of the "Alaska Block" resulted in the intrusion of Lower Cretaceous and older shale masses into the Upper Cretaceous and Tertiary sequences. This region is called the "tectonokinetic diapir field", and also is believed to have a favourable petroleum potential.

Des soulèvements et une érosion épisodiques, dans le nord de l'Alaska et du Yukon ainsi que le long de l'ensemble de l'arche ont fourni la source de sédiments détritiques d'une épaisse succession de molasse qui s'est développée en direction du large, vers la marge continentale, en une suite de cycles se découvrant progressivement. Dans le bassin de Richards Island, les boues des couches de base sont interpénétrées par des sédiments contemporains ou ultérieurs fluviodeltaïques et constituent des structures diapiriques contenant des hydrocarbures. Cette région est définie comme le "domaine des diapirs dus à la plasticité des boues". Au nord-ouest du faisceau de failles de Kaltag-Rapid, la persistence des mouvements des décrochements dextres du "bloc de l'Alaska" a provoqué l'intrusion de masses de schistes du Crétacé inférieur, ou plus anciens, dans les successions du Crétacé supérieur et du Tertiaire. Cette région est appelée "le domaine des diapirs d'origine tectonique" et on pense qu'elle a aussi un potential pétrolier favorable.

GEOLOGY OF THE BEAUFORT-MACKENZIE BASIN

INTRODUCTION

The Beaufort-Mackenzie Basin is a pericratonic basin situated adjacent to the southwestern limit of the northern Canadian continental margin. In geographic terms, it underlies the northern Richardson Mountains and Yukon Coastal Plain, the modern Mackenzie Delta, Tuktoyaktuk Peninsula and the adjacent offshore region beneath Beaufort Shelf out to the 200 m (656 ft) isobath. The area thus enclosed is approximately 155 000 km^2 (60 000 sq miles) (Fig. 1). It can be classed as a Mesozoic and Cenozoic successor basin, structurally and stratigraphically discordant above Proterozoic and Paleozoic sediments. Sedimentation began approximately 200 million years ago (Late Triassic) and continues at present in the active area of Mackenzie Delta. The basin fill consists predominantly of clastic terrigenous rocks which display an evolution of classical geosynclinal character [in depositional phases (Young, 1973b)]. These include an epicontinental phase at the base of the sequence, followed by a syntectonic flyschoid phase west of Mackenzie Delta, and then completed by a long-lived molassic phase beneath the northern Yukon Coastal Plain and modern Mackenzie Delta. These depositional phases represent responses to specific periods of epeirogenic and orogenic tectonism in the British, Barn and Richardson Mountains to the west and within the various components of the Aklavik Arch Complex.

The Beaufort-Mackenzie Basin is bounded structurally by the Romanzof Uplift in the west, the Aklavik Arch Complex in the southeast, and the continental margin. Throughout its depositional history, the boundaries of the basin varied considerably due to the various phases of epeirogenic and orogenic tectonism affecting the position, degree and longevity of marine transgressions and regressions.

PREVIOUS AND ALLIED STUDIES

Much of the interpretation presented in this paper is based on the pioneering work of the Geological Survey of Canada's Operation Porcupine, under the leadership of D.K. Norris (Norris *et al.*, 1963; Norris, 1970, 1972, 1973) and the independent stratigraphic work of J.A. Jeletzky (1958, 1960, 1961a, b, 1967, 1971a, 1972, 1974, 1975c). Important stratigraphic and biostratigraphic data have been provided also by Martin (1959), Mountjoy (1967a, b), Chamney (1971, 1973), Lerand (1973), Coté *et al.* (1975), Hawkings and Hatlelid (1975), Bowerman and Coffman (1975), Poulton and Callomon (1976), Brideaux (1973, and *in* Barnes *et al.*, 1974), Brideaux and Jeletzky (*in* Barnes *et al.*, 1974), and Staplin (1976). Important geophysical papers have been published by Hofer and Varga (1972) and Sirrine (1973).

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RECENT AND CURRENT STUDIES

Exploratory drilling began in the Mackenzie Delta in 1965 when the B.A.-Shell-I.O.E. Reindeer D-27 borehole penetrated a thick succession of Tertiary deltaic and Cretaceous marine sediments. Since that time, several important gas and oil discoveries have been made in rocks of Tertiary and Early Cretaceous age both on land and in the adjacent offshore region. The intense drilling and geophysical activity by the petroleum industry, in addition to surface stratigraphic and structural studies over the past several years by the Geological Survey of Canada, have revealed that the Beaufort-Mackenzie Basin possesses a highly complex architecture, the detailed nature of which is subject to considerable debate. The objective of the present paper is to describe, in some detail, the structural, stratigraphic, and sedimentological concepts of the development of the basin as they are understood by the authors.

The major subjects for discussion include:

1. The basic structural and stratigraphic elements;
2. The depositional styles and paleogeography associated with the various sedimentary sequences;
3. The tectonic history and structural development of the basin; and
4. The petroleum potential of the basin.

AREAS OF RESPONSIBILITY

Yorath began studies of the Beaufort-Mackenzie Basin in 1968 following mapping and stratigraphic work on the Cretaceous and Tertiary successions east of Mackenzie Delta during Operation Norman. He then carried out subsurface stratigraphic studies of the basin during the initial period of exploration activity. During the past four years, he has concentrated his interest in the adjacent offshore area and on the tectonic style of the area as it relates to the origin of the Arctic Ocean Basin.

Young began surface stratigraphic studies west of Mackenzie Delta in 1970 and subsequently extended

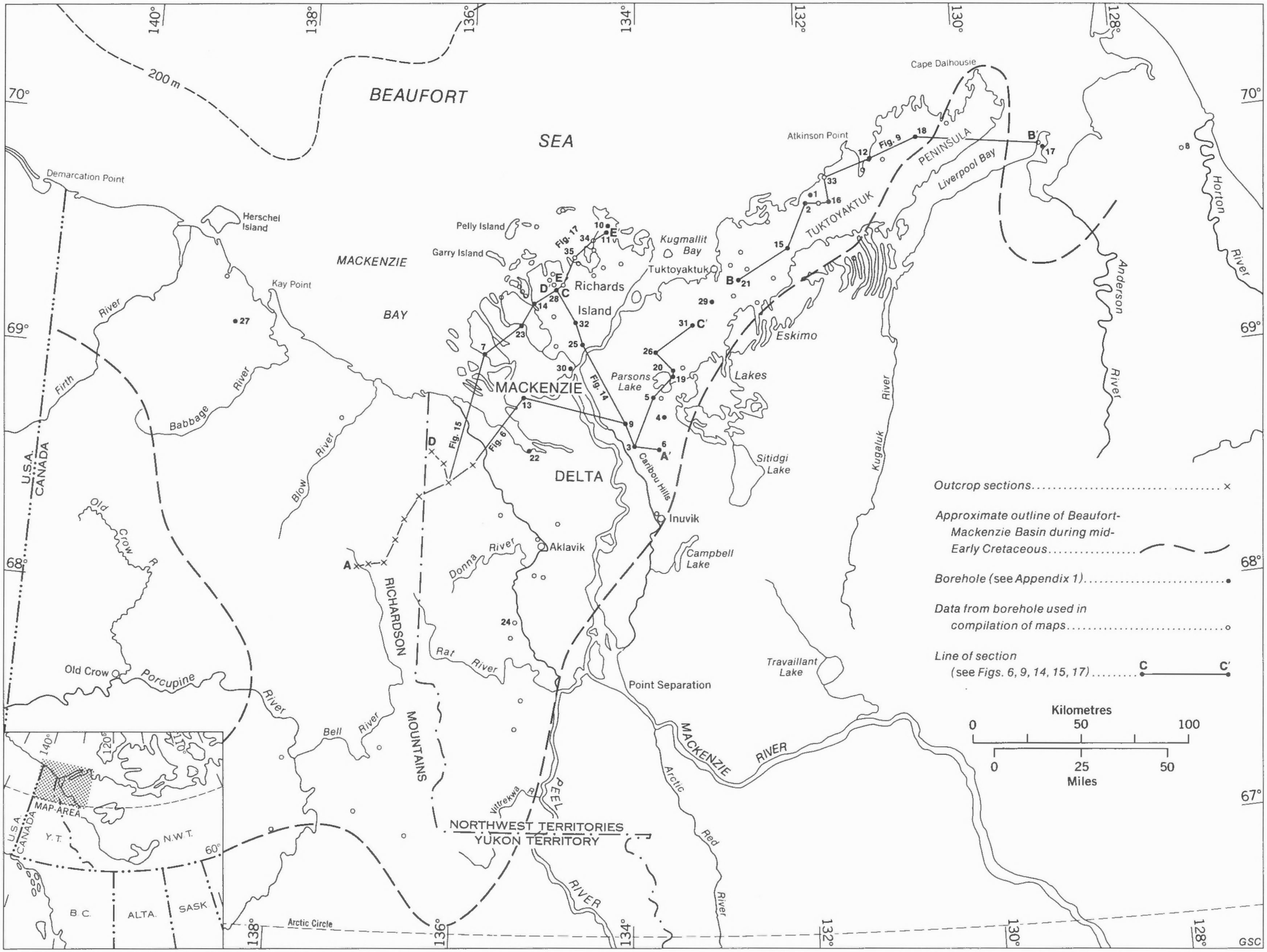


FIGURE 1. Index map showing geographic features and location of boreholes

his work to include subsurface stratigraphy and sedimentology. He is responsible in this paper for stratigraphic and sedimentological interpretations of the Mesozoic and Cenozoic rocks both west of and in the subsurface of Mackenzie Delta.

Myhr commenced subsurface stratigraphic studies in the area in 1972 and has contributed to the correlation framework and sedimentological interpretations.

The stratigraphic data on which this paper is based are derived from numerous field sections studied by the authors and by J.A. Jeletzky, as well as from approximately 100 exploratory boreholes released from confidential status as of March 31, 1976 (Fig. 1). The location of boreholes mentioned in the text and illustrated on the cross-sections are recorded in the Appendix and their locations illustrated on Figure 1. Structural data were obtained from personal observations by the authors and largely from the numerous reports by D.K. Norris. Some of the concepts related to tectonic history and structural style of the basin are derived from the present work of D.K. Norris.

ACKNOWLEDGMENTS

We wish to acknowledge our gratitude to many officers of the Geological Survey of Canada and individuals of the petroleum industry, with whom a free exchange of ideas over the years has provided many of the necessary data and influenced considerably the evolution of concepts related to basin geometry and development. Our appreciation is expressed to H.R. Balkwill and A.D. Miall of the Geological Survey who critically reviewed the manuscript and made many constructive suggestions for its improvement.

GEOLOGICAL SETTING

INTRODUCTION

The Beaufort-Mackenzie Basin is enclosed structurally by the northern Interior Platform, the Cordilleran Orogen and the northern continental margin. In terms of basin classification, it belongs to the category "Unstable Coastal Margin Basins" of McCrossan and Porter (1973) and to a combination of "Extracontinental Downwarp to Small Ocean Basins" and "Tertiary Deltas" of Klemme (1971). Although these classifications are compatible with information then available, they now are regarded as overly simplistic in view of modern data and interpretations pertaining to the origin of the Canada Basin, north Yukon wrench tectonics (Yorath and Norris, 1975), and the role of cratonic arches both beneath Mackenzie Delta and the northern rim of the Sverdrup Basin (Meneley *et al.*, 1975). Contrary to the thesis adopted by Lerand (1973), it is assumed herein that the floor of the Canada Basin is underlain by oceanic crust of Mesozoic or younger age and that the development of the Beaufort-Mackenzie Basin is related to Arctic plate tectonics. Discussion of the details of this relationship is beyond the scope of this paper; however, for the reader interested in the arguments, both in favour of and opposed to modern Arctic Ocean plate tectonic concepts, the following papers are suggested: Carey (1955), Miall (1973), Churkin (1973), Ostenso and Wold (1973), Tailleur (1973), Meyerhoff (1973), Herron *et al.* (1974), Yorath and Norris (1975), Clark (1975) and Jeletzky (1975c).

SUMMARY OF TECTONIC ELEMENTS

Recently, a large number of tectonic elements have been named in the region; some are strictly Laramide (Campanian to late Eocene, *sensu* Douglas, 1970) features, others are exclusively older and still others have sustained multiple episodes of deformation concluded by Laramide structural expression. An attempt is made herein to suggest a group of names for the exclusively ancient elements as distinct from those features with principally Laramide expression. In a generic sense, the term "uplift" is reserved for structurally and topographically elevated areas, manifest in the present geometry as anticlinoria, horsts, etc. This is distinguished from an "arch" or "high" in that the latter are considered to include positive crustal areas, which did not subside as rapidly as surrounding areas during sedimentation, and which are recognized mainly on the basis of internal and external stratigraphic relationships. Commonly these older elements were remobilized during Laramide deformation. The term "arch" is used for relatively large, antiformal positive areas, whereas a "high" is smaller in areal extent and not necessarily anticlinal in cross-section. Figures 2 and 3 illustrate Mesozoic (Columbian) and Tertiary (Laramide) tectonic elements, respectively.

Mesozoic (Columbian) tectonic elements

The Romanzof Uplift (Fig. 2) (Payne, 1955) in northern Alaska developed principally during Columbian (Late Jurassic to earliest Late Cretaceous, *sensu* Douglas, 1970, p. 450) tectonism, and in Canada is expressed as the British and Barn Mountains. Earlier Ellesmerian (Late Devonian-Early Missippian) movements are indicated by the pronounced angular unconformity between the widespread Mississippian Kekiktuk Formation and the Proterozoic Neruokpuk Formation in the Barn Mountains (Norris, 1974). Late Precambrian deformation in Romanzof Uplift is suggested where a Lower and Upper Cambrian trilobite-bearing volcanic agglomerate and limestone unit rests with angular unconformity on the Neruokpuk Formation (Norris, *ibid.*).

The Keele-Old Crow Landmass is a term first used by Jeletzky (1971a, 1972) to describe the Late Jurassic and Early Cretaceous eastward expansion of the ancestral Brooks Range of Alaska into western Yukon. This landmass was situated adjacent to a trough named the Porcupine Plain-Richardson Mountains Marine Trough by Jeletzky (1975c). This latter feature for the most part is the same as Blow Trough which the authors believe was connected to the Kandik Basin of east-central Alaska via the Keele-Kandik Trough, rather than extending southward into Eagle Plain as argued by Jeletzky (*ibid.*). Northern Eagle Plain appears to have been the site of the Eagle Arch (Moorhouse, 1966; Young, 1975a), a northeasterly trending culmination bounding the southeast side of the Keele-Kandik Trough.

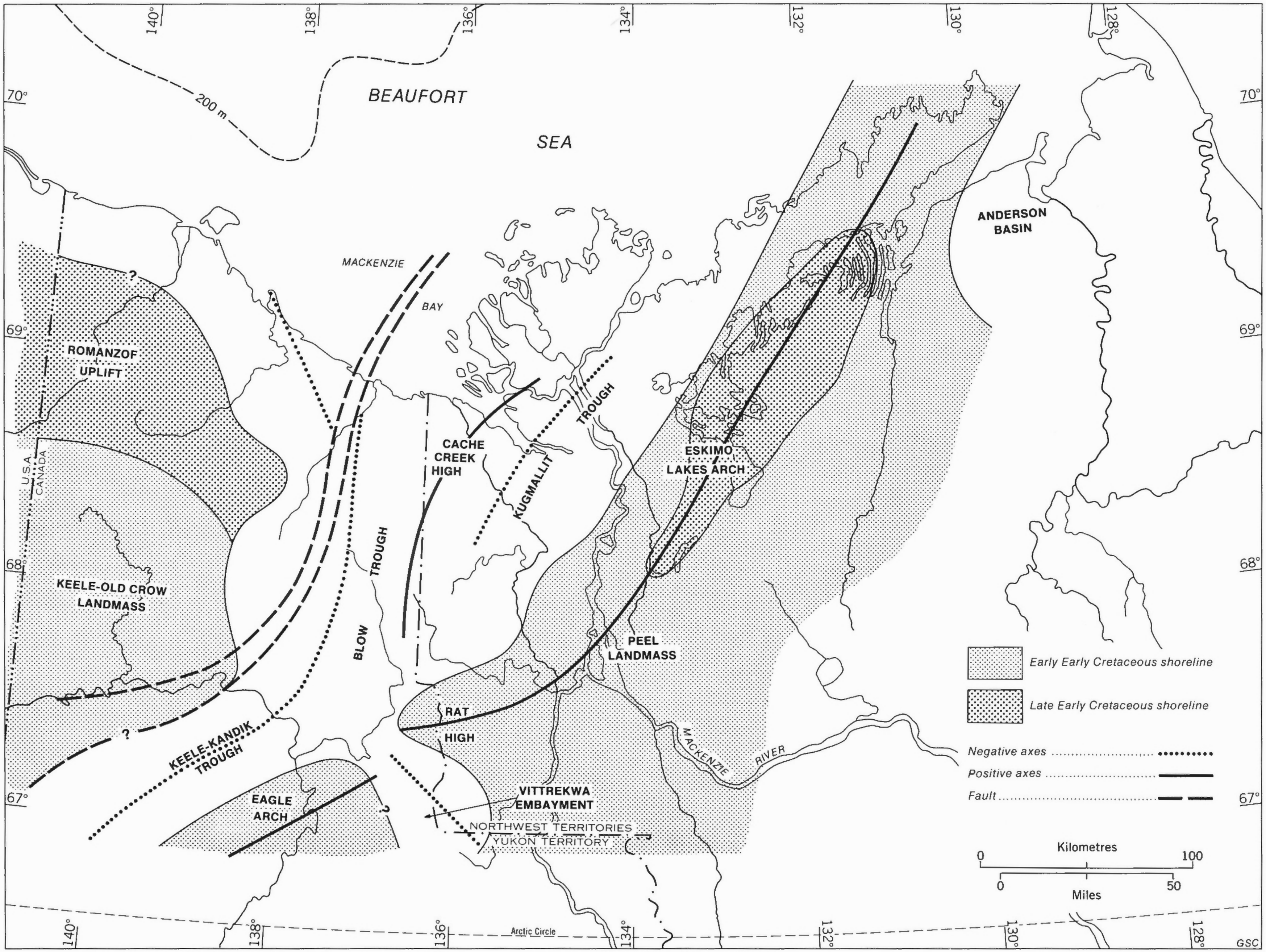


FIGURE 2. Map showing Columbian tectonic elements

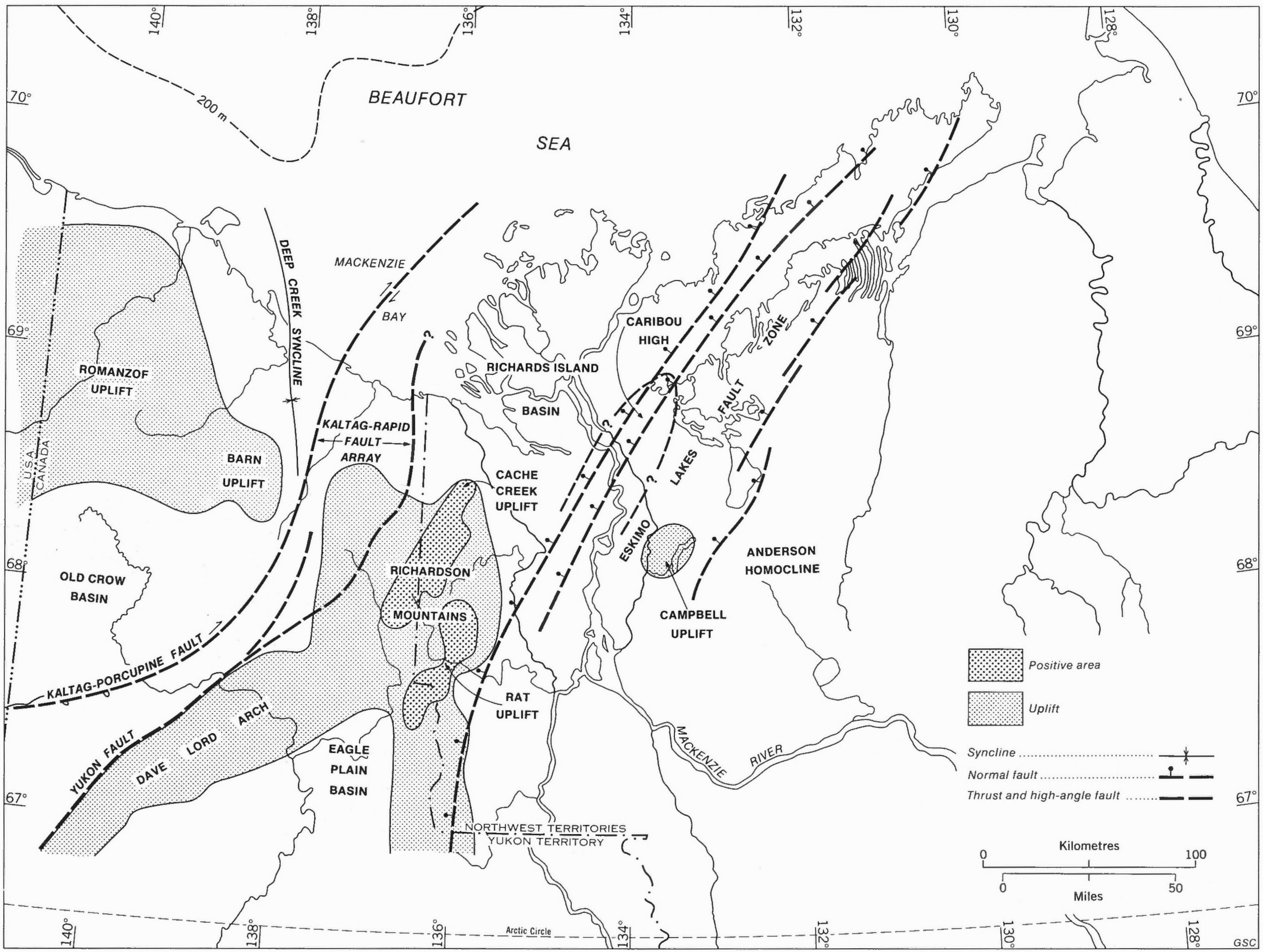


FIGURE 3. Map showing Laramide tectonic elements

The Peel Landmass, illustrated by Jeletzky (1975c), was a broad region of the exposed northern Interior Platform throughout much of Jurassic and Early Cretaceous time. Components of this landmass consisted of the Eagle Arch, Rat High, Campbell Lake High and Eskimo Lakes Arch, which, together with the Cache Creek High in the centre of the broad Jurassic and Early Cretaceous basin (Blow Trough and Kugmallit Trough), constituted the Aklavik Arch Complex.

The "Aklavik Arch" was one of the first tectonic elements to be recognized in the region (Jeletzky, 1961a). As originally defined, the arch included the Rat and Campbell Uplifts as an earliest Cretaceous anticlinal structure. More recent work by Norris (1974) has shown the arch to consist of a number of components arranged in a right-hand *en echelon* fashion. In Table 1 of Norris (*ibid.*), five angular unconformities and an equal number of disconformities partition the stratigraphic succession in the arch; these attest to a prolonged tectonic history extending from late Proterozoic to Tertiary time, during which the various components of the arch were intermittently and independently active (Norris, 1974; Yorath and Norris, 1975). The complex nature of this feature, revealed more clearly by geophysical exploration (Lerand, 1973) and drilling by the petroleum companies, led Yorath and Norris (*op. cit.*) to rename the feature the Aklavik Arch Complex. The Eskimo Lakes Arch, a part of the complex, is a term introduced herein to describe the elongate positive element extending northeastward from the Campbell Uplift into the offshore area adjacent to northeastern Tuktoyaktuk Peninsula. Throughout most of its length, the arch is buried beneath Quaternary drift, and Tertiary and Upper Cretaceous sedimentary rocks. The Cache Creek High (Fig. 2) was a positive element during Jurassic and Early Cretaceous time and had a marked influence on sediment distribution and facies. Other components of the complex include the Eagle Arch and Rat High, which represent Jurassic and Early Cretaceous structural culminations within the Peel Landmass and which likewise influenced sediment distribution and facies. This influence is particularly evident in the Vittrekwa Embayment where coarse Middle Jurassic to Lower Cretaceous clastic sediments were introduced by major streams into a paleogeographic reentrant of Blow Trough.

Situated to the northwest of the Eskimo Lakes Arch and limited by the Cache Creek High, is the Kugmallit Trough. Like the Blow Trough, it was the site of thick accumulations of Jurassic and Lower Cretaceous sediments.

Flanking the northeastern part of the Eskimo Lakes Arch on its southeastern side is the Anderson Basin (Lerand, 1973), in which Lower Cretaceous sedimentary rocks are relatively thick and change from nonmarine sandstones on its flank to marine mudstone and shale toward its axis.

The Rapid Fault Array is a tectonic element that probably played a major role in the development of the Upper Jurassic and Lower Cretaceous geology of northern Yukon and Mackenzie Delta. Named by Norris (*in* Yorath and Norris, 1975), the array consists of a bundle of north-trending faults with substantial vertical and probable right-lateral separation. The array is illustrated as a continuation of the Kaltag-Porcupine Fault which, in Alaska, has been identified as a major, right-lateral strike-slip fault with between 65 and 130 km (40 and 80 miles) of separation (Patton and Hoar, 1968; Tailleur and Brosgé, 1970). Although the separation in Alaska was recognized as occurring in post-Early Cretaceous time (possibly as young as Tertiary), Young (1974) illustrated substantial pre-Aptian vertical separation across the Blow Fault Zone which constitutes the westernmost component of the Rapid Fault Array. If the Kaltag Fault and Rapid Fault Array are geometrically and kinematically related, then initial displacements may have occurred in Alaska earlier than the time suggested by Patton and Hoar (1968) or the age of separation decreases from northern Yukon to western Alaska. Within the Blow Trough which is traversed by the array, thick Aptian to Albian flyschoid clastics were deposited which, in turn, were coextensive with similar sediments developed within the foredeep adjacent to the rising Romanzof Uplift.

Late Cretaceous and Tertiary (Laramide) tectonic elements

During the Late Cretaceous and Tertiary, many of the tectonic elements described above sustained Laramide deformation. The Romanzof Uplift developed its final expression as the British and Barn Mountains (Fig. 3) and acted as a source area for Upper Cretaceous and Tertiary clastic sediments beneath Beaufort Shelf. The Keele-Old Crow Landmass subsided to receive a relatively thin cover of upper Mesozoic and Tertiary nonmarine clastics.

The Dave Lord Arch, a component of the Aklavik Arch Complex, developed within the site of the former Keele-Kandik Trough. Other elements of the complex sustained vertical uplift resulting in trends slightly different from their older expressions (e.g. Cache Creek and Rat Uplifts).

One of the principal elements that contributed to the Late Cretaceous and Tertiary development of the Beaufort-Mackenzie Basin is the Eskimo Lakes Fault Zone (Coté *et al.*, 1975). This northeasterly trending family of down-to-basin faults, previously termed the Tuktoyaktuk Fault Flexure Zone by Lerand (1973), appears to represent reactivated displacement on ancient faults which received their present geometry during Laramide deformation. Gradients across these faults, and across those bounding the Cache Creek Uplift, permitted the deposition of thick Upper Cretaceous and Tertiary molassic clastic sediments in the Kugmallit Trough and within the Richards Island Basin, the latter being the term used herein for the principal Cenozoic depocentre beneath Richards Island and the adjacent offshore area.

A relatively small positive element, here called the Caribou High, underlies the Caribou Hills just northwest of and parallel to the Eskimo Lakes Fault Zone. The uplift is early Laramide and predates the deposition of the Reindeer Formation (Fig. 3).

The Eskimo Lakes Fault Zone transects the Aklavik Arch Complex (Eskimo Lakes Arch) and the principal fault of the zone (Eskimo Lakes Fault of Coté *et al.*, 1975) is believed to link up with the Trevor Fault which bounds the eastern limb of the Richardson Anticlinorium (Yorath and Norris, 1975). Although extensional movements appear to express mainly the structural style of the zone, right-lateral slip has been suggested by Jeletzky (1975a) on the Donna River Fault which almost certainly is a component of the zone.

STRATIGRAPHIC REVIEW

The ages, correlations, and areal distribution of the various formations and unnamed stratigraphic units of the Beaufort-Mackenzie Basin and adjacent areas are summarized in the correlation chart Table 1). Many formal stratigraphic names remain to be established, particularly in the Tertiary and Lower Cretaceous parts of the column, but no new stratigraphic names are proposed in this paper. Names accompanied by quotation marks in the table are informal only, and those with question marks are uncertain designations owing to differences in lithology, age, or contact relationships from those of the type area.

The Triassic to Tertiary sedimentary record of this area can be subdivided into three tectono-sedimentary phases. These include, from base to top: the Late Triassic to early Aptian epicontinental sequence; the late Aptian to early Campanian flyschoid sequence; and the late Campanian to Paleogene molassic sequence. Each is characterized by its facies associations, thickness variability, sandstone petrography, and inferred tectonic setting (Young, 1973b).

There is no evidence for flyschoid sedimentation east of the Yukon-Northwest Territories boundary, except for indicated Albian turbidites near the southeastern shore of Sitidgi Lake (Norris, 1975). The molassic depositional sequence directly overlies the epicontinental sequence in this area, beginning with the Tent Island-Mason River Formation and extending up into Neogene strata.

In the following discussions on detailed stratigraphy, the succession is divided into the classical time-stratigraphic intervals, including the Triassic-Jurassic, Cretaceous, and Tertiary (plus latest Cretaceous). The latter interval embraces the molassic depositional phase. This method allows time-equivalent units to be compared more readily, both inside and outside the basin.

TRIASSIC AND JURASSIC SEQUENCE

Triassic stratigraphy

Triassic rocks are unknown in the subsurface of Mackenzie Delta although nonmarine conglomerate and sandstone of the Brat Creek Formation (Jeletzky, 1967) outcrop immediately west of its southern margin. Only patchy occurrences of Upper Triassic limestone, sandstone and shale, equivalent to the Shublik Formation of northern Alaska, exist in northern Yukon (Mountjoy, 1967b). The thickest preserved sections are in the order of 150 m (500 ft) thick (*op. cit.*). This formation outcrops discontinuously around the southeast-plunging nose of Romanzof Uplift (Kupsch, 1973), and equivalent strata occur sporadically in central and southern Richardson Mountains.

The shallow-marine sedimentary rocks of the Shublik rest unconformably on rocks ranging in age from Precambrian (Neruokpuk Formation) to Early Triassic (Ivishak Member, Sadlerochit Formation) in British Mountains, and on clastic sedimentary rocks of Late Devonian to Permian age in Richardson Mountains. The common presence of the pelecypod *Monotis* sp. and *Oxytoma* sp. in the Shublik Formation and equivalents allow it to be dated as Karnian to Norian in age (Mountjoy, 1967b), but no Rhaetian fossils have yet been identified. Hence, a disconformity between the Shublik and overlying Lower Jurassic rocks is likely. In adjacent northeastern Alaska, the Shublik Formation ranges downward into the Middle Triassic (Detterman *et al.*, 1975), and is capped by the Karen Creek Sandstone of Norian-Rhaetian age. The more complete stratigraphic record in Alaska suggests that the Shublik in northwestern Yukon represents an eastern transgressive tongue which extended from the main seaway in northern Alaska.

Lower and Middle Jurassic stratigraphy

Lower and Middle Jurassic rocks lie in the subsurface of Mackenzie Delta and outcrop westward from the delta to northern Alaska. In the western part of the basin, most of the Jurassic System is represented by the Kingak Formation, the type section of which is located in the North Slope area of Alaska (Leffingwell, 1919; Detterman *et al.*, 1975). Eastward from Blow and Driftwood Rivers, the black marine shale of the Kingak changes facies to siltstone and sandstone of the Bug Creek Formation of Early and Middle Jurassic ages (Jeletzky, 1967). To the northeast in the subsurface of Mackenzie Delta, the sandstone facies grades into siltstone and mudstone, which is assigned here to the Husky Formation.

The Kingak Formation was studied by E.W. Mountjoy during Operation Porcupine (GSC) in 1962, and ammonites collected were identified by H. Frebold (*in* Frebold *et al.*, 1967). Beginning in the midfifties, J.A. Jeletzky examined Jurassic rocks and fossils from the Richardson Mountains and Keele Range (Jeletzky, 1967, 1975c). Currently, a detailed study of the biostratigraphy of Lower and Middle Jurassic rocks in the Porcupine Plateau-Richardson Mountains area is being undertaken by T.P. Poulton of the Geological Survey.

Thickness and distribution

The thickness distribution of Lower and Middle Jurassic rocks (Fig. 4) is only an approximation because of sparse stratigraphic control; however, the general trends and larger anomalies probably are valid. From the southeastern zero-edge, the wedge gradually thickens to more than 800 m (2600 ft) in

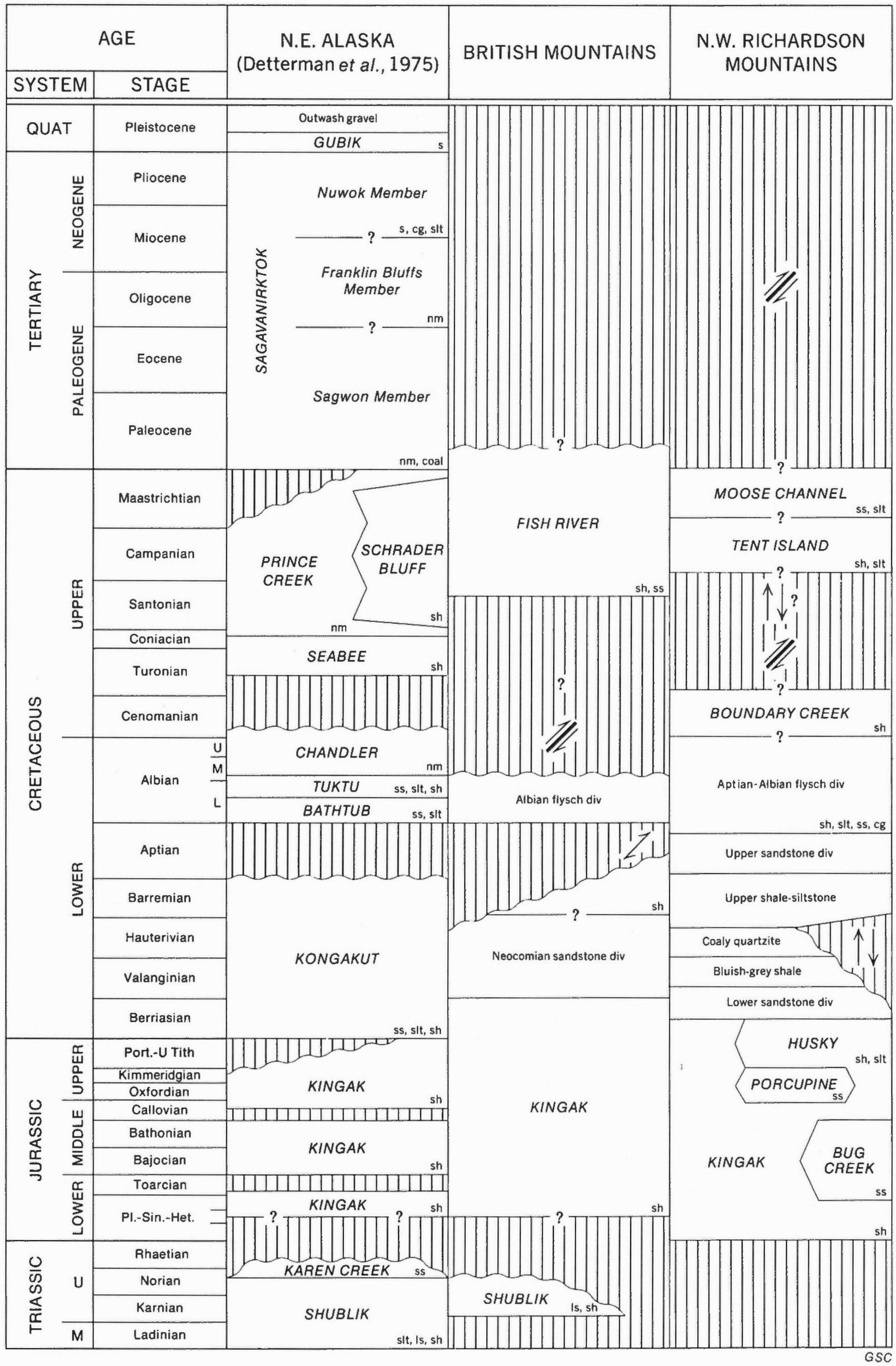
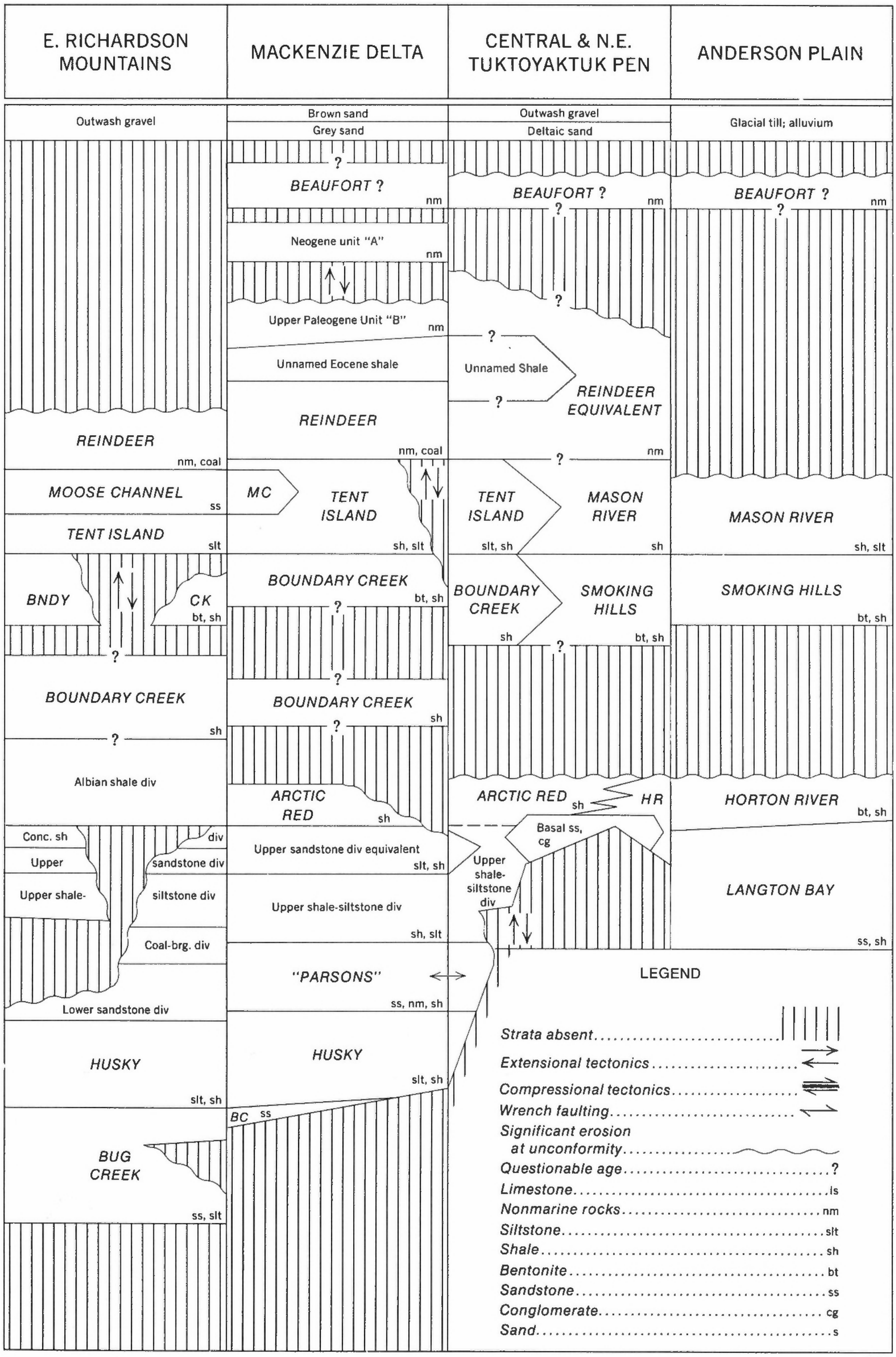


TABLE 1. Correlation chart



GSC

TABLE 1. Continued

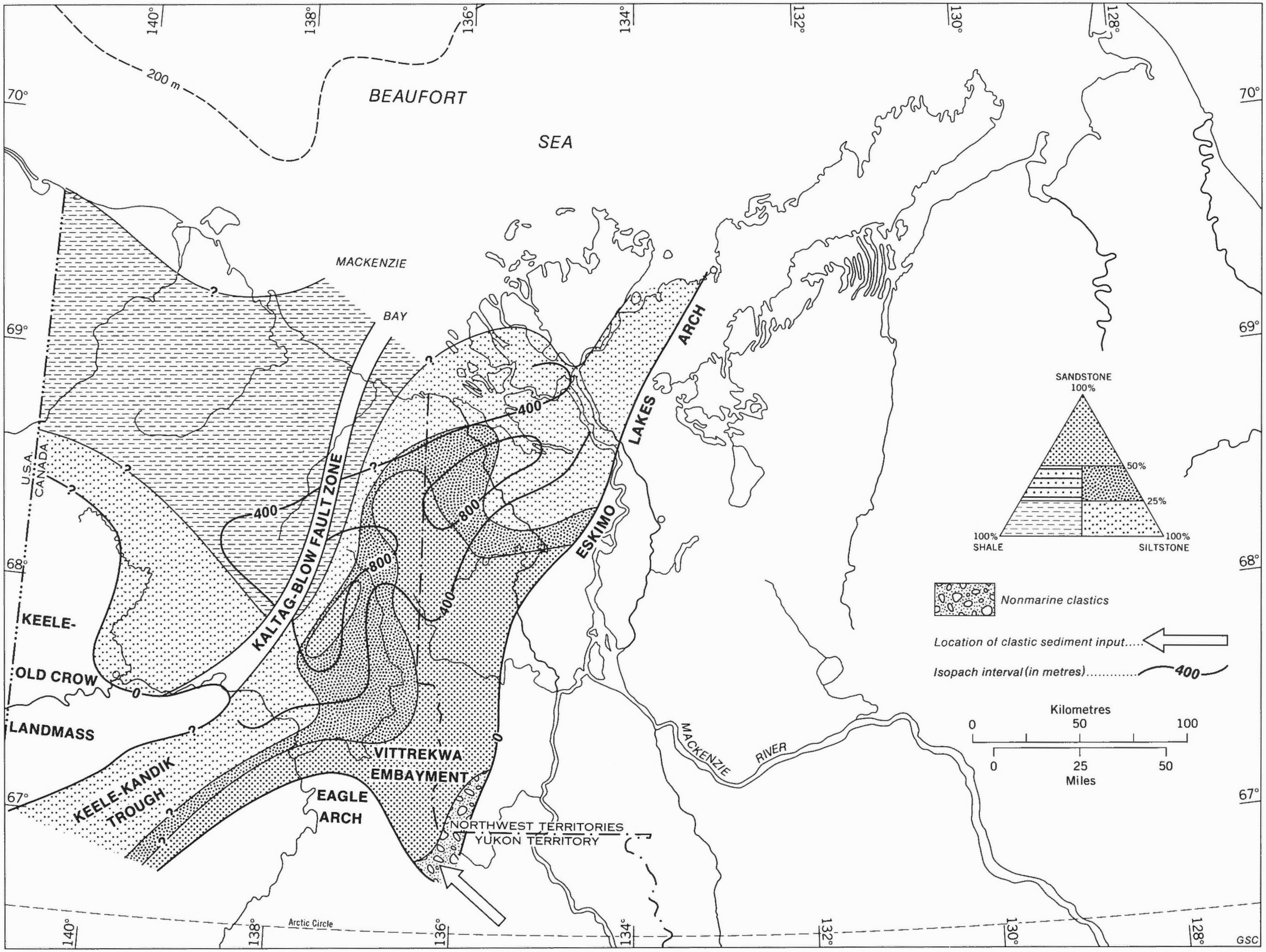


FIGURE 4. Isopach map of Lower and Middle Jurassic strata and showing Middle Jurassic (Bajocian) lithofacies

the Kugmallit-Blow Trough. A prominent positive feature underlying White Uplift projects northward, and is flanked on each side by tectonically depressed areas (Poulton and Callomon, 1976). There is little evidence of the Cache Creek High during this interval, except for a thin section (150 m; 490 ft) in the Shell Kugpik O-13 well, and the erosionally truncated section in the divide between Big Fish River and Little Fish Creek (Norris, 1976; Sec. 117A5 of Mountjoy and Procter, 1970). West of the Kaltag-Blow Fault Zone, the Kingak shale facies is generally less than 200 m (650 ft) thick, except for an anomalously thick section south of Barn Mountains.

Upper Jurassic stratigraphy

Upper Jurassic rocks include the Husky Formation (siltstone, shale, and sandstone) in the eastern half of the basin, the Kingak Formation (shale) in the western part, and the unnamed Upper Jurassic sandstone division in the southern part (Porcupine-Bell Rivers). The latter has been called informally "Porcupine sandstone" by Jeletzky (pers. com.) and Lerand (1973, Fig. 35). Toward the southeastern corner of the basin, the Husky becomes increasingly arenaceous, and is replaced laterally by the coaly and conglomeratic North Branch Formation.

The isopach map (Fig. 5) of Upper Jurassic and lowest Cretaceous rocks indicates that sediments filled a downwarp whose axes form a series of branches. One major branch (Kugmallit Trough) trends northeasterly through the Shell Unak B-11 well and, at its southwestern end, joins a northwesterly trending axis (Blow Trough) extending into a negative area here termed the Vittrekwa Embayment. Another axis parallels the northwestern margin of Eagle Arch and suggests a connection of the Beaufort-Mackenzie Basin to the Kandik Basin (Keele-Kandik Trough). A fourth axis underlies Barn Mountains and trends northwesterly into the Brooks Range. Jeletzky (1974) measured a 1000 m (3280 ft) thick section along the southern edge of this trough, which may represent a local depocentre.

Jurassic lithofacies

Jurassic lithofacies of the Beaufort-Mackenzie Basin consist almost entirely of marine, terrigenous clastic rocks of four general types comprising coarse sandstone, fine sandstone, mudstone, and shale. Of minor importance are variants of the above such as glauconitic sandstone and limonitic siltstone. Jurassic rocks have been described in detail for many localities by Jeletzky (1961b, 1967, 1972, 1974, 1975c), who pointed out the difficulty in distinguishing these rocks from the underlying Permo-Carboniferous or overlying Cretaceous lithologies (Jeletzky, 1967, p. 16).

Coarse sandstone facies

Jurassic sandstones become increasingly coarse, gritty, conglomeratic, glauconitic and carbonaceous toward the southern end of Vittrekwa Embayment in central Richardson Mountains. This facies of the Husky Formation was called the North Branch Formation by Jeletzky (1967, p. 41, 132). Glauconitic sandstone is interbedded with carbonaceous, gritty sandstone and rare pebble or cobble conglomerate. Lower and Middle Jurassic equivalents of this facies in the same area contain abundant very coarse grained chert arenites, are in part crossbedded, and contain carbonaceous shale partings and rare *Rhizocorallium* burrows. Other sedimentary structures include scours [up to 2 m (6.6 ft) deep], ripple marks, mud-cracks, plant-stem impressions, and rootlets.

Fine sandstone facies

Fine-grained Jurassic sandstone can be subdivided into two main, closely associated types; clean quartzarenite and argillaceous sandstone. The clean quartzarenite is pale grey or yellow, weathering to yellow-grey or orange-red tones, well sorted, very fine to fine grained, medium bedded to massive, and resistant to weathering. In many places, no sedimentary structures are obvious, while in others parallel lamination, rare burrows, rare lenses consisting mainly of pelecypods, low-angle crossbedding, scour-and-fill structures and ripple-drift lamination are present.

The argillaceous sandstone is very fine to fine grained, commonly thin bedded, burrowed to highly bioturbated, evenly to wavy laminated, and more easily weathered than the clean sandstone. The two types commonly are interbedded and, in many cases, they comprise parallel-laminated to burrowed sets, in which a laminated, clean quartzarenite grades upward into a burrowed, argillaceous sandstone or siltstone. In some places, these are stacked one above the other, and may grade upward into or be abruptly overlain by clean quartzarenite. Another lithic association involves large-scale, coarsening-upward rhythms in which the argillaceous, burrowed sandstone is intermediate between mudstone below and clean sandstone above (Young, 1973, p. 187).

Mudstone facies

The mudstone facies includes pelitic rocks ranging from slightly silty mudstone to clean siltstone, and includes sandy mudstone as well. Generally, these are poorly exposed rock types where they occur mixed with sandstone. They commonly are extremely bioturbated or burrowed, but rarely are evenly laminated (Myhr and Young, 1975, Fig. 42.5). This facies predominates in the subsurface of Mackenzie Delta throughout the entire Jurassic, and comprises the bulk of the Husky Formation. In western Richardson Mountains, a thick succession of this facies (825 m; 2700 ft) is described by Jeletzky (1975c, Fig. 7).

Shale facies

Dark grey to black shale is the principal facies of the Kingak Formation and also occurs within the Bug Creek Formation in which it is typically recessive and poorly exposed. It is less common in the Husky Formation but comprises the Red-weathering shale member and the basal beds of the lower member in the type area. The shale facies commonly weathers

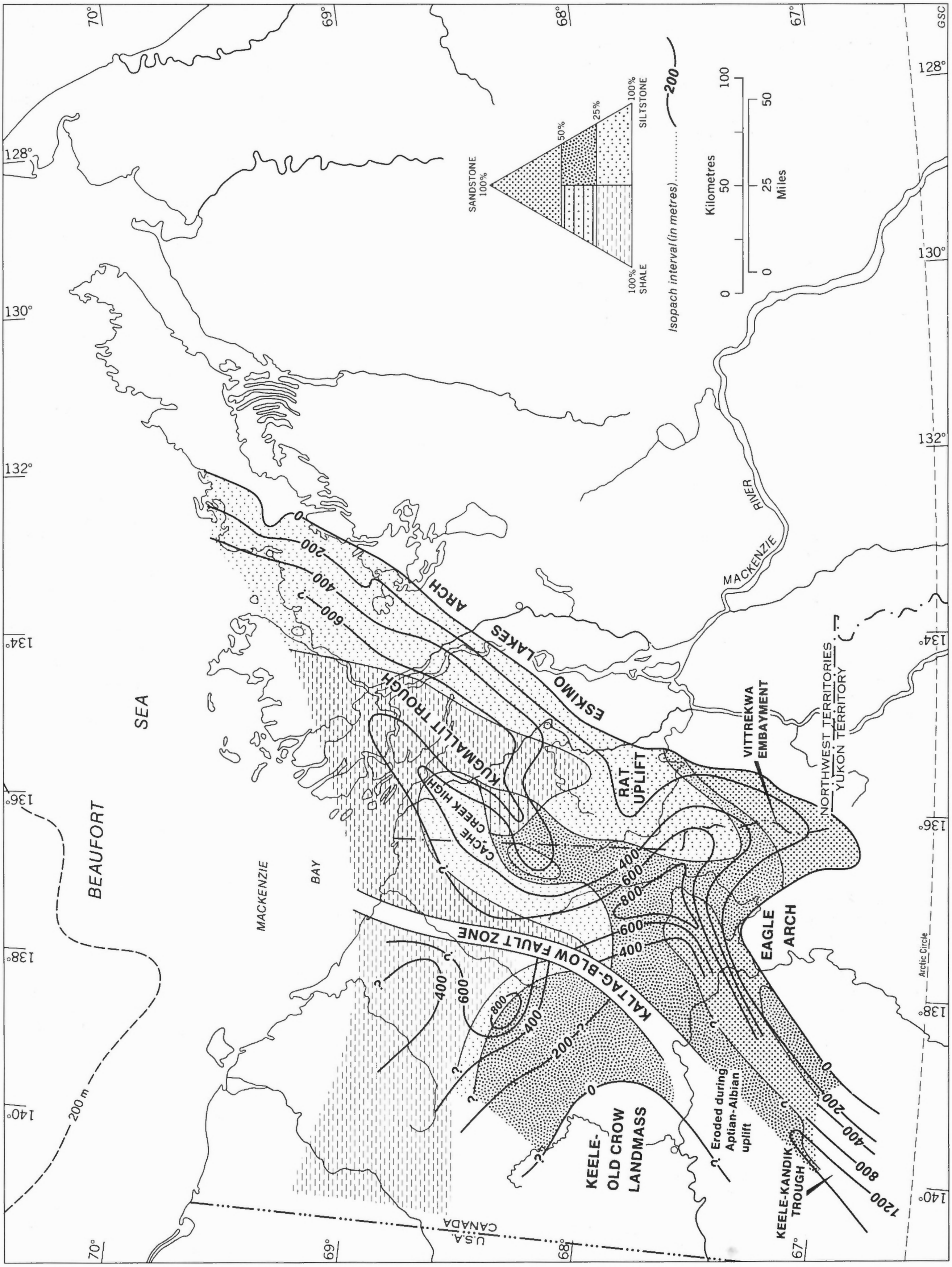


FIGURE 5. Isopach map of Upper Jurassic showing Kimmeridgian-early Portlandian lithofacies

wine-red, and contains clay-ironstone concretions commonly concentrated within the reddish-weathering horizons.

Lithofacies associations and environmental interpretations

The vertical sequence of shale-mudstone-argillaceous sandstone-clean sandstone commonly occurs in the Jurassic sequence and particularly within the Bug Creek Formation. This type of sequence was ascribed by Young (1973b) to gradual shoaling due to prograding barrier islands or marine sandbars, as suggested by Visher (1965). Owing to a lack of coaly lagoonal deposits at the tops of such sequences, and their widespread occurrence throughout Richardson Mountains, it is believed now that most of these sequences probably represent the migration or development of offshore sand-shoals, similar to those described in Jurassic rocks of Wyoming by Brenner and Davies (1974). Some of the interbedded, argillaceous and burrowed sandstones possibly represent intershoal deposits. The stacked, parallel-laminated to burrowed sets may reflect periodic high-energy conditions on the shelf followed by intervals of quiescence in which muds were deposited and burrowing took place.

The mudstone facies is more closely related than the shale facies to the arenaceous deposits. This fact, as well as the abundant bioturbation exhibited by the muds, suggests a relatively shallow, offshore marine environment, rich in nutrients, and only rarely affected by strong currents.

The shale facies probably represents calm conditions related to a deep, marine environment. Shale members within the Bug Creek succession may represent periods of, or may be the result of shifting patterns of shoal and intershoal sedimentation on a neritic platform.

The various components of the coarse sandstone facies suggest deltaic deposition in the estuarine Vittrekwa Embayment (Figs. 4, 5). The alternation of coarse and fine clastic sediments, in part showing signs of marine conditions [marine pelecypods (Jeletzky, 1967) and glauconite] and in part bearing evidence of nonmarine conditions (plant remains and rootlets), indicates a deltaic setting affected by both fluvial and marine processes. Supposedly, the coarse clastics entering the head of Vittrekwa Embayment supplied most of the marine shelf to the north with sediment.

Paleogeography

Late Triassic to Middle Jurassic paleogeography

In Late Triassic time, shallow-marine waters advanced eastward into the present-day British Mountains region, flooding a low-lying area between the Barrow Arch to the north and the Keele-Old Crow Landmass to the south. In this relatively small arm of the sea, limestone and sandstone were deposited in active shoreline and shoal areas, and siltstone and argillaceous limestone in quieter water. The temporal and areal relationships, if any, of the nonmarine Brat Creek Formation of the southern Mackenzie Delta area and marine rocks of the central Richardson Mountains to the Shublik Formation in northwestern Yukon still are unknown. In latest Triassic (Rhaetian) time, the sea apparently withdrew temporarily from this embryonic form of the Beaufort-Mackenzie Basin.

A regional marine transgression, probably from northwest to southeast, flooded the axial part of the basin in earliest Jurassic (Hettangian) time, but did not inundate the marginal areas until late Sinemurian time (Jeletzky, 1967; 1975c, p. 18). Local uplift and erosion of parts of the Aklavik Arch Complex in late Early or early Middle Jurassic time resulted in a local unconformity within the Bug Creek Formation (Jeletzky, 1967). An apparent biostratigraphic hiatus in the Kingak Formation (Frebold *et al.*, 1967) may reflect only a lack of fossils.

A pattern of sediment distribution became established in the early history of the basin which did not change substantially until Late Jurassic time. This pattern is illustrated by the lithofacies map (Fig. 4) of the Middle Jurassic Bajocian Stage which shows that sand was deposited on the southeastern edge of the basin, along the flank of the Peel Landmass, and was spread northward into most of the area now occupied by the Richardson Mountains. Sandstone units intertongue with siltstone and shale facies over most of this area and become increasingly carbonaceous and coarser toward the southeastern margin of the basin. Presumably, much of the terrigenous detritus entered the basin in the area of the Vittrekwa Embayment. The siltstone facies is dominant beneath Mackenzie Delta and probably along the northeastern flank of the Keele-Old Crow Landmass. Dark grey to black marine shale of the Kingak predominates west of Rapid Creek, and extends all the way to the north slope of Alaska.

A comparison of the thickness trends with the lithofacies trends suggests that coarse clastics were deposited on a metastable shelf in the southeastern part of the basin; this shelf subsided differentially faster toward its outer edge. The abrupt basinward thinning and change to shale facies suggests the existence of a clinoform-fondoform paleotopography. Note that the locus of this change coincides with the location of the Kaltag-Blow Fault Zone (Fig. 4). This coincidence is not necessarily due to lateral displacements along the fault zone, because even a restoration of 80 km (50 miles) of one side with respect to the other, does not materially alter the profile described.

Late Jurassic paleogeography

Lithofacies deposited during the Late Jurassic interval are similar to those of the Early and Middle Jurassic interval, but their distribution is different. The lithofacies map (Fig. 5) is based on the approximate distribution of sediments of Kimmeridgian to early Portlandian age (*Buchia mosquensis* Zone). A large volume of sand ("Porcupine sandstone") was deposited at the northeastern end of Keele-Kandik Trough and paleocurrent data indicate that these sediments were transported northeastward and dumped at the mouth of the strait where the

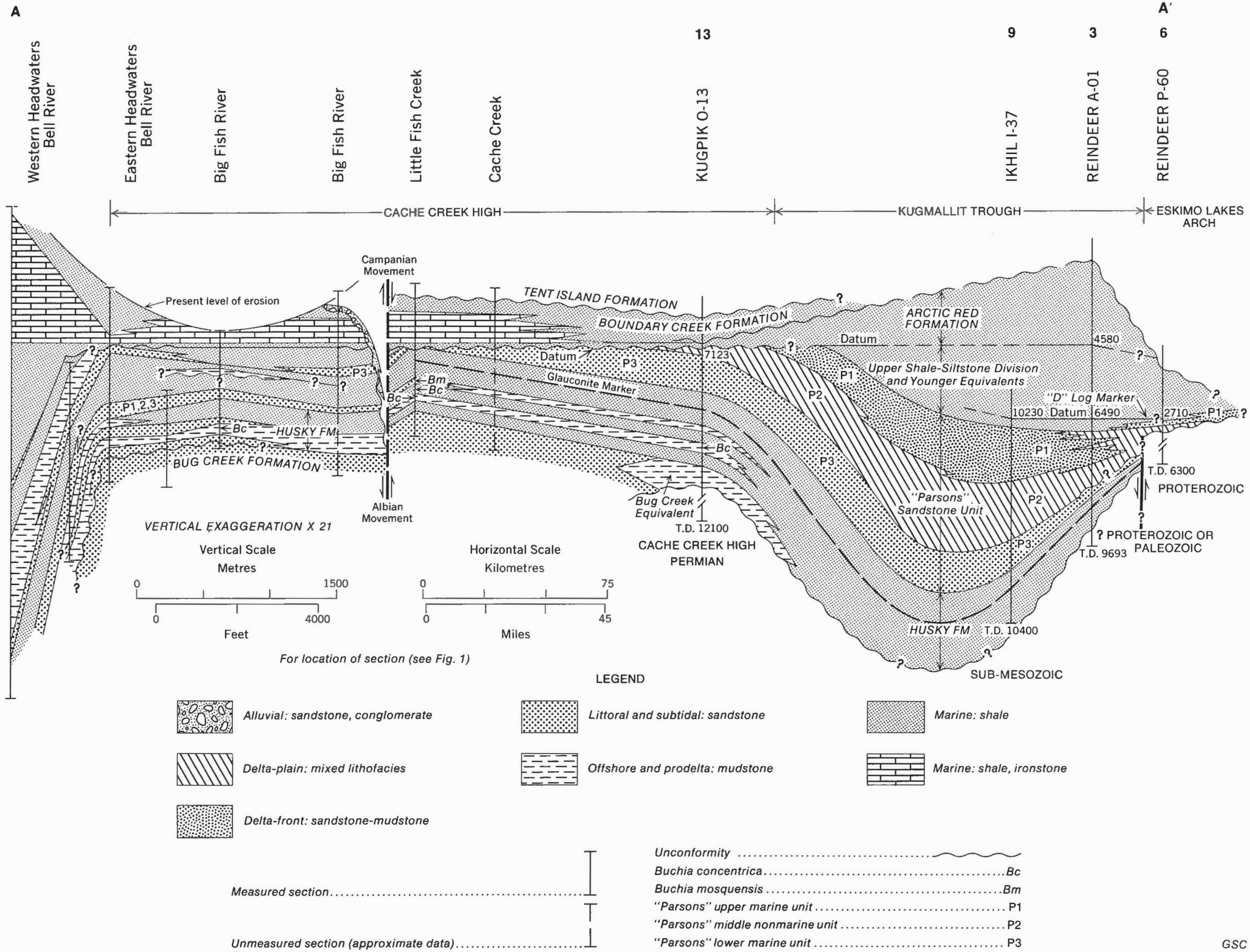


FIGURE 6. Stratigraphic profile of Jurassic-Cretaceous units, Cache Creek High and Kugmallit Trough

currents converged with northwesterly currents in the Blow Trough (Young, 1975a). Also, sand was dispersed northward over the shelf-like platform in the area of the present Richardson Mountains and deposited as marine sand-waves and offshore bars within a generally bioturbated mudstone facies. This depositional pattern was maintained throughout most of Late Jurassic time but, in latest Jurassic and earliest Cretaceous time, an eastward transgression resulted in the deposition of marine shales over a broad region in northern Richardson Mountains.

To the northeast, beneath southern Mackenzie Delta and southwestern Tuktoyaktuk Peninsula, bioturbated siltstone and silty mudstone predominate (Myhr and Young, 1975). Approximately 30 m (100 ft) of sandstone are present locally (e.g. in Shell Unak B-11 and Shell Beaverhouse Creek H-13 boreholes). The trends of both lithofacies and isopach contours suggest that the northeast-trending zero line of the Husky Formation east of Vittrekwa Embayment is a relict of post-depositional erosion. Abrupt thinning of the Husky within wells of the Aklavik and central Tuktoyaktuk Peninsula areas supports this suggestion, and suggests early movements (late Hauterivian to early Barremian) on the Treeless Creek-Tuktoyaktuk and Trevor-Eskimo Lakes Faults (Norris, 1975).

Although parts of the Upper Jurassic sequence were eroded during early Hauterivian and late Aptian uplifts, the preserved record indicates that Rat and Cache Creek Highs were joined and slightly positive during Late Jurassic time. The Late Jurassic sea apparently onlapped the Middle Jurassic shelf and caused migration of the shoreline farther southeastward. The Keele-Kandik Trough, a structural depression joining Kandik Basin, became wider and subsided more rapidly as indicated by the great thickness of sediments (1250 m; 4100 ft) preserved at its southwestern end.

The southward-directed tongue of shale west of Richardson Mountains may be in part the result of right-lateral displacements along the Kaltag-Blow Fault Zone. If 65 km (40 miles) of displacement are considered possible in post-Jurassic time, a palinspastic restoration would align the sandy deposits southwest of Barn Mountains with those at the headwaters of Driftwood River, and would thereby account for the apparent southerly trending tongue of shale (Fig. 5).

CRETACEOUS SEQUENCE

This sequence includes sedimentary rocks deposited in a pericratonic epicontinental seaway in earliest Cretaceous time which became increasingly influenced by tectonic forces due to the episodic rise of the Brooks Geanticline flanking the west side of the basin. By mid-Cretaceous time (Albian) the Blow Flysch Trough had formed adjacent to the eastern termination of the orogen (Young, 1973b), causing a complete change in sedimentary style in northern Yukon. Gradual infilling of the trough and erosion of the western highland complete the record throughout most of Late Cretaceous time.

NEOCOMIAN (BERRIASIAN-HAUTERIVIAN)

Stratigraphy

Units and correlations

Correlations within the Neocomian succession are difficult owing to complex lateral facies changes. The present status of slowly evolving correlation concepts is shown in Table 1. Informal lithostratigraphic units (Jeletzky, 1958, 1960, 1961b; Young, 1973a) are used to designate mappable units in the outcrop area west of Mackenzie Delta.

The informal name "Parsons sandstone" (Coté *et al.*, 1975) and its various members comprise most of the Neocomian succession in the subsurface of the Mackenzie Delta and Tuktoyaktuk Peninsula (Fig. 6). In the Anderson Basin, the Langton Bay Formation (Yorath *et al.*, 1975) includes the entire Neocomian succession.

Dating and correlation of Berriasian and Valanginian rocks have been facilitated by the presence and zonation of *Buchia* pelecypods, which have been studied intensively by Jeletzky (various publications, particularly 1960, 1961b). Ammonites and belemnites are useful for dating rock-units of the Hauterivian and Barremian Stages, but these are much too scarce for refined correlations, and are unavailable in well cuttings. Current research on microfossils, miospores and dinoflagellate cysts (Brideaux and Myhr, 1976) should greatly aid in more precise correlation of those units which exhibit abrupt facies and thickness changes.

Except for the steep northwestern flank of Eskimo Lakes Arch, the Parsons sandstone and its western equivalents gradationally overlie the Husky or Kingak Formation. Two cycles of regression-transgression, each ending with mild tectonism and local erosion, characterize the late Berriasian to late Hauterivian time interval in the central and eastern parts of the basin. The first cycle is represented by the Lower sandstone division (and Buff sandstone member) and Bluish grey shale division, ending in late Valanginian time. In the vicinity of Cache Creek High, a sharp, possibly disconformable contact occurs at the top of the Bluish grey shale but, in most places, this shale grades up into the White quartzite division and its equivalents. The second cycle is represented by the White quartzite division (White sandstone division) and Coal-bearing division; the latter is composed of a lower deltaic sequence capped by a transgressive marine sequence. The upper contact with the Upper shale-siltstone division varies from unconformable in structurally positive areas such as Rat High (Jeletzky, 1958, p. 10) and Eskimo Lakes Arch (Myhr and Young, 1975, p. 225) to gradational in the negative areas.

Thickness and distribution

Neocomian sediments were deposited over much the same area as those of the Jurassic sequence (Fig. 7) but, unlike the Jurassic, preserved thicknesses are less uniform. Isolated thick sequences occur in the Caribou Hills, central and northwestern

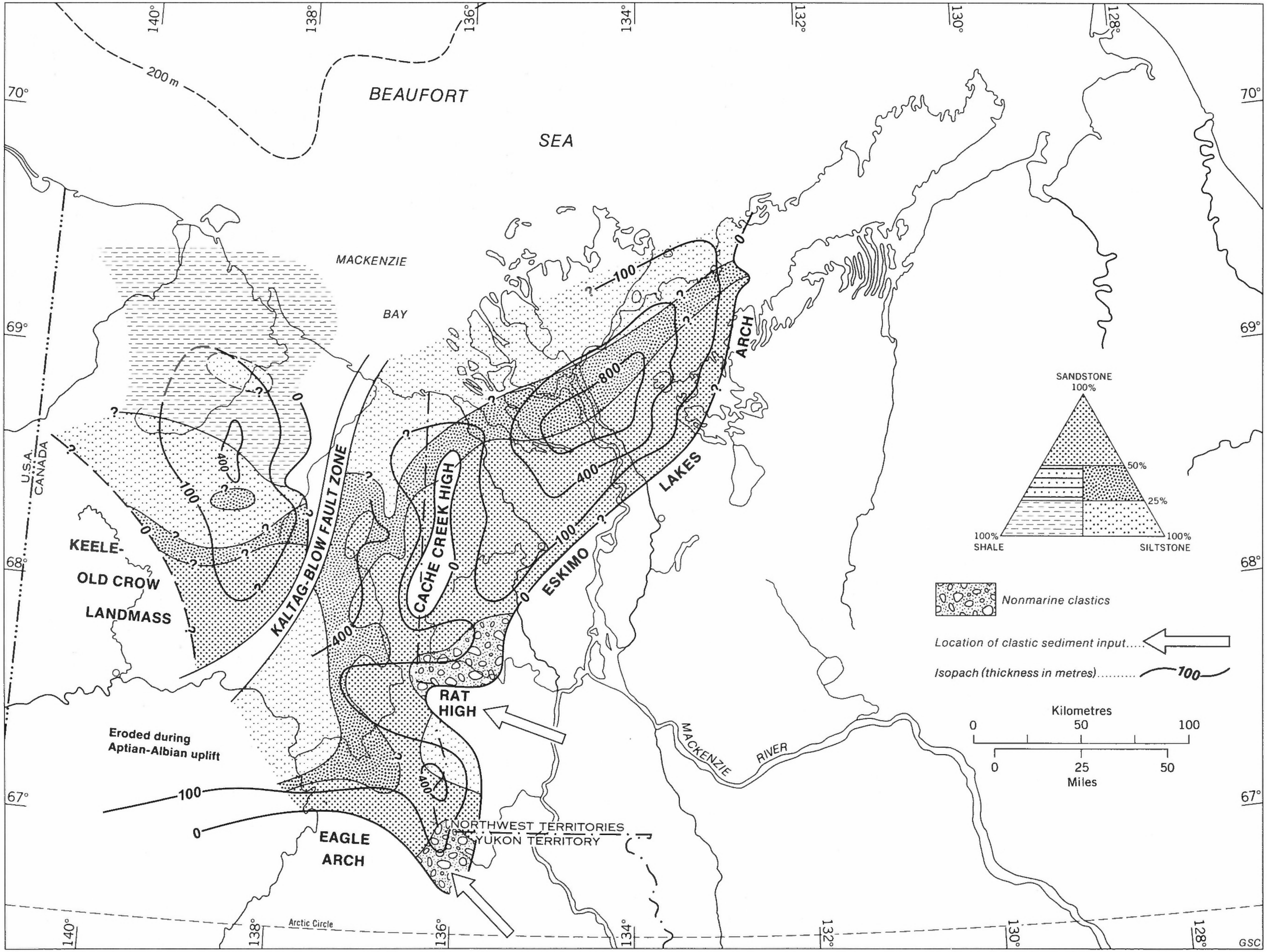


FIGURE 7. Isopach map of "Parsons" sandstone showing upper Berriasian lithofacies

Richardson Mountains, and Barn Mountains. Although this succession was subjected to considerable erosion following late Hauterivian and Aptian uplifts, it can be concluded, nevertheless, from facies distribution that the thickness maxima represent original depocentres because later erosion tended to occur on structural highs that probably were positive at the time of deposition. Positive areas that probably influenced Neocomian sedimentation (*see* lithofacies distribution, Fig. 7) include Cache Creek High, Rat High, Eagle Arch (Young, 1975a), and Eskimo Lakes Arch. Late Hauterivian dextral displacements along the Kaltag-Blow Fault Zone brought a much thinner sequence into contact with the very thick northwestern Richardson section (Young, 1974; Myhr and Young, 1975).

The diagrammatic profile (Fig. 6) depicts the stratigraphic relationships from Eskimo Lakes Arch to Blow Trough, and shows trends observed across Cache Creek High, typical also of other positive features. All Jurassic and Neocomian units gradually thicken northwest of the Eskimo Lakes Arch toward Kugmallit Trough; internal unconformities cause thinning and omissions on the flank and crest of the arch. Also, relatively proximal clastic facies occur nearest the arch (fluvial and deltaic facies in Gulf Mobil East Reindeer A-01 change to delta-plain and delta-front facies in Gulf Ikhil I-37). The Neocomian succession is very thin in the Gulf Mobil East Reindeer P-60 borehole, and completely absent in the Inuvik D-54 borehole located on the crest of the Eskimo Lakes Arch. A thin fluvial sequence preserved south of Sitidgi Lake may be equivalent to the Parsons sandstone unit (Norris, 1975).

Lithofacies assemblages and interpretations

Neocomian lithofacies, their spacial distribution and depositional environments were described and interpreted recently by Myhr and Young (1975). The emphasis herein will be to provide a broader view of the basin and to fit this succession into the overall history of deposition. A revised lithofacies map of the late Berriasian time-interval is shown here for the sake of continuity (Fig. 7); this interval (*Buchia volgensis* Zone) is preserved more extensively than several younger zones following the late Hauterivian and Aptian erosional interludes.

The major lithofacies and associated depositional environments described by Myhr and Young (1975) included: (1) a mudstone-siltstone facies (offshore and transitional); (2) a sandstone facies (nearshore); (3) a pelitic facies (restricted and open marine); (4) a mixed facies (delta-plain and estuarine); and (5) a sandstone-mudstone facies (delta-front and prodelta). The first and fifth facies are very similar and have been grouped together in this more general description under the name sandstone-mudstone facies.

Sandstone-mudstone facies

The sandstone-mudstone facies can be subdivided into two distinct subfacies that are closely associated; these include the mudstone and siltstone-sandstone subfacies.

The mudstone subfacies is medium brownish grey, silty, completely bioturbated, and non-fossiliferous. It is similar to the previously described Jurassic mudstone facies and, in part, forms thick, uniform mudstone units without significant arenaceous beds. These units probably were deposited in an offshore environment.

Alternating beds of mudstone and siltstone (transitional facies of Myhr and Young, 1975), similar to the Jurassic argillaceous sandstone facies, comprise the bulk of this facies. At Martin Creek (Lat. 68°12'20"N, Long. 135°36'W), just west of Mackenzie Delta, this facies is approximately 30 to 40 m (90-131 ft) thick at the top of the Husky Formation, and consists of alternating arenaceous and shaly beds comprising parallel-laminated to burrowed sets or rhythms that are abundantly fossiliferous. The sets increase in thickness and number upsection in the transition zone between the Husky Formation and the Buff sandstone member of the "Parsons" unit. These rocks are considered to have been deposited in the lower shoreface zone (Myhr and Young, 1975, p. 247).

A somewhat coarser subfacies, in which sandstone alternates with beds of mudstone and siltstone, comprises the Upper marine member (Fig. 6) of the "Parsons" sandstone in the subsurface of Caribou Hills and southwestern Tuktoyaktuk Peninsula. This sandstone is very fine to coarse grained, moderately well sorted, glauconitic, carbonaceous, and exhibits both parallel lamination and bioturbation. Palynomorphs, dinoflagellates (Brideaux and Myhr, 1976), and arenaceous foraminifers (T.P. Chamney, pers. com., 1974) are present. The thickness of this facies [425 m (1390 ft) in Gulf Mobil Ikhil I-37] and its arenaceous and carbonaceous characteristics suggest a close relationship to a deltaic depositional system, and it is interpreted as originating on a shallow-marine shelf (Myhr, 1974), or as mixed delta-front and prodelta deposits.

Sandstone facies

The sandstone facies is common in the upper Berriasian Buff sandstone member (Figs. 6, 7), the White sandstone member, and the Neocomian sandstone division west of Blow River. It consists predominantly of very fine to fine-grained sandstone with minor amounts of interbedded mudstone and shale. In the White sandstone member of eastern Richardson Mountains it is medium grained with some intercalated granular grit and flat-pebble conglomerate. Typically, the sandstone is well sorted, quartzose, pale and, in part, glauconitic. Silica cement predominates, but calcite cement occurs locally. Sedimentary structures are common and include parallel-laminated to burrowed sets, low-angle, tangential crossbedding, wedge-shaped crossbedding with associated current ripples, ripple-drift cross-lamination, and bioturbation. These features commonly are associated with such nearshore settings as beach-shoreface, tidal inlets, and offshore shoals (Howard and Reineck, 1972).

Pelitic facies

The pelitic facies includes a bituminous mudstone and a shale subfacies. They are widespread regionally, and overlie and intertongue with the sandstone facies.

The bituminous mudstone subfacies is known only from boreholes in the subsurface of central Tuktoyaktuk Peninsula. It consists of extremely bioturbated, silty and sandy mudstone with lenticular interbeds and mottles of siltstone. Typically these rocks are pyritic, bituminous, and dark brown. The subfacies is thought to have been deposited in a brackish, restricted environment, such as that of a lagoon, shallow bay, or tidal-flat (Myhr and Gunther, 1974; Coté *et al.*, 1975). In the Parsons boreholes it occurs unconformably above the basal Buff sandstone member of the "Parsons" sandstone and forms a unit varying in thickness from 21.2 to 24.4 m (70-80 ft).

The shale subfacies occurs in boreholes and in outcrops along the western margin of the Mackenzie Delta and comprises much of the Bluish grey shale division of the Richardson Mountains. It consists of dark grey shale or mudstone with sparse siltstone interbeds. Ferruginous concretions, accumulations of the pelecypod *Buchia*, and belemnites are common in these rocks. This facies resulted from open-marine, neritic to bathyal sedimentation.

Mixed facies

The mixed facies includes a mixture of sandstone, siltstone, mudstone, bituminous shale and, characteristically, coal. Arenaceous rocks comprise the bulk of the facies, and consist of very fine to very coarse grained sandstone units, some of which include small amounts of shale-chip and lithic pebble conglomerate. The coarser varieties of sandstone are very porous (>25%), and display scoured basal contacts, tabular cross-stratification, and ripple-drift lamination; they are interpreted as distributary channel deposits.

Interbedded with the coarse-grained arenites are very fine grained sandstone, siltstone and mudstone, commonly arranged in fining-upward or coarsening-upward cycles. Bituminous shale and coal occur rarely at the tops of fining-upward cycles. The sandstone is sublithic, non-calcareous, commonly carbonaceous, and exhibits horizontal lamination and some burrow mottling and root markings. These rocks are considered to be overbank (levee, splay) and floodbasin (lake, swamp, marsh) deposits (*see* Myhr and Young, 1975, p. 253; Shawa *et al.*, 1974), originating on a deltaic plain, and genetically associated with the coarse-grained, channel sandstones.

This facies forms most of the Coaly quartzite division in south-central Richardson Mountains (Jeletzky, 1972), the Coal-bearing division of the eastern Richardson Mountains (Jeletzky, 1960), and the Nonmarine member (Fig. 6) of the subsurface "Parsons" sandstone of southwestern Tuktoyaktuk Peninsula (Coté *et al.*, 1975).

An assemblage of rocks similar to the above, but lacking coal, outcrops in "Grizzly Gorge" (Lat. 68°16'N, Long. 135°43'W) on the west side of Mackenzie Delta. The sandstone there is grey and orange weathering, limonitic, poorly sorted, and contains rootlets and *Ophiomorpha* burrows. Subordinate lithologies include dark grey shale, concretionary ironstone, and pebble conglomerate. This facies probably is estuarine in origin (Myhr and Young, 1975, p. 253).

Paleogeography

The following paleogeographic discussion is modified only slightly from that published in Myhr and Young (1975, p. 255). The lithofacies map (Fig. 7) of the upper Berriasian rocks provides a general picture of sediment distribution that persisted throughout the Berriasian to Hauterivian interval.

Berriasian paleogeography

Shale and mudstone continued to be deposited over much of the basin in early and middle Berriasian time, but the effects of widespread shoaling and local emergence began to be expressed by late Berriasian time. Well-sorted, very fine and fine-grained, shallow-marine and nearshore sandstone was deposited on a broad shelf along the southeastern margin of the basin (Fig. 7). Coarse clastic sediments entered the basin via deltaic systems apparently from the east in the areas of Stony Creek, Vittrekwa River and Treeless Creek (Jeletzky, 1975c, Fig. 11). Sands were dispersed by marine currents to the northwest and northeast and formed offshore sand-shoals and possibly barrier islands on the shelf surrounding Cache Creek High and on the flank of the Eskimo Lakes Arch. An extensive facies-belt of bioturbated, argillaceous, silty sandstone of marine offshore origin formed basinward of the sand-shoals in northwestern Richardson Mountains. In Kugmallit and Blow Troughs, and west of the Kaltag-Blow Fault Zone, siltstone, mudstone and shale were deposited.

Valanginian paleogeography

Beginning in the Valanginian Stage, large deltaic complexes formed along the northwestern flank of the Eskimo Lakes Arch, partly in response to tectonic uplifts of the Arch. The locus of deltaic deposition shifted numerous times but the greatest accumulation of deltaic sediments seems to be located in the area north of Inuvik [e.g. 890 m (2900 ft) in the Gulf Mobil Ikhil I-37 borehole, Fig. 6]. Thinner deltaic wedges flanked Rat High, whereas west of Cache Creek High the Bluish grey shale division represents open-marine conditions. Uplifts of Cache Creek and Rat Highs during mid-Valanginian time caused a high-energy, sandy nearshore system (White sandstone member) to form between the two highs in eastern Richardson Mountains and eventually caused closure of the strait between them. This closure in turn resulted in restricted marine circulation in the resulting bay.

West of the Kaltag-Blow Fault Zone, general shoaling conditions prevailed during the Valanginian and sandstones typical of the shallow-marine environment were deposited widely.

Hauterivian paleogeography

In early(?) Hauterivian time, deltaic deposition shifted away from the present area of Tuktoyaktuk Peninsula toward the southwest in the area of Aklavik and the Vittrekwa Embayment. Further uplifts of Cache Creek High probably occurred, cutting off one delta complex from the other (Myhr and Young, 1975, Fig. 42.14). A thick sequence of sandstone outcropping in northwestern Richardson Mountains that indicates a shallow-marine environment, probably was deposited by north-flowing currents carrying sand from a southern prograding delta system.

The "Aklavik" delta system appears to have filled the former Valanginian embayment with coaly, arenaceous sediments, providing a possible source for the thick delta-front facies in the Kugmallit Trough.

The Kaltag-Blow Fault Zone appears to have become active during late Hauterivian time (Young, 1974), and caused uplift of the eastern termination of the Brooks Range Geanticline and northeastward regression of a nearshore sand facies. Late Hauterivian uplift of and local erosion on the Aklavik Arch Complex removed large parts of the Neocomian sandstone sequence over crestal areas of the arch.

BARREMIAN-ALBIAN

Stratigraphy

Very little formal stratigraphic nomenclature has been established for the Barremian to Albian sequence in the Beaufort-Mackenzie Basin. Informal designations for the Barremian shale unit (Upper shale-siltstone division), the Aptian sandstone unit (Upper sandstone division), and Albian shale unit (Albian shale-siltstone division) have been used for over fifteen years (Jeletzky, 1960, 1961b). In the subsurface of Mackenzie Delta and Tuktoyaktuk Peninsula, Albian shale is identical and co-extensive with the Arctic Red Formation of Peel Plateau to which it can be referred (Mountjoy and Chamney, 1969; Aitken *et al.*, in press). In northern Yukon, Albian and associated flyschoid strata are referred to as the Aptian-Albian flysch division.

Paleontological dating in this sequence has been accomplished by means of ammonites, belemnites (Barremian), and pelecypods (Jeletzky, 1958, 1960) and, more recently, by foraminifers (Chamney, in press) and palynomorphs (Brideaux and Fisher, 1976; Brideaux and McIntyre, 1975). Fossils in the western half of the basin are rare and the internal biostratigraphy of the Aptian-Albian flysch division is poorly known (*see* Jeletzky, 1975c, p. 26).

Thickness and distribution

The isopach map of preserved Barremian to Albian rocks (Fig. 8) illustrates the extent of deposition and the existence of several structurally positive and negative areas, most of which were inherited from the earlier framework of the basin.

The western margin of the basin continued to be modified by the slow eastward migration of the rising Brooks Range Geanticline. Adjacent to the western margin is the Blow Trough, which received in excess of 4000 m (13 000 ft) of sediments along much of its length, principally during late Aptian and Early Albian time. The thinning over Cache Creek High is partly due to erosion represented by the pre-Albian unconformity (Fig. 8). Thinning over Eagle Arch and Eskimo Lakes Arch is due to gradual onlap by the Barremian sea over earlier positive features. The Kugmallit Trough extended southwesterly into Yukon Territory where it branched into the former Keele-Kandik Trough on the northern flank of Eagle Plain and the newly formed Peel Trough, an Albian foredeep flanking the ancestral Richardson and Mackenzie Mountains. It is interesting to note the similarity of these depositional trends to those of modern major structural elements (*see* Norris, 1973, Fig. 2). This similarity and persistence of trends suggest that tectonism subsequent to Albian deposition followed similar, earlier established patterns, and that no major lateral offsets transverse to these trends have occurred (*see also* Jeletzky, 1975c, p. 49).

Contacts and unconformities

The upper Hauterivian to Barremian Upper shale-siltstone division unconformably overlies the Lower sandstone division and Husky Formation (Jeletzky, 1958) in southern Aklavik Range and Stony Creek areas (Rat High). This unconformity is recognized also in adjacent boreholes to the east, for example, the Banff *et al.* Rat Pass K-35 borehole (Brideaux and Fisher, 1976). In northern Aklavik Range, the contact is normally sharp and apparently conformable (Jeletzky, 1960, p. 12) but locally is gradational (Myhr and Young, 1975, p. 253). To the west, the Dark grey siltstone division (Jeletzky, 1961b) now is recognized as the equivalent of the Upper shale-siltstone division to which it is referred now. Its basal contact also is conformable and commonly sharp in this area. West of Blow River and north of Barn Mountains, the Upper shale-siltstone division is poorly dated and may be as young as Aptian. It lies with abrupt contact on Neocomian sandstones of variable thickness in the Ladas Creek area (Young, 1973a), suggesting the existence of a local unconformity. On the southwestern and southern flank of Barn Mountains, the contact apparently is conformable.

The upper contact with the Upper sandstone division is generally a thick transition zone consisting of interbedded sandy siltstone and mudstone; it comprises the entire upper member proposed by Jeletzky (1958, 1960). Where the Upper sandstone division and equivalents grade laterally into siltstone and shale, it becomes very difficult to distinguish the Barremian from the Aptian and Albian shale units. This problem exists on Yukon Coastal

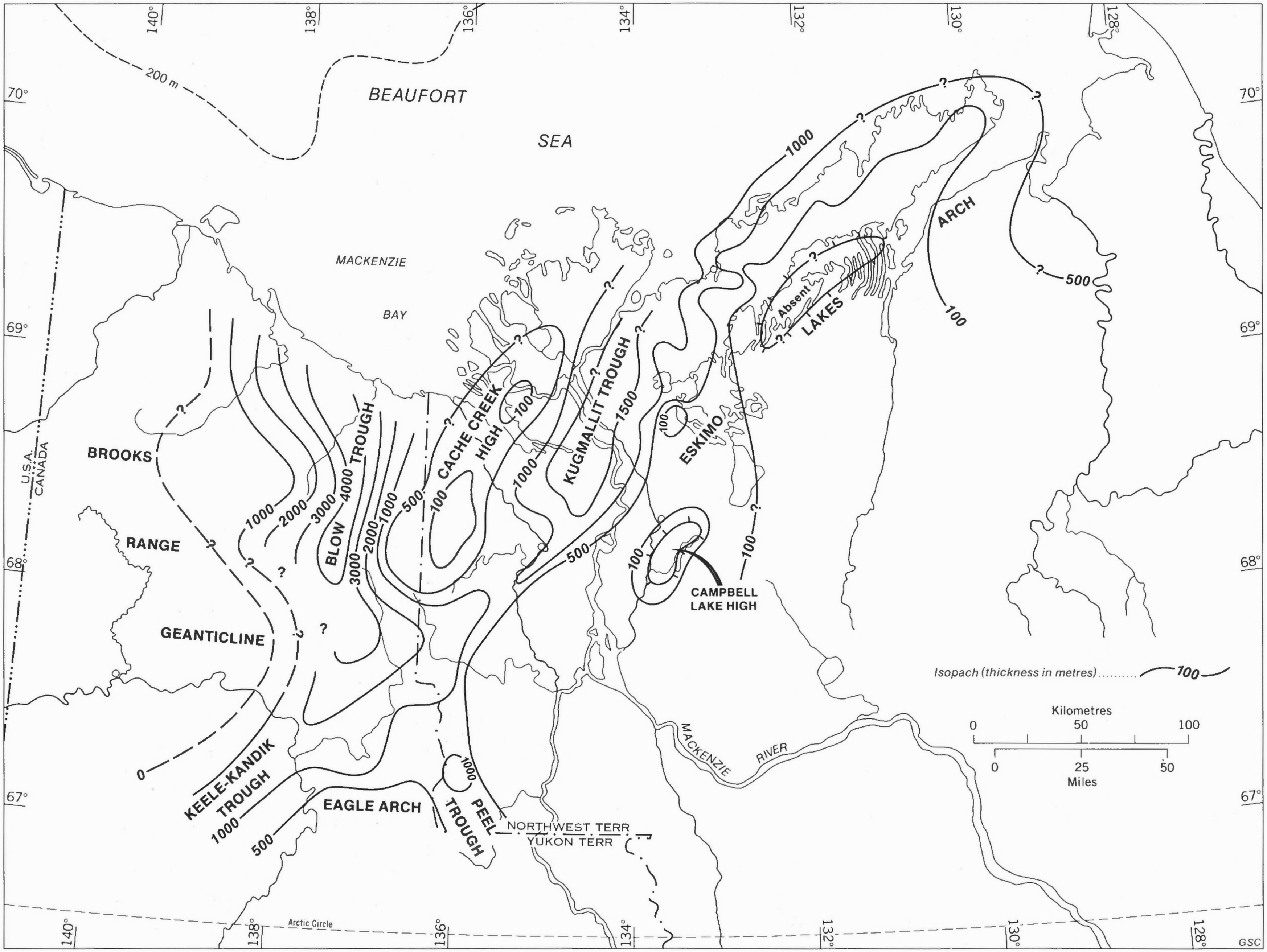


FIGURE 8. Isopachs showing preserved sediments of the Barremian-Albian interval

Plain, northeastern Eagle Plain (Young, 1975a, Fig. 2), and Southern Tuktoyaktuk Peninsula (Kugmallit Trough) (Fig. 8).

In the upper course of Big Fish River (Lat. 68°20'N, Long. 136°41'W), a thin (13-30 m; 43-98 ft), marine sandstone and siltstone unit, containing belemnitids, ammonites, and the sea lily *Pentacrinus*, rests with angular unconformity on eroded Upper shale-siltstone division. Because *Pentacrinus* and belemnitids never have been reported from post-Neocomian rocks in Arctic Canada (J.A. Jeletzky, written com.), this sandstone unit is interpreted tentatively to be within the Upper shale-siltstone division, associated with a local unconformity on the crestal part of Cache Creek High (Fig. 6).

In the western half of the basin, Aptian sedimentation continued uninterruptedly into the early Albian only in structurally depressed areas, such as the Blow and Kugmallit-Peel Troughs. Elsewhere, the Albian lies unconformably on older Mesozoic rocks, most commonly of Aptian age, but in places as old as Jurassic [e.g. Fig. 6, Sec. 7; and probably in the IOE Spring River N-58 borehole at a depth of 5280 ft (1609 m) on northwestern Yukon Coastal Plain]. The Aptian-Albian flysch division and Albian ironstone and shale unit in Richardson Mountains appears to be overlain conformably by younger Albian and lower Upper Cretaceous shale of the Boundary Creek Formation (however, the latter are very poorly dated). South and east from Richardson Mountains, the Lower and Middle Albian rocks are separated from younger Cretaceous sediments by an unconformity (Chamney, 1973; Myhr, 1975; Young, 1975a).

Upper shale-siltstone division

The Upper shale-siltstone division consists principally of silty shale, mudstone, and siltstone, with rare very fine grained sandstone. The basal 100 m (300 ft) approximately are generally dark grey silty shale, containing numerous clay-ironstone concretions which, at many localities, are in part spindle-shaped. A medial member, consisting of silty mudstone, siltstone and rare sandstone, commonly is present; the base of the member may correspond to a distinctive gamma ray log and electric log marker ("D" marker) in boreholes of Mackenzie Delta and southwestern Tuktoyaktuk Peninsula (Coté *et al.*, 1975; Brideaux and Myhr, 1976). Close to and at the top of this member in many surface outcrops are hard, limonitic siltstone beds resembling "hardgrounds". Silty shale and lesser amounts of siltstone prevail upward into the Lower Albian Arctic Red Formation in the subsurface of Tuktoyaktuk Peninsula.

The Upper shale-siltstone varies in thickness from 260 m (860 ft) on the axis of Cache Creek High to approximately 1200 m (3900 ft) west of Bell River (Jeletzky, 1974, p. 13; Young, 1975a, p. 316) in the Blow Trough, and is 642 m (2125 ft) thick in the Gulf Mobil East Reindeer A-01 well (Kugmallit Trough) (*see* Fig. 6).

Upper sandstone division

The Upper sandstone division occurs throughout most of central and northern Richardson Mountains and varies greatly in thickness and in its vertical sequence of facies. In the Aklavik Range, it consists of numerous sandstone units up to 60 m (190 ft) thick, which alternate with similarly thick units of dark, silty, bioturbated mudstone. Its total thickness in this area is approximately 200 to 250 m (660-800 ft).

In the western parts of northern Richardson Mountains, the unit is divisible into lower and upper members (Jeletzky, 1974, p. 16), the lower being dominantly sandstone, 200 to 450 m (660-1500 ft) thick, and the upper member mainly siltstone, 450 to 750 m (1500-2500 ft) thick. The upper member grades laterally to shale in northeastern Eagle Plain (Young, 1975a) and in the most northwestern and northern parts of Richardson Mountains, where it probably comprises the lower shale member of late Aptian age of the Aptian-Albian flysch division (Jeletzky, 1975c, p. 25). This shale unit apparently lies unconformably on Jurassic shale in the Blow River area (Young, 1974). In the axial and northern parts of Cache Creek High, the upper shale member (Concretionary silty mudstone unit of Young, 1972) is a concretionary, dark grey, marine shale which grades downsection into the lower arenaceous member. The two members together are commonly about 300 m (1000 ft) thick in this area (Fig. 6).

Basal sandstone and conglomerate unit

In the subsurface of northeastern Tuktoyaktuk Peninsula, the mid-Cretaceous sequence unconformably overlies Paleozoic and possibly Proterozoic rocks. The basal sandstone and conglomerate unit (Fig. 9) of this sequence contains the oil discovered in the IOE Atkinson H-25 well, and is dated tentatively as Albian (Grieve *et al.*, 1972) or possibly Aptian (based on foraminifers in the IOE Natagnak H-50 well, dated by Chamney *in* Barnes *et al.*, 1974). The maximum thickness of this unit is 110 m (360 ft).

Arctic Red and Horton River Formations

Lower to Middle Albian shale of the Arctic Red Formation is widespread in the subsurface of Mackenzie Delta and Tuktoyaktuk Peninsula and in outcrops south and immediately west of the Delta (Albian shale-siltstone division of Jeletzky, 1960). This shale is dark brownish grey, moderately soft and fissile, concretionary, and fossiliferous (fish scales, bone fragments, microfauna, palynomorphs, rare ammonites and pelecypods). On the northwestern flank of Eskimo Lakes Arch, the shale is silty in part, contains clay ironstone concretions, a number of sandstone units, and *Inoceramus* beds. It varies in thickness from 10 m (30 ft) or possibly less over Eskimo Lakes Arch (Figs. 9, 11) to approximately 515 m (1700 ft) on its northwestern flank (Gulf Mobil East Reindeer G-04 well). In some boreholes (e.g. Gulf Mobil Parsons N-10 and Gulf Mobil East Reindeer C-38), the Albian sequence

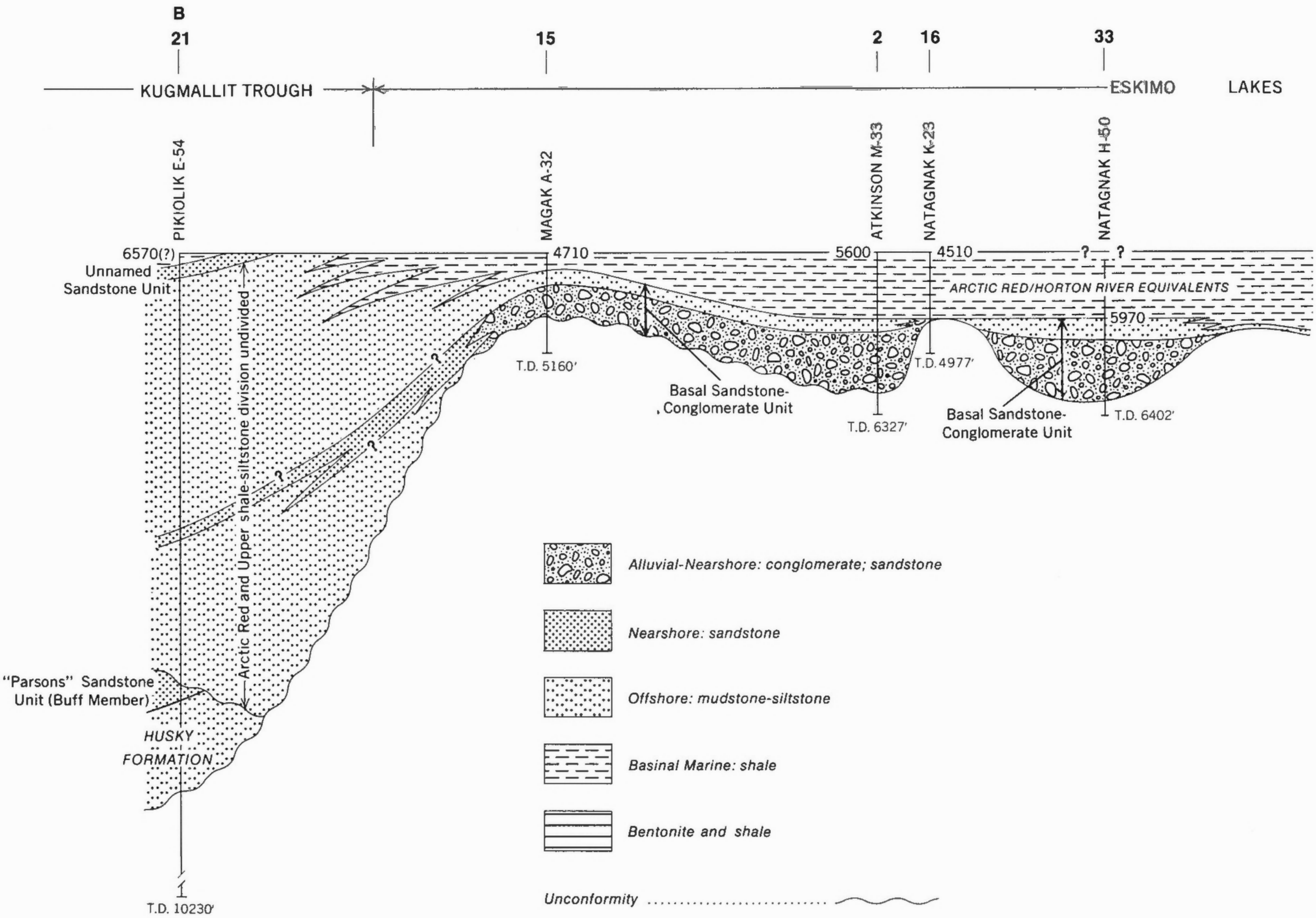


FIGURE 9. Stratigraphic profile of Jurassic-Cretaceous units, northeastern Eskimo Lakes Arch

is very thin to absent, probably due to pre-Late Cretaceous erosion (Brideaux and Myhr, 1976; Chamney, 1973).

Bentonitic shale is common in the Horton River Formation of Anderson Plain (Yorath *et al.*, 1975) but is not common southwestward over Eskimo Lakes Arch (Fig. 9; Myhr, 1975, Fig. 2) where it grades laterally into the Arctic Red Formation. The thickness of the Horton River Formation is variable because of erosion prior to deposition of the overlying Upper Cretaceous Smoking Hills Formation. In outcrops on the Anderson Plain, the Horton River Formation ranges in thickness between 150 and 185 m (500-600 ft), while in the Elf Horton River G-02 borehole, it is 235 m (770 ft) thick (Yorath *et al.*, 1969, 1975).

Albian flysch and related units

In the environs of Cache Creek High, the Bell River drainage area, and points westward of these, the Albian sedimentary sequence takes on a flysch-like character. The sequence thickens abruptly west of Cache Creek High (Fig. 6; Young, 1972, 1973b) to approximately 2000 m (6500 ft) and, in ascending order, consists of the Turbidite member (chert conglomerate unit of Jeletzky, 1971a), the Brittle silty mudstone member, and the Bedded ironstone and shale member (Young, 1972). In the area north of Barn Mountains, the flysch sequence includes a lower turbidite member, a lower shale member, an upper turbidite member, and an upper shale member. Very little dating of these rocks has been done.

Lithofacies assemblages and interpretations

Basal sandstone and conglomerate

The basal sandstone and conglomerate unit in boreholes of northeastern Tuktoyaktuk Peninsula can be divided into two members: a lower, sandstone-conglomerate member, and an upper argillaceous

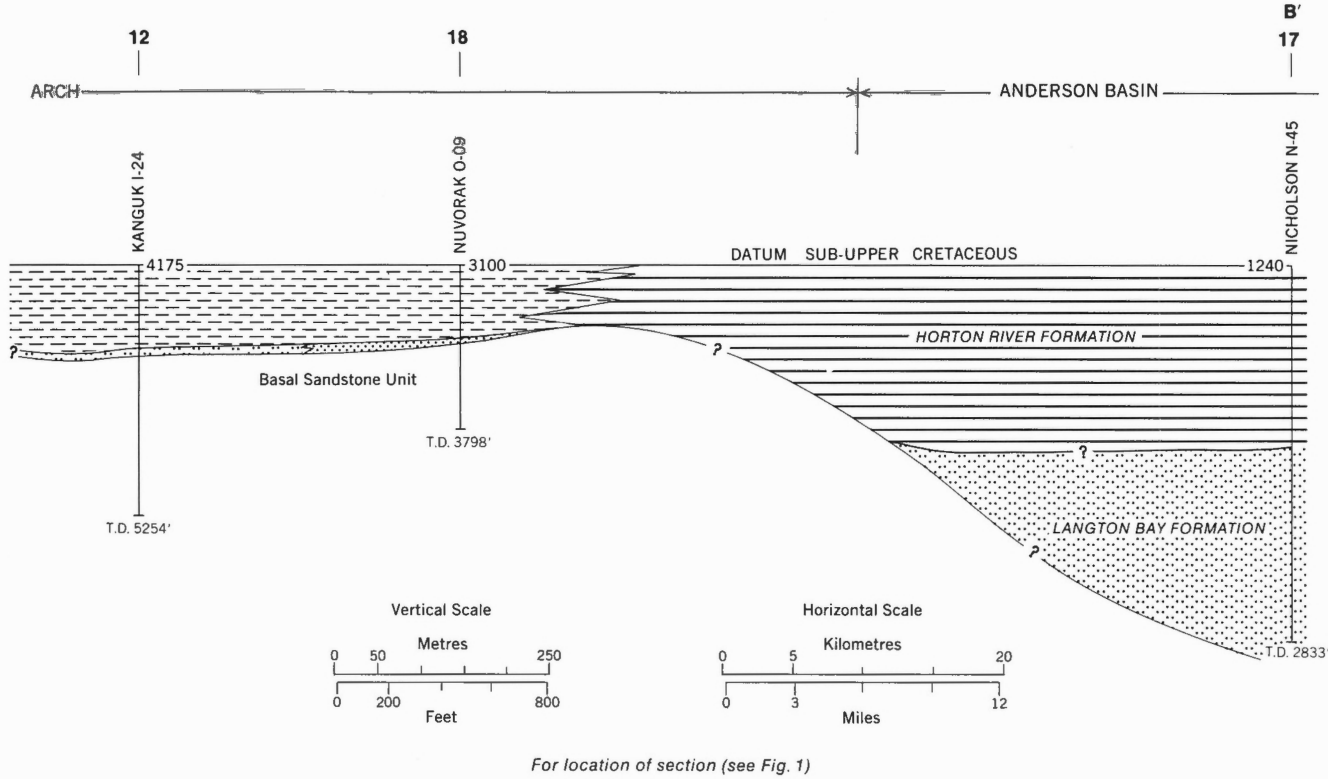


FIGURE 9. Continued

sandstone-mudstone member. The lower member consists of two main facies, including an interbedded conglomerate and sandstone facies, and a massive sandstone facies. A conglomeratic, poorly sorted, coarse-grained sandstone facies also exists in the Upper sandstone division in the central Richardson Mountains (Jeletzky, 1960, p. 14; 1974, p. 6), and may be similar in origin to the conglomerate and sandstone facies of Tuktoyaktuk Peninsula.

Cores reveal that the conglomerate of the lower member is poorly sorted and has a matrix of fine- to medium-grained sand, and a mixture of clay, calcite, and pyrite cements. Graded co-sets, typically 5 to 20 cm (2-8 in) thick and exhibiting scoured basal contacts are common. Pebbly or granular conglomerate sets and lentils grade upward into horizontally laminated sandstone within each coset. These beds possibly are the result of waning current deposition in shallow braided streams.

The massive sandstone facies consists predominantly of well-sorted, medium-grained sandstone of mainly homogeneous texture, and exhibits rare, horizontal to low-angle stratification and laminae of granular sandstone. Also present in minor amounts are "floating" pebbles and circular burrow-fill structures. This facies alternates with the conglomerate-sandstone facies in vertical sequences and forms depositional units from a few to 25 m (10-80 ft) thick. The texture and structure of this sandstone suggest a beach origin. These interpretations of the lower member are essentially the same as those put forward by Imperial Oil Limited geologists (Grieve *et al.*, 1972).

The lower sandstone-conglomerate member is confined to paleotopographical depressions which were infilled by fluvial and littoral sediments that grade basinward and upward into shallow-marine deposits of the upper member (Fig. 9).

Marine shelf and trough facies-assemblage

The most common and widespread facies of the Barremian-Albian interval are the terrigenous clastic deposits of marine shelf and trough origin. Several of these facies are practically identical with those of the Jurassic and Neocomian successions and are reviewed here for the sake of completeness. The dominant facies include the shale, mudstone-siltstone, silty sandstone, and laminated sandstone facies.

Pelitic rocks, included in the shale and mudstone-siltstone facies, comprise the majority of the Upper shale-siltstone division and the Arctic Red and Horton River Formations. The shale facies is typically dark grey, concretionary and, in places, contains very thin beds of siltstone or very fine grained sandstone. Besides comprising a large part of the shelf-trough assemblage, it also is abundant in the flysch facies-assemblage.

The mudstone-siltstone facies is generally poorly stratified, may contain ironstone or pyrite concretions and, typically, is bioturbated, with *Chondrites* burrows being particularly common. This facies, in places, grades laterally and vertically into the silty or laminated sandstone facies, indicating a genetic relationship among these facies.

As in the cases of the older successions, the pelitic facies represent quiet-water sedimentation in marine waters of bathyal to neritic depths. These environmental interpretations are supported by the presence of belemnitids, ammonites, and dinoflagellates in these rocks.

Rocks of the silty sandstone facies commonly are carbonaceous, glauconitic, and medium to dark brown in colour. Burrows and trails commonly are preserved, as well as deformative bioturbation fabrics. These features support the interpretation of deposition in relatively shallow depths on an open-marine shelf (probably the *Cruziana*-facies of Seilacher, 1967).

The laminated sandstone includes very fine to fine-grained, well-sorted, frequently calcareous units that form relatively prominent outcrops. Its slabby fracturing habit is caused by abundant internal, even laminae. Burrow structures are rare, but surface trails, pelecypods, and ripple marks are common attributes. In places, this facies is interbedded with the silty sandstone facies forming rhythms, 25 to 40 m (80-150 ft) thick, in which the argillaceous, bioturbated facies grades upward into the laminated sandstone. These sequences are thought to represent offshore sandbars or sand-shoals, similar to those observed in the Jurassic and Neocomian sequences.

Albian flysch facies

The conglomerate and laminated sandstone facies is characterized by a section, 600 m (2000 ft) thick, on Skull Ridge (Lat. 68°31'30"N, Long. 137°24'W) just east of Blow River. There, an imposing, horizontal basal conglomerate, up to 60 m (200 ft) thick, outcrops over an area of 13 km^2 (5 sq miles), and lies with abrupt contact above the lower mudstone unit of the Aptian-Albian flysch division. The conglomerate consists of rounded pebbles and cobbles of chert, quartzite, and sandstone, and appears massive, non-imbricated, and only rarely cross-stratified. Lenticular masses of sandstone with scour-and-fill structures occur internally and appear more commonly toward the flanks of the conglomerate mass.

A thick, homogeneous sequence of sandstone with scattered conglomerate lenses overlies the main conglomerate. This sandstone is uniformly textured, very fine to fine grained, evenly laminated, and slabby fracturing and, in most lithologic respects, is identical with the laminated sandstone facies of the Aptian Upper sandstone division. However, the Albian sandstones contain considerably more chert and lithic fragments than those of the Upper sandstone division, which commonly are enriched in carbonate particles (Young, 1973b). Current lineations and carbonaceous plant debris are common and the occurrence of indigenous ammonites and inoceramid pelecypods indicates a marine origin. The alternation of thin conglomerate beds with laminated sandstone units and minor amounts of mudstone, localized within the flysch-trough, suggests that deposition took place on the mid-portion of a deep-sea fan (Nelson and Nilsen, 1974).

The mixed conglomerate-sandstone-shale facies occurs mainly in the headwaters area of Blow River (Jeletzky, 1971a, 1975c) along the western margin of the Blow Trough and ranges in thickness from 100 to 550 m (300-1800 ft). The outcrop section near the junction of Annett and Anker Creeks (Lat. 68° 40'N, Long. 137°48'W) (Mountjoy and Procter, 1970) consists of lenticular units of sandstone, conglomerate and mixed coarse clastics ranging in thickness from a few to 37 m (120 ft), alternating with intervals of shale and silty mudstone up to 100 m (300 ft) thick. Beds of coarse clastics have sharp basal contacts on eroded surfaces, and may be either internally homogeneous or composed of superimposed graded sets. The sandstone and conglomerate units range from very poorly sorted to moderately well sorted, and maximum phenoclast size is in the range of 0.5 to 1 m (1.5-3.5 ft). The data indicate that this facies is composed of proximal turbidites, hemipelagic deposits, and resedimented conglomerates of the graded-stratified type (Walker, 1975), typical of submarine canyon fills and upper deep-sea fans (Nelson and Nilsen, 1974).

Eastward, and apparently downcurrent from the above-described facies, the turbidite facies includes alternating sandstone-rich and shale-rich units, and alternating single beds of sandstone and shale. This facies is well exemplified by outcrops on the east bank of Purkis Creek at Latitude 68°33'N, Longitude 137°12'W. The sandstone is generally fine grained, argillaceous, lithic and chert-rich, and occurs in beds 0.1 to 2 m (0.3-7 ft) thick which have sharp basal contacts. Sole markings include flute-casts, groove-casts, tool marks and current lineations. The upper parts of beds are parallel- and ripple-laminated and, in places, show convolutions. These features are typical of deposits formed by turbidity currents (Bouma, 1964).

Of minor volumetric importance are sedimentary breccias, or mixtites, which occur along the eastern flank of the flysch-trough. Their association with pebbly mudstone and slump-folds indicate that they owe their origin to the breaking up of the fronts of slump-folds, where they are converted into mass-flows on a submarine slope.

The silty mudstone facies consists of brittle mudstone, argillite, and siltstone, which are interbedded with dark grey shale. These rocks are mainly dark grey and brittle, and have a platy fracture. Scattered pebbles and pyrite nodules are common attributes, and bioturbation fabric is rare. Some thin siltstone beds display ripple-lamination and current lineations, and may represent distal turbidites. This interpretation is supported by the fact that the facies is interbedded with, and gradationally overlies, turbidites with abundant sole-marks.

The bedded ironstone and shale facies occurs at the top of the thick flysch sequence (Young, 1972) and comprises the bulk of the Albian succession immediately east of Cache Creek High (Fig. 11), which thins to a minimum of 60 m (200 ft) in the headwaters area of Big Fish River (Lat. 68°10'30"N, Long. 136°53'W) (Fig. 6, column 3). Thin lentils and even beds of phosphatic siderite-mudstone (ironstone), ranging in thickness from a few millimetres to 70 cm (2.3 ft), comprise 3 to 40 per cent of the ironstone facies, the remainder being brittle shale or silty mudstone. The proportion of ironstone increases from west to east and is at a maximum in the Big Fish-Little Fish Rivers area where a total net thickness of approximately 45 m (150 ft) of ironstone outcrop. Besides being of interest for iron, manganese and phosphate (Young, 1972), this facies also contains an unusual suite of phosphorous-bearing minerals, including lazulite, brazilianite, augelite, vivianite, wardite, and several others (Sturman and Mandarino, 1975).

Paleogeography

Aptian lithofacies and paleogeography

Control data for the Aptian lithofacies map (Fig. 10) are concentrated in Richardson Mountains and the subsurface of Tuktoyaktuk Peninsula. West of Blow River, Aptian strata are not recognized; their absence may be due largely to non-deposition on the uplifted block west of the Kaltag-Blow Fault (Young, 1974; Yorath and Norris, 1975), or to erosion of the sedimentary record prior to and during Albian flysch sedimentation. In the Kugmallit Trough, Aptian strata are recognized (Brideaux and Myhr, 1976) within the thick siltstone-shale unit representing continuous offshore marine sedimentation from late Neocomian to Early Albian time.

The lithofacies map-pattern reflects shoaling and widespread deposition of sand which formed marine sandbars and shoals on the northwestern side of the Cache Creek High. Several sets of paleocurrent measurements from crossbeds are directed consistently northwestward away from this emergent area. Units interpreted to have formed as sandbars also are common south of Cache Creek High and are concentrated particularly along the axis of Rat Uplift. In the upper Bell River drainage area, structures indicate that paleocurrents were directed southward (Young, 1975a) toward an embayment in which shale and mudstone now predominate. These facies, in turn, abut against the northern margin of Eagle Arch. Coarse sand and gravel entered the basin near the head of Vittrekwa Embayment as they did in Jurassic and Neocomian times.

In late Aptian time, the basin apparently subsided, resulting in the widespread deposition of shale and siltstone represented now by the upper member of the Upper sandstone division and the lower shale-siltstone unit of the Aptian-Albian flysch division.

Albian paleogeography and paleocurrents

Early Albian time was one of widespread marine transgression into the interior of western North America (Jeletzky, 1971b) and, in northern Yukon Territory, a time of tectonic uplift of the Brooks Range Geanticline and downwarp of the Blow Trough (Young, 1973b). The lithofacies map (Fig. 11) of the late Early Albian clearly shows this change in paleogeography when compared with the Aptian lithofacies distribution (Fig. 10).

An elongated island is postulated to have remained emergent at the site of Eskimo Lakes Arch. This is indicated by the progressive thinning of Albian rocks on its flanks, together with the increase in the amount of sandstone in some sections flanking the arch. Arenaceous Albian sections occurring near Campbell and Sitidgi Lakes (Norris, 1974, 1975; Dyke, 1975) probably owe their origin to erosion from this positive element. The widespread shale facies surrounding Eskimo Lakes Arch becomes increasingly bentonitic eastward toward the Anderson Plain where the Albian Horton River Formation is composed largely of montmorillonitic shale (Yorath *et al.*, 1975).

West of Mackenzie Delta, the Arctic Red Formation grades into the bedded ironstone and shale facies over Cache Creek High. Farther west, the Albian section increases greatly in thickness and the iron-rich facies grades into shale and turbidites. These sediments filled the rapidly foundering Blow Trough mainly from the west, as indicated by paleocurrent data and facies changes. For example, the turbidite member varies greatly in facies from west to east across the trough. In the Blow River area, it consists of conglomerate, laminated sandstone, and interbedded shale. Eastward, in the Rapid Creek area, it is represented by fine-grained turbiditic sandstone, siltstone and shale interbeds. Farther east, on the western flank of Cache Creek High, it grades into brittle silty mudstone.

Several submarine canyons and fans developed basinward of a highland now occupied by Barn Mountains. In the southern extension of this trough in the present Bell River area, no coarse clastics have been observed (Young, 1975a). The trough apparently extended southwesterly through northern Eagle Plain, which is flanked on the north by the Lower Albian Sharp Mountain Formation (Jeletzky, 1975b), a local conglomerate and sandstone unit.

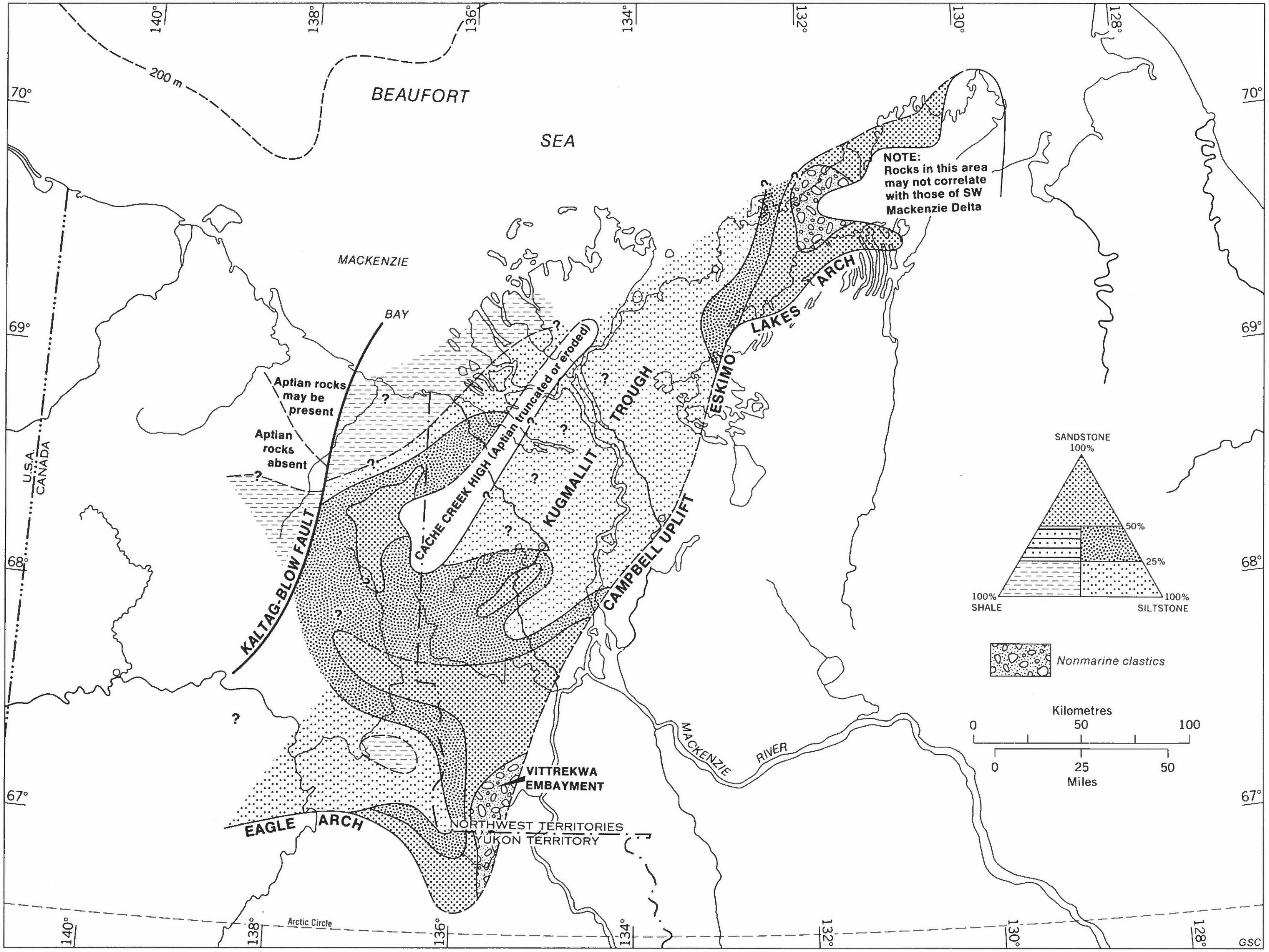


FIGURE 10. Lithofacies map; Early Aptian

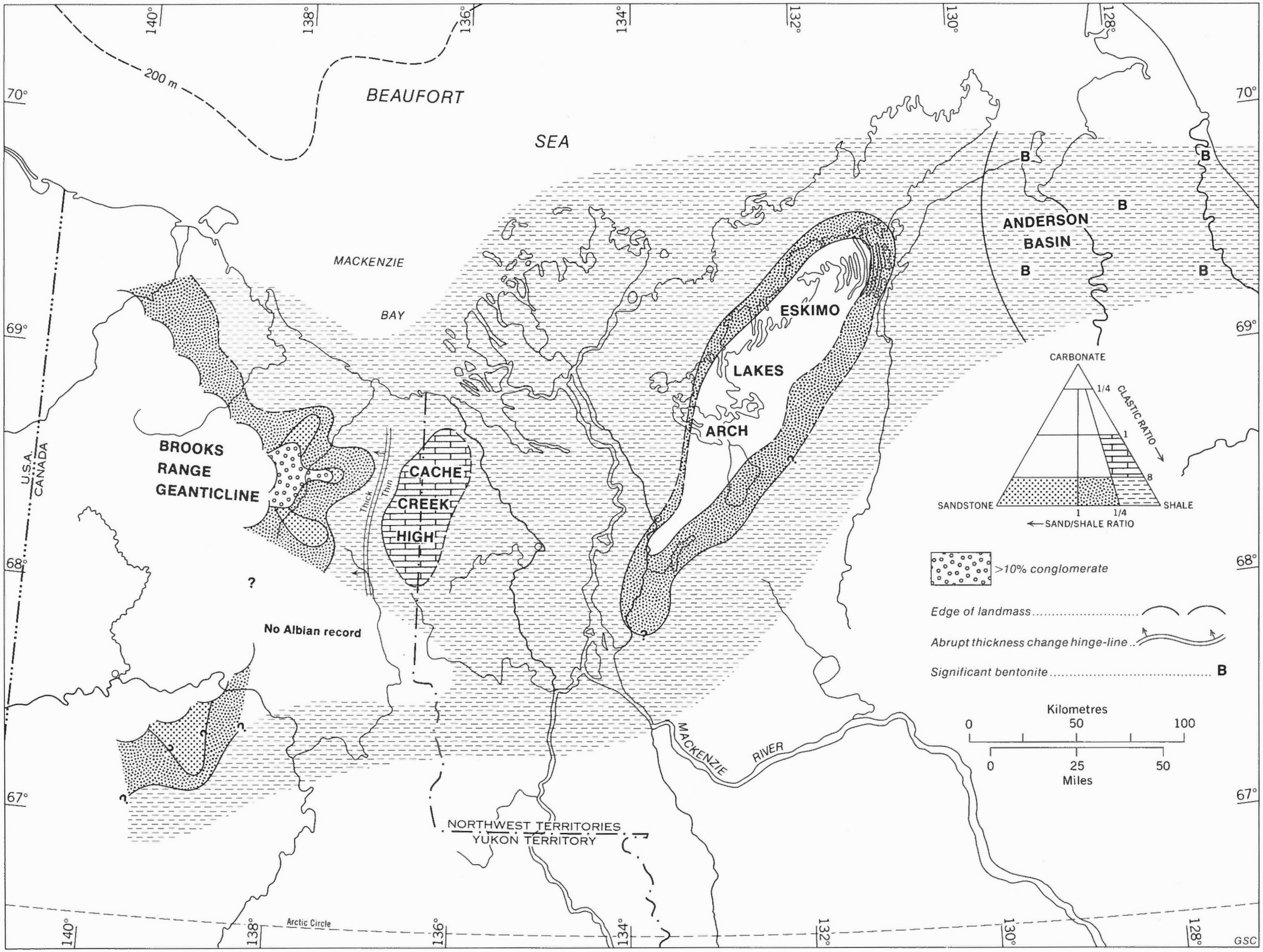


FIGURE 11. Lithofacies map; Early Albian

Few fossils exist to document Middle and Late Albian time in the northern Yukon but the unfossiliferous shale (and in part ironstone) that lies above dated Lower Albian rocks is believed to represent continuous deposition and filling of the Blow Trough. It is known that an unconformity representing late Middle and most of Late Albian time exists in the Mackenzie Delta (Jeletzky, 1971b; Chamney, 1973; Brideaux and Myhr, 1976).

UPPER CRETACEOUS

Stratigraphy

Lower Upper Cretaceous rocks in the Beaufort-Mackenzie Basin consist mainly of marine shale of fairly uniform character. In the Mackenzie Delta and northern Yukon, this shale is called the Boundary Creek Formation (Young, 1975b); on Anderson Plain and in the subsurface of northeastern Tuktoyaktuk Peninsula, the partly equivalent shale unit is called the Smoking Hills Formation (Yorath *et al.*, 1975; Myhr, 1975). The detailed stratigraphy of these units probably is more complex than appearances would suggest, a view supported by the recent discovery of an internal hiatus (Brideaux and Myhr, 1976).

The Boundary Creek Formation, incorporating the former "Upper Cretaceous shale division" of Jeletzky (1960), has yielded invertebrate macrofossils only at Treeless Creek; these were dated as Cenomanian to latest Turonian by Jeletzky (*ibid.*). The upper part of the formation contains a sparse microfauna of foraminifers and radiolarians, correlative with the Smoking Hills Formation (Chamney, 1972). The latter has an upper age limit of early Campanian on the basis of vertebrate fossils (Russell, 1967) and pelecypods (Jeletzky, 1971b). The lower age limit of the Smoking Hills Formation in outcrop was estimated to be late Coniacian, on the basis of foraminifers (Chamney *in* Yorath and Balkwill, 1970), and Santonian, based on palynomorphs (McIntyre, 1974). A recent study of marine dinoflagellates in cuttings of the Parsons N-10 borehole by Brideaux (Brideaux and Myhr, 1976) indicates that the Boundary Creek Formation is divisible into two parts: an upper member of Santonian(?) to middle Campanian age, overlying a lower member of Cenomanian to Turonian(?) age. The age of the upper member suggests its correlation with the Smoking Hills Formation to the east and northeast, whereas the lower member is equivalent to Jeletzky's Upper Cretaceous shale division, or to the lower 190 m (640 ft) of the type Boundary Creek Formation (Fig. 3).

In northern Yukon and Richardson Mountains, the Boundary Creek Formation lies above a sharp contact with Albian ironstone and shale. Little physical evidence exists to indicate an unconformity at this contact except for that in the vicinity of Treeless Creek (Jeletzky, 1960), where the Boundary Creek Formation unconformably overlies the Aptian Upper sandstone division. In the area of Cache Creek High, the upper contact is sharp and unconformable with the Fish River Group but, elsewhere, it appears to be conformable.

In the subsurface of Tuktoyaktuk Peninsula, the lower contact of the Upper Cretaceous shales is unconformable on Middle Albian or older rocks, based on micropaleontologic and palynological data (Chamney, 1973; Brideaux and Myhr, 1976). In the Anderson Plain region, the Smoking Hills Formation unconformably overlies the Albian Horton River Formation on a paleosurface which has a relief in the order of several metres. The upper contact with the Mason River or Tent Island Formation in these areas is generally gradational and conformable, but may be unconformable locally.

Lithology and thickness

In outcrops of Anderson Plain, a basal conglomerate occurs discontinuously at the base of the Smoking Hills Formation, above which the formation consists of interbedded black to medium grey, soft, commonly fissile, bituminous shale and white to dark yellow, orange-weathering, waxy to crumbly, very thin to thin-bedded jarosite. The formation is burning locally in the Smoking Hills, resulting in the formation of brightly coloured, hardened mudstone, cinders, earthy hematite, and selenite crystals. Gypsum crystals also occur in well-cuttings, particularly in the lower, highly bituminous member (Brideaux and Myhr, 1976; Myhr and Barefoot, 1976), suggesting that some oxidation of the shale took place during its diagenetic history.

In the subsurface of Mackenzie Delta-Tuktoyaktuk Peninsula, the Boundary Creek and Smoking Hills Formations consist of interbedded black, bituminous shale, and very dark grey shale with minor amounts of bentonitic shale and bentonite. The two formations are arbitrarily segregated areally on the basis of bentonite content, which is minor and restricted to the upper portion of the Boundary Creek Formation. Organic and pyritic shales are common within these formations, and commonly the basal few metres are extremely radioactive (Myhr, 1975; Myhr and Barefoot, 1976). The Boundary Creek-Smoking Hills Formations in the subsurface consist largely of black to very dark grey, papery, bituminous, fissile shale. Minor components of these formations in the subsurface include *Inoceramus* aragonite prisms, fish scales, small vertebrate bone fragments, ironstone concretions, bentonite, and zeolitic tuffs. *Inoceramus* prisms constitute a good marker bed in the Smoking Hills Formation of northeastern Tuktoyaktuk Peninsula (Myhr, 1975).

The upper part of the Smoking Hills Formation is highly radioactive, a fact which aids in the definition of the upper contact in the subsurface. At the southwest end of Tuktoyaktuk Peninsula, the Boundary Creek Formation contains two radioactive marker zones. Sample and core analyses suggest that the radioactivity is associated with highly organic and sulphate-rich shale (Myhr and Barefoot, 1976).

The thickness of the Smoking Hills Formation varies from 0 to 50 m (0-165 ft) in outcrop sections of Anderson Plain and thickens to over 100 m (330 ft) in the subsurface of Tuktoyaktuk Peninsula (Myhr, 1975, Fig. 3) (Fig. 12).

The Boundary Creek Formation outcrops sporadically in northern Richardson Mountains and is recognized easily by its soft and relatively light-coloured shale above the dark and brittle Albian shale and ironstone. The formation is subdivided into four members, comprising the three proposed by Jeletzky (1960) at the Treeless Creek section and an uppermost papery shale member.

The basal dark grey shale member consists principally of soft, bentonitic, dark grey shale which weathers to a light, ash-grey tone or, rarely, dark red, especially near the top. This member is more than 100 m (350 ft) thick at Treeless Creek, but only in the order of 65 to 80 m (200-250 ft) in the Big Fish-Little Fish Rivers area.

The overlying orange-weathering member is ferruginous, resulting in bright orange and red-weathered outcrops. It consists of dark grey to black shale, in part bentonitic and streaked with yellow, interbedded with ferroan limestone and sideritic ironstone, similar to that of the Albian sequence. Weathering of these beds results in the formation of selenite crystals and hematitic breccias. The large sulphur and iron content (disseminated pyrite) of this member is due probably to a combination of euxinic bottom conditions and an influx of volcanic exhalatives, as evidenced by bentonite seams and the presence of andesite lapilli (Young, 1975b). This marker unit varies from 20 to 30 m (60-90 ft) thick in the vicinity of Cache Creek High but thickens and becomes indistinct in thicker sections north and west of the type area.

The bluish-weathering member varies greatly in thickness because of erosion at the sub-Fish River Group unconformity. It is a recessive unit, consisting mainly of soft, fissile, commonly bentonitic shale, which varies from light to very dark grey. It contains thin calcareous beds and concretions, and yellowish-white bentonite beds up to 0.3 m (1 ft) thick.

In sharp, possibly disconformable, contact above the bluish-weathering member at the type section is the papery shale member, which consists of dark grey to black, papery-thin shale, with large, calcareous, septarian concretions, and abundant whitish clay laminae and selenite crystals.

Paleogeography and interpretations

The thickness of the Upper Cretaceous shales is quite variable (Fig. 12) because of both differential accumulation and local erosion at the top of the succession. The sequence thickens abruptly northwest of Eskimo Lakes Arch into Kugmallit Trough, where a maximum known thickness of 485 m (1600 ft) occurs in the IOE *et al.* Tununuk K-10 borehole. Farther northwest is a zone of relatively thin Upper Cretaceous shale, the alignment of which is uncertain, but which appears to be on an extension of Cache Creek High through the Shell Kugpik O-13 and B.A. *et al.* Reindeer D-27 wells. West of this uplift, the Boundary Creek Formation thickens markedly into the Blow Trough, whose axis trends approximately north-south along Longitude 137°30'W, and continues southward into Eagle Plain. A mid-Late Cretaceous western shoreline is evident according to thickness and lithologic data derived from exposures on the Porcupine River upstream from the village of Old Crow (Jeletzky, 1972). Here, Santonian sandstone oversteps Turonian siltstone and shale westward, and represents shoreline deposits of the Late Cretaceous sea from which, otherwise, mud was deposited.

These rocks are derived in part from fine debris shed from the final erosional phase of the Columbian geanticlinal upland lying to the west of the basin. Throughout northern Alaska, the northern Canadian mainland, and the Arctic Islands, similar deposits of this age reflect generally quiescent tectonic conditions, except for the widespread evidence of vulcanism. East of the Blow Trough, anaerobic conditions seem to have prevailed, as indicated by the high organic and pyrite contents of the shales and the dwarfed and depauperated microfauna.

TERTIARY (AND LATEST CRETACEOUS) SEQUENCE

The Tertiary and latest Cretaceous sequence consists of several wedge-like, molassic, transgressive-regressive cycles that were deposited in a restructured, pericratonic basin greatly influenced by Laramide tectonic activity. The oldest clastic cycle comprises most of the Fish River Group (Tent Island and Moose Channel Formations); this is overlain by the Ministicoog Member of the Moose Channel Formation and the Reindeer Formation, forming the second cycle. A third clastic wedge consists of an unnamed Eocene shale formation and overlying unnamed upper Paleogene fluviodeltaic unit. At least one, and possibly two, younger offlapping units are indicated from seismic data beneath the Beaufort continental shelf (Hawkings and Hatlelid, 1975; Fig. 24). Evidence available to date suggests that these clastic cycles consist of similar suites of lithofacies. They are described in a summary following descriptions of the stratigraphy.

UPPER CRETACEOUS (UPPER CAMPANIAN-MAASTRICHTIAN) STRATIGRAPHY

The oldest rocks of the molassic sequence are late Late Cretaceous in age, and comprise a large-scale transgressive-regressive cycle. In northern Yukon and northwestern Mackenzie Delta areas, these sediments comprise the Fish River Group (Young, 1975b), which consists of the Tent Island Formation, a marine mudstone unit, and the overlying Moose Channel Formation, a coarse, terrigenous clastic unit (Fig. 3). These formations grade laterally eastward into shale of the Mason River Formation (Yorath *et al.*, 1975), formerly known as the "Pale shale zone" (Fig. 13).

Dating of these and younger parts of the sequence has depended considerably on palynology and micropaleontology (foraminifers) because of the lack of macrofossils. Pollen, spores, and dinoflagellates (identified by W.W. Brideaux), and foraminifers (identified by T.P. Chamney) indicate a

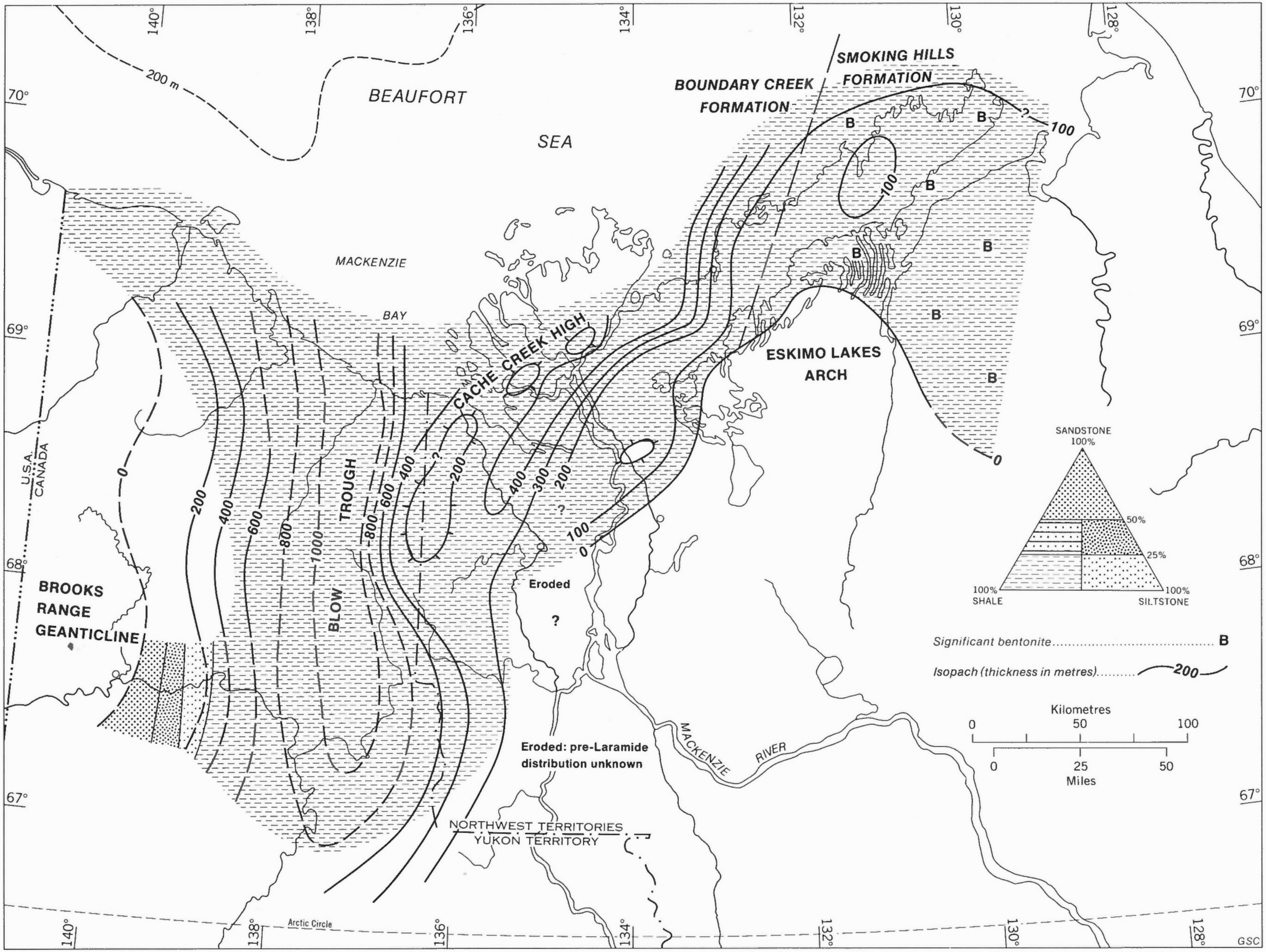


FIGURE 12. Lithofacies and isopach map; Cenomanian-early Campanian (Late Cretaceous)

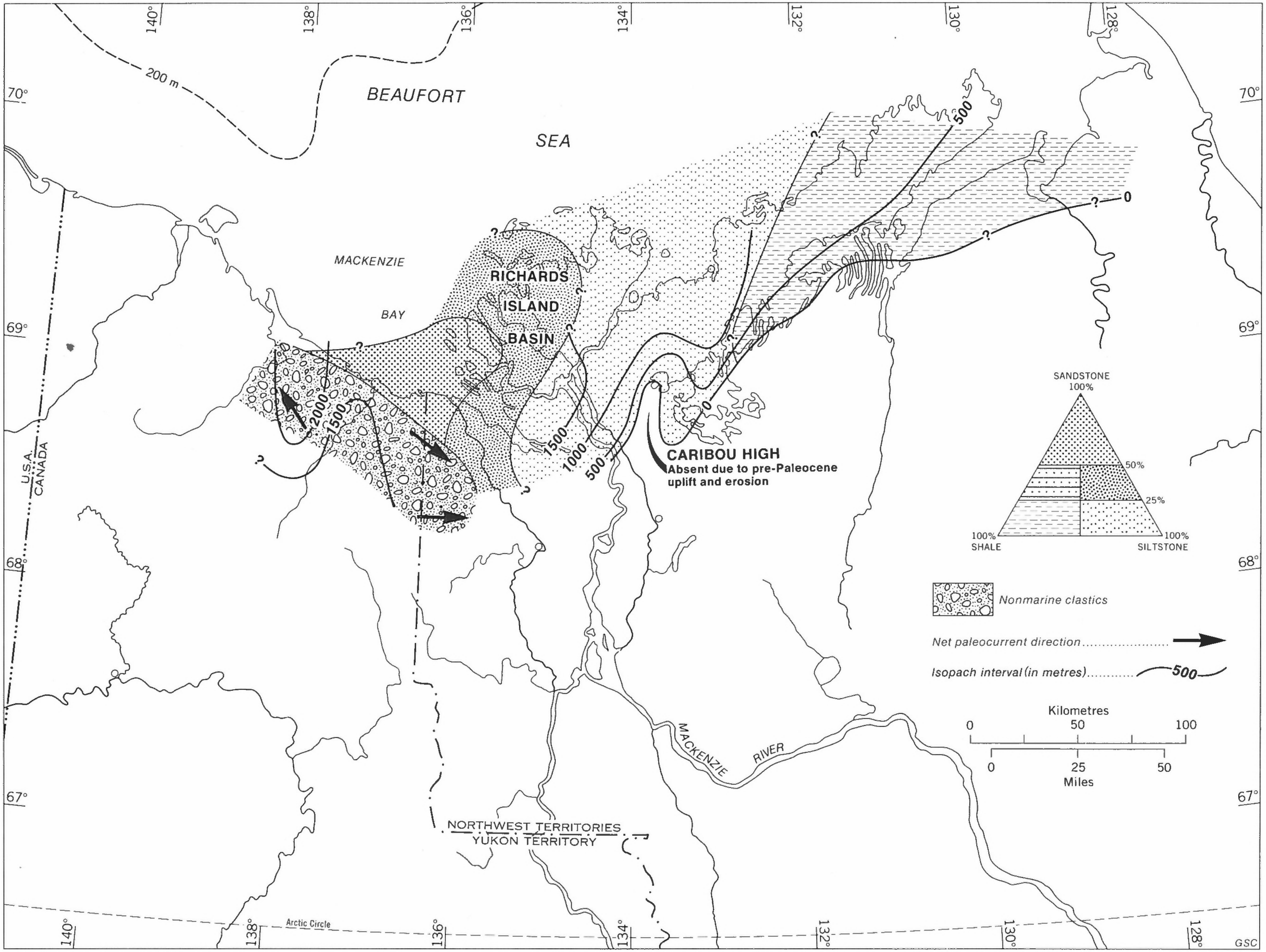


FIGURE 13. Lithofacies and isopach map; Campanian-Maastrichtian (Late Cretaceous)

a very Late Cretaceous age for the lowest major cycle, with the possibility of an Early Tertiary age for the uppermost part of the Moose Channel Formation (A.R. Sweet, pers. com.). Reworking of older microfloras and foraminifers into younger sediments in the molassic sequence is evident constantly and causes confusion and disagreement among biostratigraphers regarding age assignments.

Outcrops of the Late Cretaceous cycle occur on Yukon Coastal Plain (Young, 1975b) and in the Anderson Plain region (Yorath *et al.*, 1975). These sediments, presumably, were much more extensive in the northern Yukon area than present distribution would suggest, as evidenced by thickness trends and rare outliers. Present southerly limits in the subsurface of Mackenzie Delta apparently lie along Latitude 68°35' North.

Thickness of the cycle increases from a zero edge on Anderson Plain to approximately 1000 m (3280 ft) beneath Tuktoyaktuk Peninsula and increases to a known maximum in the order of 2000 m (6560 ft) in northwestern Mackenzie Delta (Fig. 13). Structural features that cause irregularities in isopach trends include the post-depositional Caribou High (Fig. 3) which trends northeast-southwest beneath Caribou Hills and, probably, a pre-depositional positive area trending north-south immediately west of Rapid Creek in northern Yukon.

The Tent Island Formation appears to be particularly thick (1800 m; 5950 ft) in Kugmallit Trough which trends through the Shell Unak B-11 and IOE *et al.* Tununuk K-10 boreholes. This trend probably extends into the Cache Creek Uplift (Norris, 1976), which became a negative element, apparently, in latest Cretaceous time, and into the Shallow Bay area where a negative Bouguer gravity anomaly suggests the presence of thick sediments (Norris, 1974, 1976).

Contact relationships and lithology

Geological mapping in the Big Fish River area west of Mackenzie Delta (Young, 1975b; Norris, 1976) indicates the existence of a local unconformity between the Boundary Creek and Tent Island Formations. A basal conglomerate and sandstone unit, the Cuesta Creek Member, occurs locally on eroded Boundary Creek or older formations (Figs. 6, 15) but is generally absent north of a line approximating the 500-foot elevation contour and under Mackenzie Delta. Norris (1976) recently recognized a large stratigraphic gap between the Cuesta Creek Member and the Jurassic Bug Creek Formation immediately west of Little Fish (Cache) Creek (Fig. 6).

The lower contact of the sequence may be disconformable locally in the subsurface of Tuktoyaktuk Peninsula, where, in some boreholes such as IOE Siku C-55 and IOE *et al.* Tuk F-18, a thick basal sandstone unit, 10 m (33 ft) thick, abruptly overlies shale and bentonite of the Boundary Creek Formation (Fig. 14) (Myhr and Barefoot, 1976, Fig. 2).

The upper contact of the Fish River Group with the Reindeer Formation is conformable and commonly abrupt west of Mackenzie Delta but becomes increasingly gradational to the northeast in subsurface sections. In the Caribou Hills area north of Inuvik, the Upper Cretaceous cycle is truncated by an unconformity at the base of the Reindeer Formation (Figs. 13, 14).

In outcrops on Anderson Plain and in boreholes of northeastern Tuktoyaktuk Peninsula, the Mason River Formation conformably overlies the Smoking Hills Formation. However, in the IOE Magak A-32 borehole, a local unconformity may exist between the two formations. Evidence for this lies at a depth of 1350 m (4425 ft), where there are abrupt changes in lithology and bedding attitude.

The Mason River Formation grades upward into the Reindeer Formation equivalent in the subsurface of northeastern Tuktoyaktuk Peninsula; in the outcrop area to the southeast (Yorath *et al.*, 1975) and in the IOE Nuvorak O-09 borehole, however, it is overlain unconformably by the Neogene Beaufort Formation (Fig. 21).

The Mason River Formation consists principally of pale grey, soft, marine shale with minor thin laminae of jarosite and bentonite (Yorath *et al.*, 1975). Dark, ferruginous carbonate concretions and dark grey shale occur in the middle of the formation. It grades laterally westward into non-bentonitic shale and becomes increasingly silty in boreholes southwest of the village of Tuktoyaktuk. An arbitrary cut-off of 50 per cent shale is used to demarcate the lateral change from the Mason River Formation to the Tent Island Formation (Fig. 13).

The Tent Island Formation consists mainly of mudstone, shale and siltstone of prodeltaic and shallow-marine origin (Young, 1975b). In many places, relatively thin units of sandstone occur [for example, in the lower part of the Shell Unipkat I-22 borehole (Fig. 15) and in the IOE Wagnark G-12 borehole (Fig. 14)], some of which are calcareous. Calcareous siltstone beds are minor but characteristic components of the Tent Island Formation in the type area and in the subsurface to the east.

In the western part of the basin, a coarse clastic wedge appears in the upper half of the cycle (Figs. 13, 15), comprising the Moose Channel Formation. This formation consists of deltaic sandstone, conglomerate, mudstone, and rare coal, and extends eastward as far as the west side of Richards Island. Tongues of marine mudstone, such as the Ministicoog Member at the top of the formation, represent local cessations in deltaic sedimentation and marine transgression (Fig. 15). Coal is relatively rare in the Moose Channel Formation in comparison with the younger Reindeer Formation but occurs in the northwestern part of Mackenzie Delta (Fig. 13).

Sandstone and conglomerate of the Fish River Group are rich in chert, volcanic and metamorphic rock fragments, quartz and feldspar (Young, 1973b, 1975b). These materials evidently are derived from source-terrains of mixed lithologies in northern Yukon and Alaska and transported easterly, as interpreted from paleocurrent data and lithofacies trends

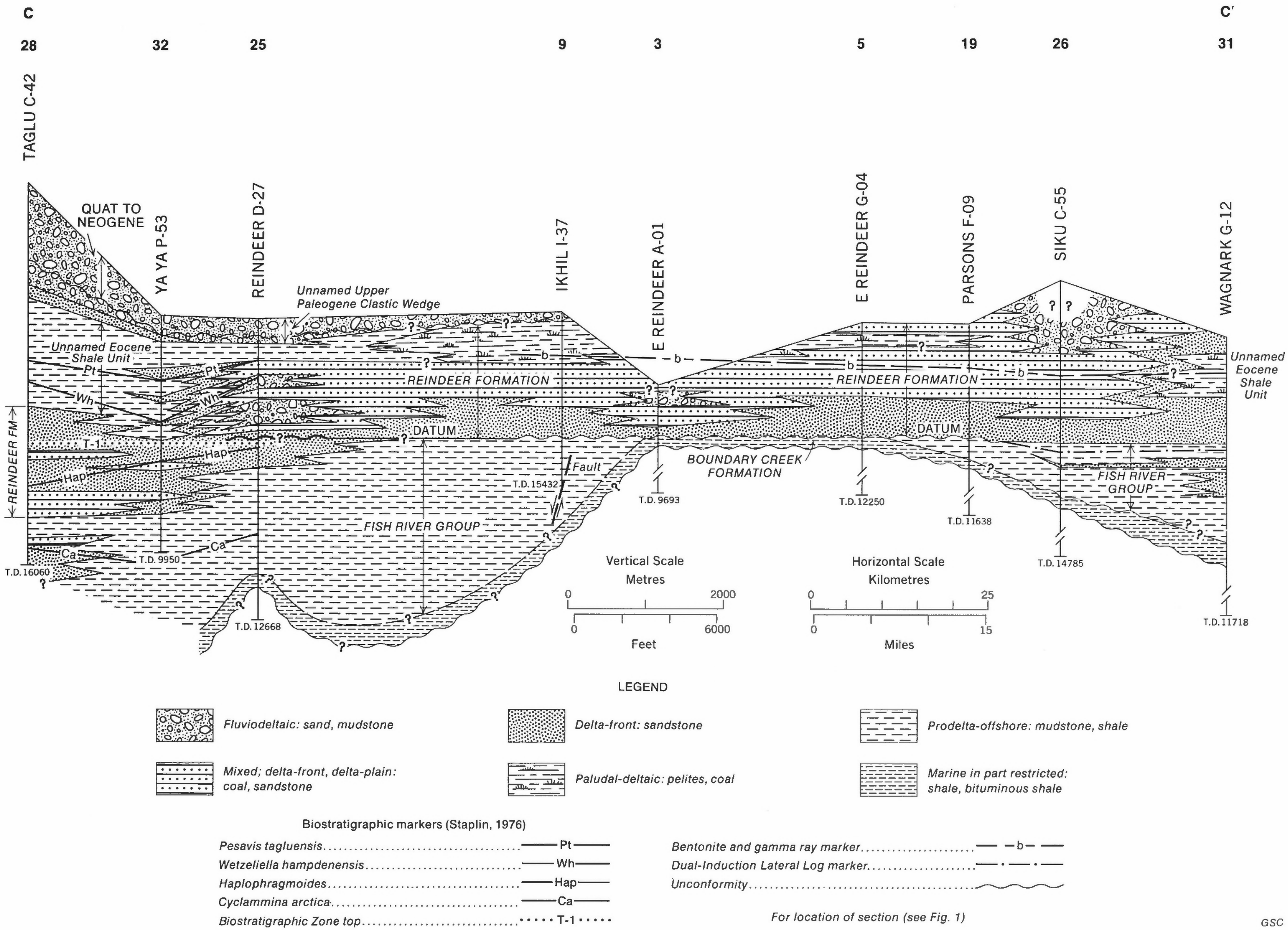


FIGURE 14. Stratigraphic profile of Upper Cretaceous and Paleogene lithogenetic units, Richards Island Basin, Caribou High and Kugmallit Trough

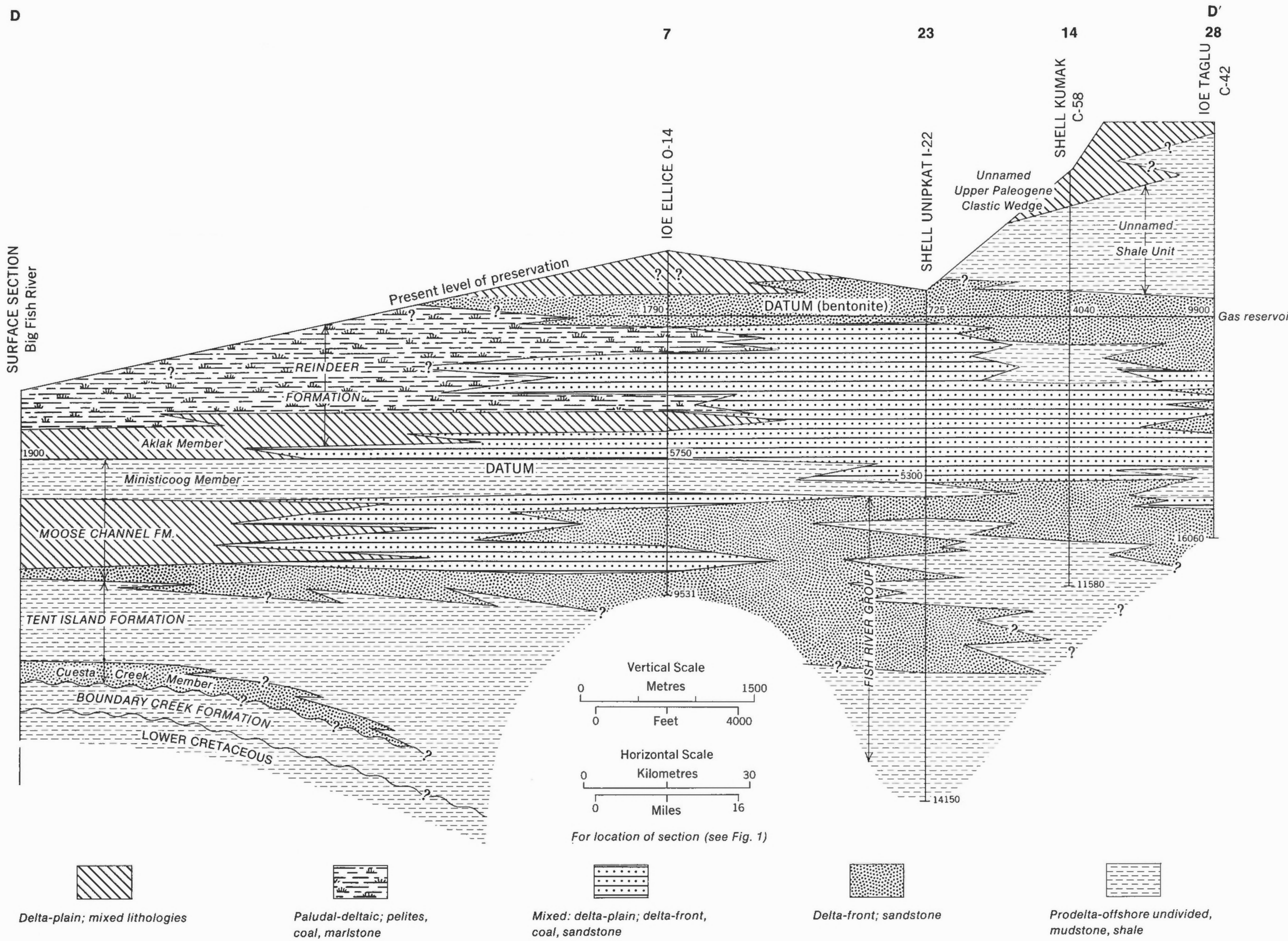


FIGURE 15. Stratigraphic profile of Upper Cretaceous and Paleogene lithogenetic units, Big Fish River to Taglu field

(Fig. 13). A Lower Cretaceous volcanic terrain containing abundant andesite lies in Koyukuk Basin of west-central Alaska (Patton, 1973), and may have supplied andesitic detritus to both the Moose Channel and Reindeer Formations.

LOWER TERTIARY (PALEOCENE AND EOCENE) STRATIGRAPHY

A widespread, regressive clastic wedge, the Reindeer Formation (Mountjoy, 1967b), overlies and offlaps the Fish River Group in the Mackenzie Delta area. Two sections in the Caribou Hills were measured during Operation Porcupine, 150 and 180 m (485 and 594 ft) thick, respectively, but more recent observations by the authors indicate that at least 1200 m (4000 ft) of nonmarine sand, gravel, lignite and mud are present in the type locality. Boreholes in the area, such as Gulf-Mobil Ikhil I-37, have penetrated 1600 m (5230 ft) of Tertiary sediments of which approximately 1465 m (4800 ft) are assigned to the Reindeer Formation (Fig. 14). West of Mackenzie Delta, equivalent rocks comprise the Aklak Member (Young, 1973b, 1975b) of the Reindeer Formation. This formation, consisting of numerous deltaic lobes and coalesced alluvial complexes, underlies much of the inner Beaufort Sea shelf, the outer Mackenzie Delta, and the Tuktoyaktuk Peninsula.

The Reindeer Formation in the Caribou Hills is Paleocene (Mountjoy, 1967b; Brideaux *in* Young, 1975b, p. 17) and probably Eocene (A.R. Sweet, pers. com.) in age, while the Aklak Member is slightly older, according to palynomorph assemblages (Fig. 3). Fossil plant material from this member was assigned a Santonian-Maastrichtian age by Smiley (*in* Young, 1975b, p. 16), but recent studies on megaspores by A.R. Sweet (pers. com.) suggest an early Paleocene age. The gas-bearing sandstone units of the Taglu field are delta-front equivalent beds of the type Reindeer (Fig. 15) and have been dated as Paleocene to Eocene in the IOE Taglu G-33 borehole (Brideaux *in* Barnes *et al.*, 1974). Imperial Oil palynologists recognize only Eocene assemblages (Staplin, 1976).

In boreholes of Tuktoyaktuk Peninsula, mudstone of the Mason River-Tent Island Formation grades upward into a unit consisting of sandstone and mudstone of marine and/or delta-front origin. This unit is Late Cretaceous(?) to Paleogene in age (Chamney, 1973; Brideaux *in* Brideaux *et al.*, 1976), and is in part correlative with the Reindeer Formation. Thicknesses of this poorly defined unit range from 0 to 700 m (0-2300 ft). The upper contact with the Beaufort Formation (?), a gravel and sand unit, is difficult to delineate but, in the subsurface of northeastern Tuktoyaktuk Peninsula, the contact is commonly sharp and may be unconformable.

Beneath Richards Island and the outer Mackenzie Delta, an unnamed marine shale formation intertongues with and overlies the Reindeer Formation (Figs. 3, 14, 15). An Eocene age has been established from pollen and dinoflagellate assemblages (Brideaux *in* Barnes *et al.*, 1974; Staplin, 1976). This shale is overlain gradationally by an upper Paleogene clastic wedge. In the Taglu area, the shale is 1370 m (4500 ft) thick, but thins from there toward the east [750 m (2280 ft) in the Niglintgak-Kumak area (Fig. 15)] and south toward Caribou Hills (Fig. 14). It probably thickens north and northeast of the Taglu field and forms diapiric structures associated in part with growth faults under northeastern Richards Island (Fig. 21).

Contact relationships and lithology

In most areas, the Reindeer Formation conformably overlies the Fish River Group; the contact may be sharp or gradational and results from the over-stepping of marine shale and sandstone by nonmarine or deltaic sediments. Over the Caribou High (Fig. 3), Upper Cretaceous marine rocks are overlain unconformably by shallow-marine and fluviodeltaic rocks of the Reindeer Formation (Lerand, 1973; Coté *et al.*, 1975), as exemplified by the stratigraphy of the Gulf Mobil Parsons F-09 borehole (Fig. 14). The unconformity is recognized in local boreholes by a sandstone unit, 10 to 15 m (33-50 ft) thick, that represents a marine transgression over the high.

The Aklak Member of the Reindeer Formation outcrops on creeks entering the northwestern margin of Mackenzie Delta and occurs in the subsurface adjacent to the east (Fig. 15). It consists of massive sandstone, pebbly to cobbly conglomerate, dark grey mudstone, red siltstone, coal, marlstone, and variably sintered carbonaceous rocks (ancient bocannes). Thick units of non-arenaceous sediments, which may represent lacustrine and marsh environments, occur in the middle and upper parts of the Reindeer Formation in the IOE Ellice O-14 borehole (Fig. 15).

Unconsolidated sediments of the Reindeer Formation outcrop in the Caribou Hills, the type area (*see* index map, Fig. 1). There, three informal members are recognized: a basal mudstone member, a medial arenaceous member, and an upper pelitic member. The basal member is moderately recessive and comprises shale, mud, bocanne, bentonite, and minor arenaceous beds, including a basal sandstone unit. This member is overlain gradationally by a more resistant member, consisting of sand with minor mud and lignite, the latter capping many of the sand units. The upper member is a shaly sequence which is recessive and light grey weathering, and includes minor amounts of sand and lignite, and abundant clay and bentonite. The Reindeer Formation is overlain abruptly, and probably unconformably, by lithic gravel and sand of probable Neogene age (Fig. 14).

In boreholes on Richards Island, the upper part of the Reindeer Formation interfingers with the unnamed Eocene shale unit, hence the contact varies in stratigraphic level from one well to another (Fig. 14). The shale unit consists mainly of marine mudstone and shale, with minor bentonite, marlstone, and argillaceous conglomerate (Glaister and Hopkins, 1974).

MID-TERTIARY TO QUATERNARY STRATIGRAPHY

An unnamed, coarse clastic wedge overlies the unnamed Eocene shale formation in the Richards Island Basin and inner continental shelf. A thick transitional unit consisting of interbedded sandstone

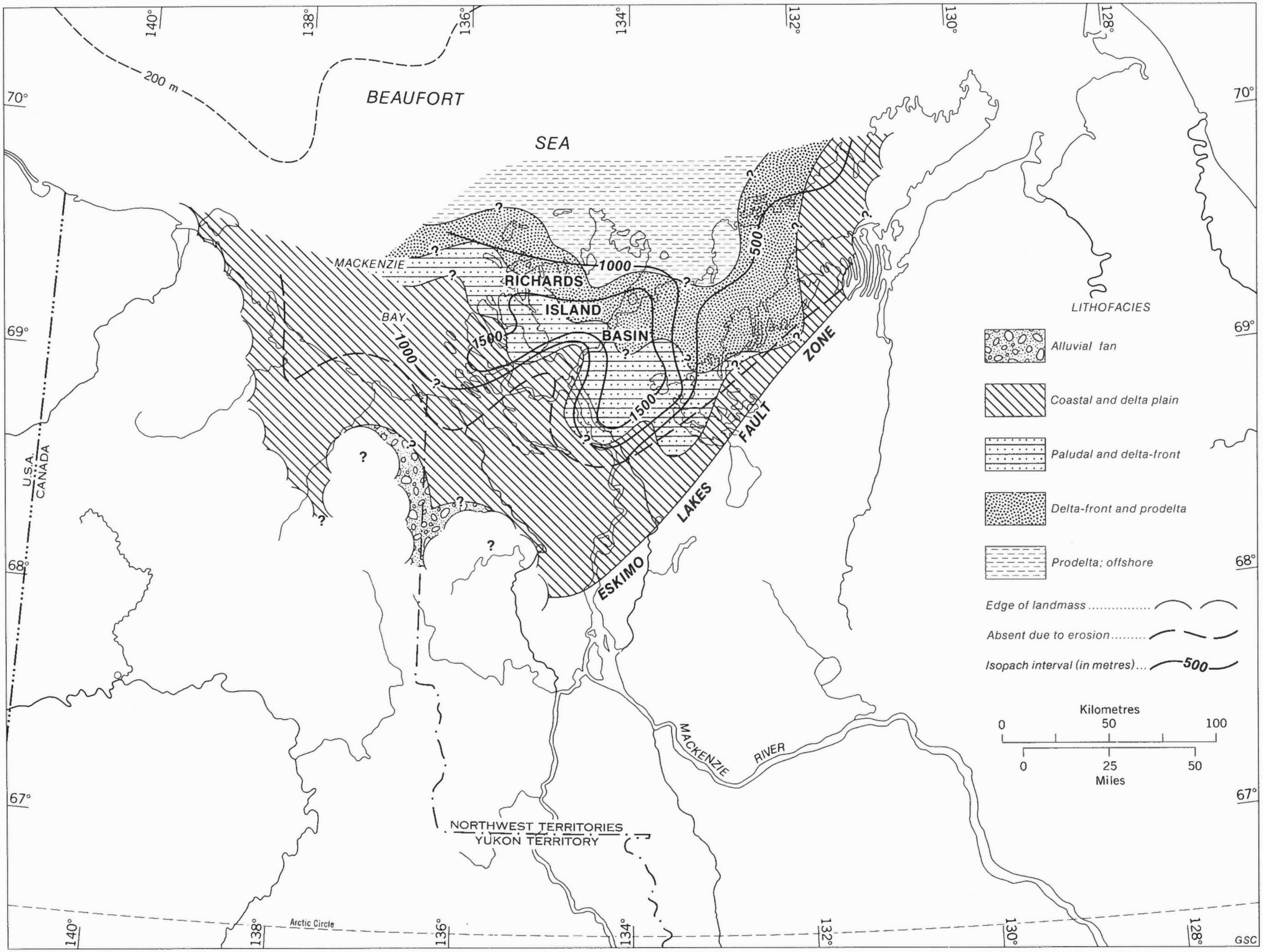


FIGURE 16. Isopach map showing late Paleogene paleogeography

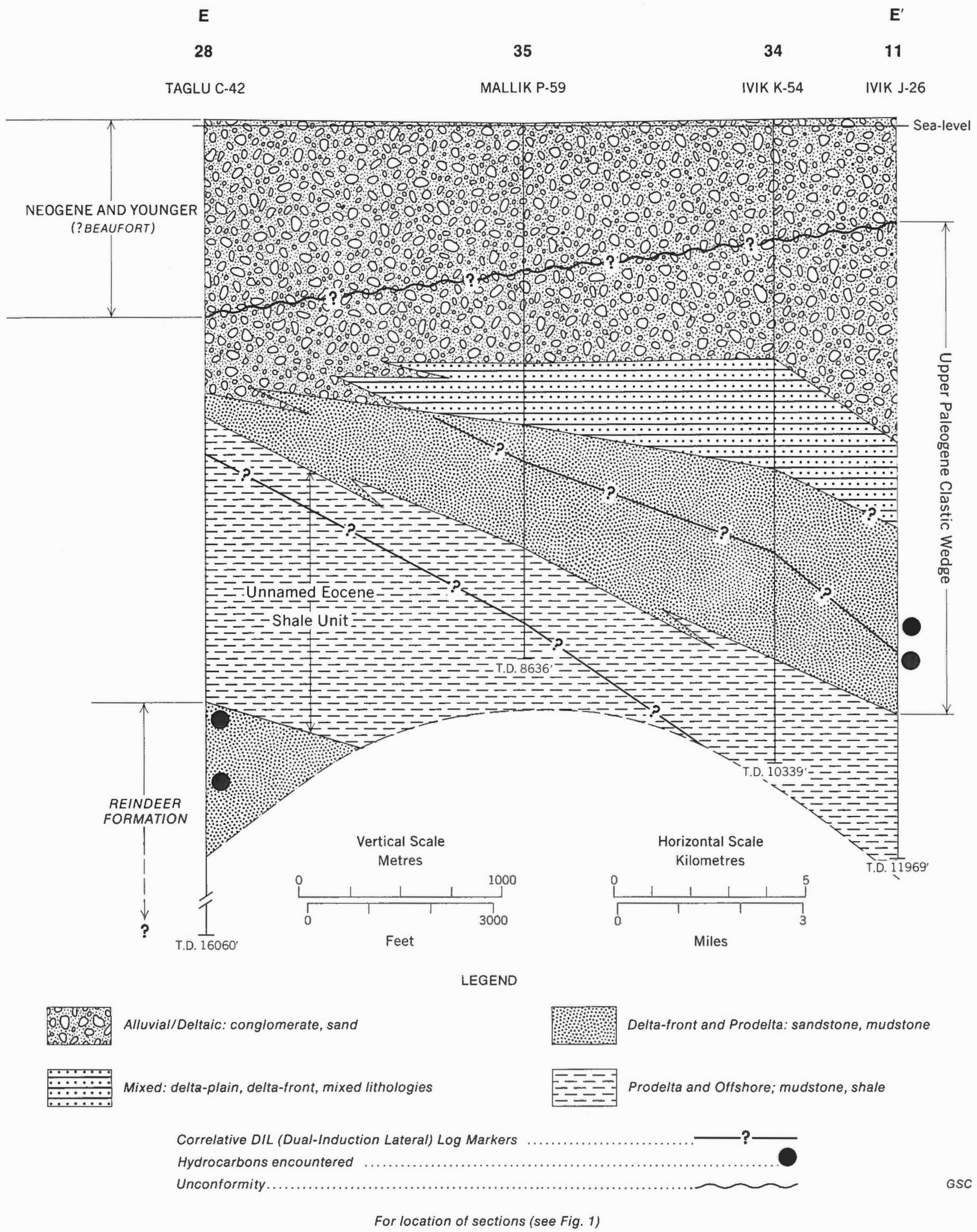


FIGURE 17. Structural profile of Tertiary lithogenetic units, Richards Island Basin

and shale is overlain by coarse-grained alluvial sediments, which generally persist throughout the upper part of borehole sections in this area (Fig. 17). This overall vertical sequence indicates gradual basinward progradation of a thick clastic wedge.

Micropaleontological research (Staplin, 1976) reveals the existence of an unconformity within the alluvial facies, separating Neogene from upper Paleogene clastics. Palynological studies of the section below the unconformity indicate an Oligocene to late Eocene age (Brideaux and Sweet *in* Brideaux *et al.*, 1975).

Offshore seismic profiles (Hawkings and Hatlelid, 1975) reveal the presence of an upper offlapping, clastic wedge, identified as possibly Plio-Pleistocene in age (Fig. 24). The Neogene wedge between this and the upper Paleogene wedge may be equivalent to the Beaufort Formation which outcrops on the Arctic Coastal Plain, east and northeast of the delta. Offshore seismic profiles indicate that horizontal stratification in the thin, uppermost unit is possibly due to sheet-like deposition related to episodic eustatic rises in sea level during the late Pleistocene and Holocene.

Up to 3000 m (10 000 ft) of clastic sediments were deposited rapidly in the foundering Richards Island Basin and peripheral areas in the combined upper Paleogene to Quaternary succession. This wedge thins abruptly southward to zero along the southeastern margin of Kugmallit Trough (Fig. 18). Outliers of gravel and sand assigned to the Neogene Beaufort Formation exist in the lower Anderson Plain (Yorath *et al.*, 1975) but no known equivalents occur in the outcrop area west of Mackenzie Delta.

Prodeltaic and delta-front facies prograded seaward across the continental shelf, as indicated by clinoform sets shown on marine seismic profiles (Hawkings and Hatlelid, 1975). Successively younger sets extended the edge of the shelf progressively seaward, and their respective thickness maxima, which probably represent deltaic depocentres, also offlapped seaward (*op. cit.*).

LITHOFACIES OF THE MOLASSIC SEQUENCE

Diverse terrigenous clastic rocks, coal, and marlstone comprise the molassic sequence and reflect a large group of sedimentary environments related to alluvial, deltaic, littoral, and marine depositional systems. Various lithogenetic facies associations of the Fish River Group were described by Holmes and Oliver (1973) and Young (1975b). These authors also discussed nonmarine facies in the Aklak Member of the Reindeer Formation, whose basinward equivalents in the subsurface of Richards Island were described by Bowerman and Coffman (1975), Shawa *et al.* (1974), and Glaister and Hopkins (1974). A recent study of cuttings, cores and well-logs from this sequence, combined with the published data, allows most of the facies associations to be described and interpreted.

The following lithogenetic units and their respective facies associations comprise the major lithofacies of the molassic sequence.

Alluvial lithofacies - (a) Braided stream complex:
(i) conglomerate-sandstone and (ii) coarse sandstone facies;
(b) Meandering stream complex: mixed lithologies, fining-upward trends;

Deltaic lithofacies - (c) Delta-plain, channel-dominated: sandstone-mudstone-coal facies;
(d) Paludal deltaic: siltstone-carbonaceous mudstone-marlstone facies;
(e) Mixed delta-front/delta-plain: small-scale coarsening-upward trends, capped by coal and minor channel sandstone;
(f) Prodelta-delta front: large-scale coarsening-upward trends, without coal, commonly capped by distributary channel sandstone;

Littoral lithofacies - (g) Beach-bar: massive to laminated sandstone and burrowed mudstone in coarsening-upward rhythms;
(h) Tidal flat: interbedded sandstone-mudstone;

Marine lithofacies - (i) Offshore: mudstone-shale with thin sandstone beds.

It is beyond the scope of this paper to describe in detail the attributes of each lithogenetic unit. However, the following is a brief review of facies associations, stratigraphic trends, and borehole geophysical log response associated with each. The reader is referred to previously published works (noted above) for greater detail on most facies associations.

Alluvial lithofacies

The following three facies associations have been ascribed to the alluvial lithofacies: the interbedded conglomerate and sandstone facies, the coarse-grained sandstone facies, and the mixed lithology facies. The first two were interpreted as braided stream deposits in the Cuesta Creek Member and Moose Channel Formation by Young (1975b); however, Holmes and Oliver (1973) considered the derivation of the coarse-grained sandstone facies in the latter to be a shallow, meandering stream system. The third facies with its fining-upward rhythms is interpreted as a meandering stream deposit.

The conglomerate and sandstone facies consists of lenticular, intertonguing beds of conglomerate, pebbly sandstone, sandstone (sand) and, rarely, shale or coal. Abrupt lateral gradations from conglomerate to sandstone are common. Holmes and Oliver (1973) performed granulometric analyses on these rocks and found that most samples contained large, coarse-suspension populations, typical of high turbulence. The great variation in grain sizes and the poor sorting point to an extremely variable and episodic stream discharge, typical of braided streams.

The coarse-grained sandstone facies exhibits extensive, tabular sets of crossbedding, scour-and-fill structures, pebble-conglomerate beds, and thin (0.5-1.5 m; 1.6-4.6 ft), fining-upward rhythms. Thin shale units interrupt in places the generally arenaceous character of this facies. These characteristics are consistent with those observed in sandy, braided streams in which transverse, longitudinal, and other bar-forms co-exist with pebbly chute and channel deposits (Ore, 1965; Smith, 1970).

The meandering stream complex is characterized by mixed clastic lithologies and fining-upward sedimentary rhythms that are thicker than those of the coarse-grained sandstone facies. Each rhythm begins with a pebbly sandstone having a sharp, scoured contact at its base. This is followed by finer grained sandstone, commonly parallel-laminated, and finally by ripple-laminated silty sandstone, siltstone and

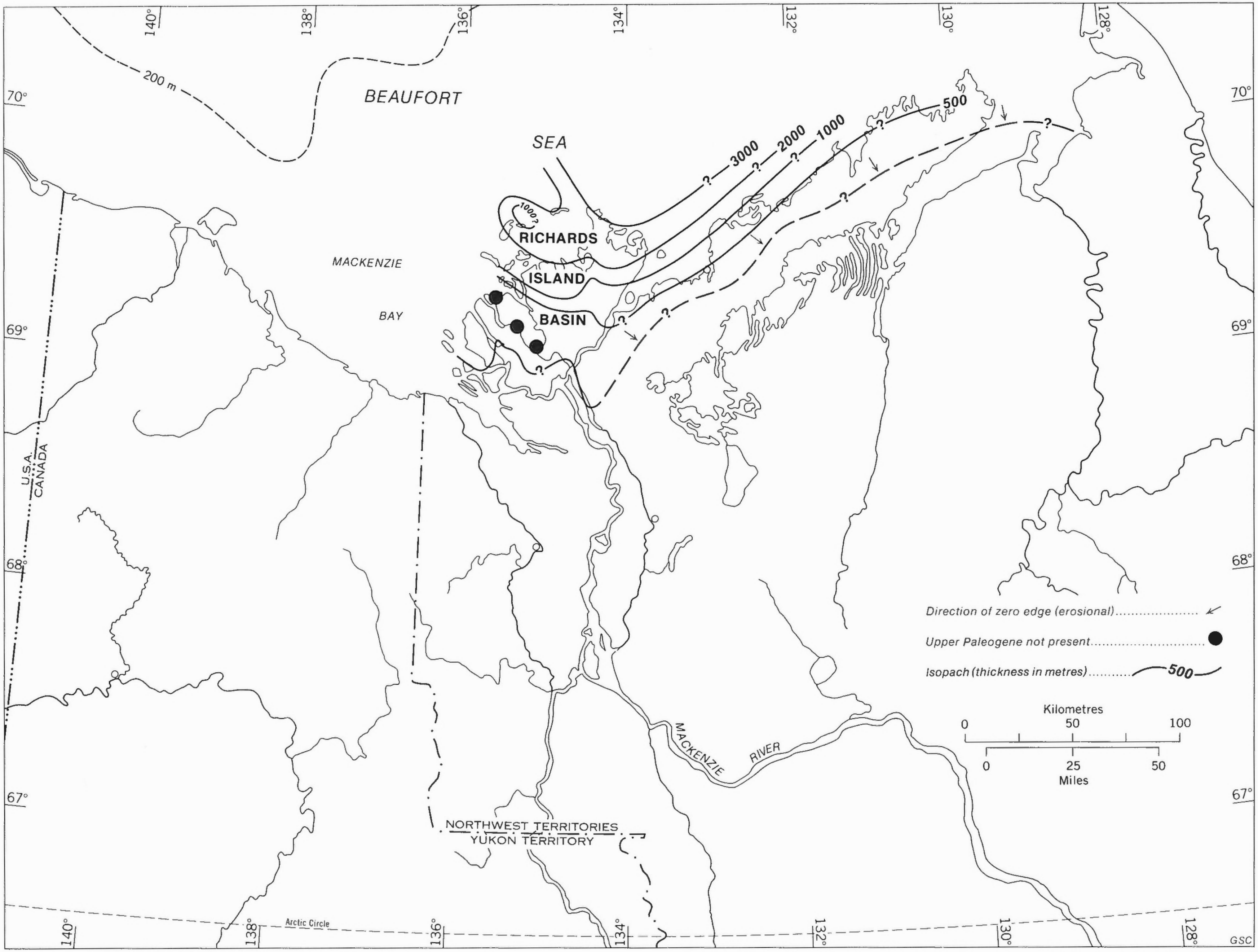


FIGURE 18. Isopach map from surface to base of upper Paleogene fluviodeltaic unit

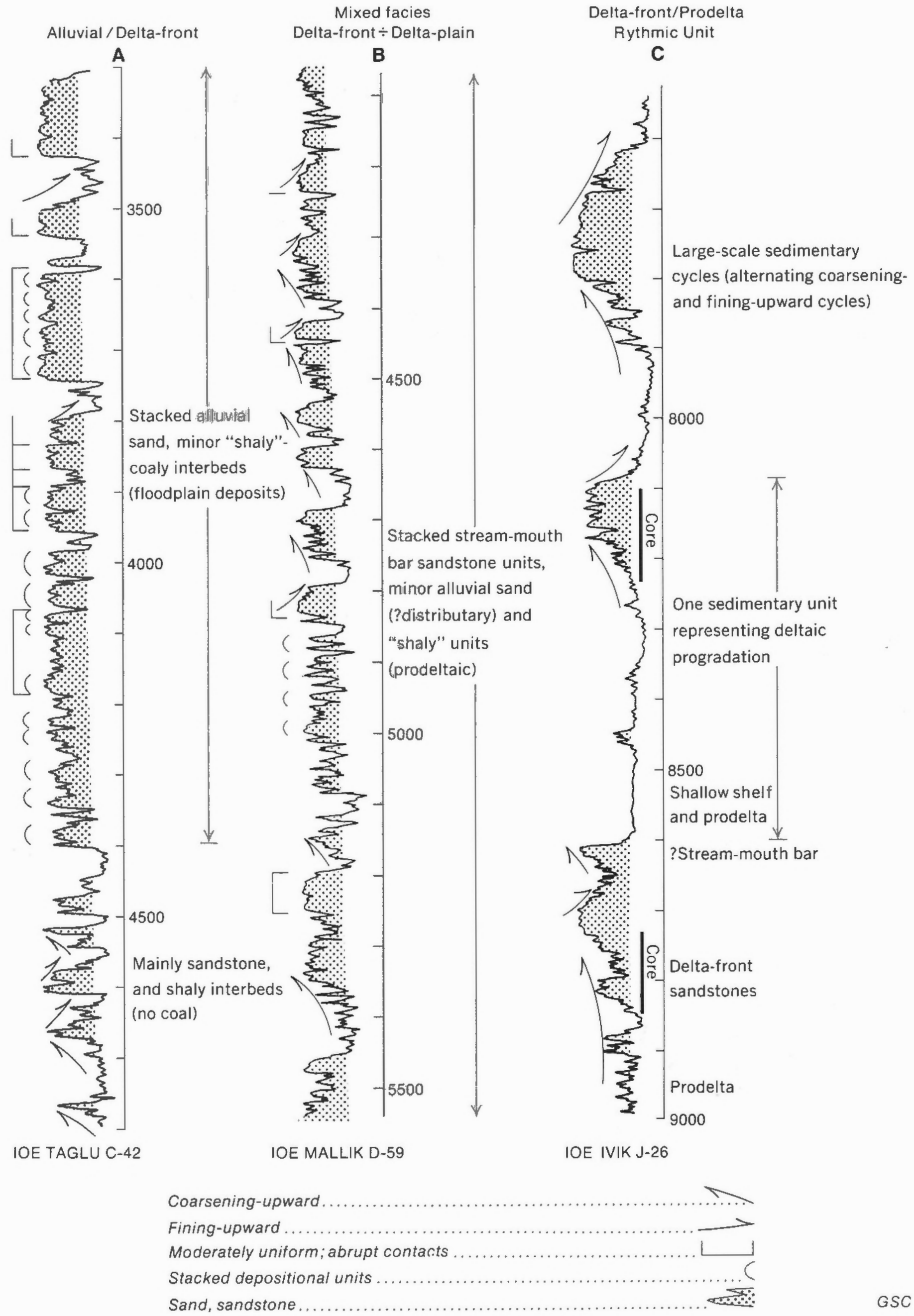


FIGURE 19. Representative spontaneous potential (SP) log response of upper Paleogene fluviodeltaic lithofacies

mudstone. These sedimentary cycles probably are produced by the lateral migration of fluvial point-bars and their associated overbank deposits (Bernard and Major, 1963; Visher, 1965).

In the subsurface of Mackenzie Delta, the alluvial facies is particularly well developed in the unnamed upper Paleogene and Neogene clastic wedges. The above-described lithologic attributes of the alluvial lithofacies can be recognized on the gamma ray and spontaneous potential logs which record abundant sandstone units with abrupt basal contacts, occasional shale breaks, and minor fining-upward trends (increasingly positive SP response; gradually increasing gamma ray counts) (Fig. 19, log A). Log B in Figure 19 also illustrates the character of a few channels that cap small-scale coarsening-upward trends, and a few fining-upward trends.

Deltaic lithofacies

The deltaic lithotope can be subdivided into the delta-plain, delta-front, and prodeltaic

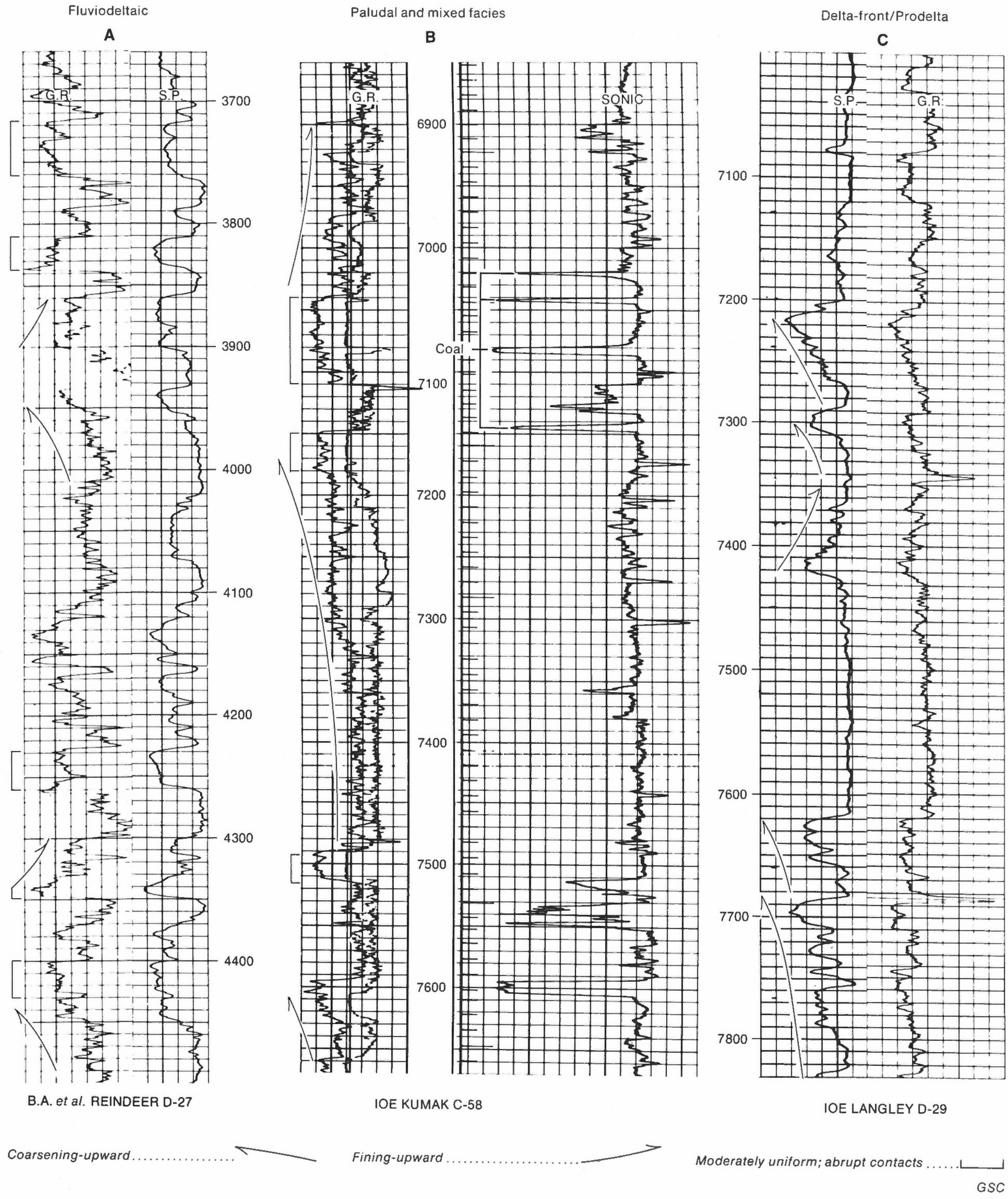


FIGURE 20. Representative log responses of deltaic lithofacies, Mackenzie Delta

depositional environments. These commonly comprise a classical, river-dominated deltaic sequence in which the delta-front sands, in some cases capped by eroded channels, prograde over the prodeltaic muds, forming a coarsening-upward trend (Fig. 19, log C) (Scruton, 1960; Coleman and Wright, 1975). A mixed facies association, involving delta-plain (swamp and/or channels) and delta-front facies, also is common in many borehole sections (Fig. 19, log B; Fig. 20, logs A, B). Two end-member delta-plain facies associations can be described: a sandstone-dominated (fluviodeltaic) facies, and a mudstone-coal-dominated (paludal) facies.

The sandstone-dominated, delta-plain facies includes conglomerate and sandstone units with sharp basal contacts, silty and coaly mudstone, and thin, discontinuous coal seams. These are arranged, in some cases, as fining-upward sequences and, in other instances, as alternating facies with sharp contacts. The latter facies pattern is recorded in the type Aklak Member (Young, 1975b) and is attributed to channel avulsion and infilling with organic debris. Holmes and Oliver (1973) interpreted this facies as tributary channel deposits of an alluvial plain. In general, it is difficult to distinguish between alluvial and deltaic plains in this facies association, hence it is often referred to as fluviodeltaic.

In borehole sections this facies is expressed by blocky spontaneous potential and gamma ray log-signatures (channel sandstones), together with alternating mudstone and coal log-signatures (e.g. Fig. 20, log A). Small-scale coarsening-upward trends at the bases of some channel sandstones may be due to gradual avulsion of distributary channels and rapid progradation across shallow lakes and bays.

The paludal, delta-plain facies consists principally of siltstone and silty mudstone, commonly carbonaceous, and containing plant fossils. Coal, fine-grained sandstone, and marlstone are associated typically with these rocks, and probably were deposited in interdistributary lakes, marshes, bays, and minor channels. The borehole log-signature of this facies is similar generally to that of the distal delta-front facies but includes resistivity and sonic log characteristics of coal and marlstone (Fig. 20, log B, upper part). An arbitrary limit of 50 per cent or greater non-arenaceous sediments is suggested to distinguish the paludal from the channel-dominated, fluviodeltaic facies.

The delta-front environment includes the subaqueous margin of the deltaic wedge, where sand and silt are deposited at the mouths of distributaries and are commonly reworked by tidal and wave-generated currents. Basinward of this zone is the prodelta lithofacies which includes the toe and slope of the deltaic wedge. Carbonaceous mudstone is typical of this environment whereas, on the slope, increasing amounts of interbedded siltstone and sandstone occur at shallower depths.

Due to basinward progradation of deltaic wedges, the sandy delta-front deposits gradationally overlie pelitic prodeltaic sediments, thus forming a coarsening-upward trend (e.g. Fig. 19, log C; Fig. 20, log C). Bioturbation, slump-structures, graded beds, carbonaceous debris, and planar- and ripple-laminated silty sandstone beds are typical of the proximal prodelta environment (e.g. Shawa *et al.*, 1974, Fig. 5). The delta-front environment is dominated by sandstone deposited in distributary-mouth bars, distributary channels and beaches. The beach and stream-mouth bar sandstones generally exhibit gradational basal contacts and coarsen upward, but the channel sandstones, which commonly overlie the former, have sharp, erosional bases and are uniformly textured (Fig. 20, log B, middle part). In areas where modern deltaic lobes have extended a considerable distance seaward of the main delta-platform, abandonment of distributary channels occurs in many places in order to take advantage of steeper gradients and to fill by-passed bays and basins (Coleman and Wright, 1975, p. 113). Hence, proximal delta-front deposits may be terminated abruptly and, with subsequent subsidence, overlain by swamp deposits or prodeltaic muds followed by another coarsening-upward trend.

Many deltaic vertical sequences, especially in the Reindeer Formation, consist of complex alternations of delta-front and delta-plain facies (Figs. 14, 15); these are grouped for convenience into the mixed delta-front/delta-plain facies association. This facies is characterized by coarsening-upward trends of delta-front origin (probably stream-mouth bars) that are capped by coal, organic shale, and rare channel sandstones of delta-plain origin (e.g. Fig. 19, log B; Fig. 20, log B). The paleogeographic position of this facies with respect to that of the repetitive, large-scale, coarsening-upward trends previously described is more proximal, as indicated by the relative thinness of the prodeltaic mudstone units of the mixed facies. The mixed facies occurs throughout the Reindeer Formation in the Caribou Hills, Parsons Lake and Richards Island areas (Fig. 14, 15) and in the upper Paleogene deltaic unit of central Richards Island (Fig. 17).

Littoral and marine lithofacies

Well-sorted, fine- to medium-grained sandstone containing vertical burrows and low-angle crossbedding has been attributed to beach and shoreface environments in the molassic sequence (Young, 1975b; Bowerman and Coffman, 1975). This type of sandstone generally lies in gradational contact above burrowed, offshore mudstone and is difficult to distinguish from distributary-mouth bars on the basis of geophysical logs alone, although it may comprise thinner units than the latter. Beach deposits of barrier island or strandplain origin are relatively rare in the molassic sequence.

A tidal-flat facies, consisting of alternating sandstone and thinly interbedded sandstone and shale units, occurs on Eagle Creek in the Fish River Group (Young, 1975b, p. 24) but has not been recognized yet in the subsurface.

An offshore marine mudstone facies, not necessarily prodeltaic in origin, occurs in the Ministicoog Member of the Moose Channel Formation (Young, 1975b; Unit 4 of Holmes and Oliver, 1973). Thin-bedded siltstone, shale and mudstone are the principal rock types, and these tend to be more burrowed than similar rocks of prodeltaic origin (Holmes and Oliver, 1973). Rare, thin, lenticular sandstone units and beds, possibly representing offshore bars, also occur in this facies. Much of the Tent Island Formation and the unnamed Eocene shale formation beneath Richards Island are presumably of mixed shallow-marine and prodeltaic origins. Coarse, poorly sorted, argillaceous conglomerates of probable debris-flow origin (Young, 1971; Holmes and Oliver, 1973; Glaister and Hopkins, 1974) occur rarely in both facies.

PALEOGEOGRAPHY OF THE MOLASSIC SEQUENCE

Molassic sedimentation commenced in late Campanian time with an increased rate of subsidence in most basinal areas and a concomitant tectonic upheaval of landmasses around the southwestern edge of the Richards Island Basin. Subsidence seems to have occurred at a faster rate than clastic supply entering the basin, resulting in widespread transgression and the deposition of approximately 1000 m (305 ft) of muddy sediments in several major depocentres (Fig. 13). This detritus was fed into the basin by rivers entering from the south and southwest, probably forming estuarine deltas at their mouths.

This initial transgression was followed by the first major regressive pulse, which formed the Moose Channel Formation of latest Cretaceous age. This clastic wedge resulted from abundant clastic supply shed from further uplift of the Brooks Range Geanticline, other tectonic complexes in central and western Alaska, the Yukon Fold Complex and possibly the Eskimo Lakes Fault Zone. Numerous short streams and, possibly, a single large river drained north and eastward from these highlands and created a tectonic delta complex along the outer Yukon Coastal Plain and western part of Richards Island Basin. As the Moose Channel clastic wedge aged, a transgression of the sea occurred and pelitic sediments of the Ministicoog Member were deposited at the top of the formation in the western part of the basin.

A second major clastic wedge began to prograde eastward near the beginning of Tertiary time and, at about the same time, regressive wedges first appeared in the northeastern Tuktoyaktuk Peninsula area. This coalescent wedge formed a wide coastal plain which stretched from Alaska around to northern Tuktoyaktuk Peninsula (Fig. 16). The major source-area, however, still was the western tectonic upland. The Reindeer wedge seems to be composed of several cycles in which the basal portions are relatively rich in sand and gravel, and the upper parts rich in mudstone and coaly sediments. These vertical sequences suggest a morphologic cycle of delta-formation, consisting of steep-gradient lobate deltas at the base, followed by low-gradient estuarine or tide-influenced deltas at the top.

A major marine transgression is represented by the unnamed Eocene shale unit in the Richards Island area, which appears to have shaly, paludal deltaic equivalents landward in the Caribou Hills-Tuktoyaktuk Peninsula area (Fig. 14). The upper part of the shale unit probably is of prodeltaic origin and comprises the northeastward migrating toe of the prograding lobate or birdfoot delta-systems of the unnamed upper Paleogene unit.

The upper Paleogene clastic wedge thickens markedly toward the northeast side of Richards Island area, and probably resulted from late Laramide tectonism of the Aklavik Arch Complex and the Yukon Fold Complex. This tectonism involved the older molassic deposits of the Fish River Group and Reindeer Formation near the landward margin of Mackenzie Delta. Meagre evidence suggests that alluvial fans probably coalesced and formed fan deltas along the southeastern margin of Richards Island Basin. Possibly a southern river, ancestral to the modern Mackenzie River, was responsible partly for the deltaic system in the Richards Island area.

Following an apparent uplift in much of the area, including the Richards Island Basin, several Neogene clastic wedges prograded out onto the continental shelf of the Beaufort Sea. These reached the edge of the continental shelf and comprise a large volume of the continental terrace-wedge. Presumably the Mackenzie River was becoming an integrated continental stream during Neogene time, supplying much of the detritus, especially in the youngest wedge.

STRUCTURAL GEOLOGY

REGIONAL GEOLOGY

Figure 21 illustrates the simplified modern surface geology of the region. The contours offshore represent the free-air gravity anomaly field. The basic structural and tectonic elements as expressed by the distribution of geologic map-units include the following.

1. The northern Interior Platform, underlain by a northwesterly dipping homoclinal succession of Proterozoic, lower and middle Paleozoic, Cretaceous and Tertiary clastic and carbonate strata. Structural dislocations are minor and consist of local small folds and normal faults. To the east of the map-area, a northeasterly trending structural grain is expressed by conspicuous fractures in the lower Paleozoic Franklin Mountain Formation carbonates on Parry Peninsula (Yorath *et al.*, 1975). The dominant strike of these fractures is parallel to the trend of extensional structures that extend through the Aklavik Arch Complex along which recurrent Phanerozoic tectonism has occurred.

2. The Aklavik Arch Complex, represented by the Campbell and Cache Creek Uplifts and Eskimo Lakes Arch. These northeast-trending structural culminations of the complex enclose structurally and stratigraphically discordant rocks of mainly Proterozoic and Paleozoic age. In the Campbell Uplift, faulted Albian flyschoid clastic strata have been described and illustrated by Dyke (1975). These relationships, in addition to the Lower Tertiary-Albian unconformity on the south flank of the uplift (Norris, 1974) attest to Laramide and/or late Columbian movements on this component of the complex.

3. The Rapid Fault Array and related structures dislocating Cretaceous clastic rocks in northern Richardson Mountains.

4. The Barn Uplift, immediately west of the Rapid Fault Array enclosing lower and upper Paleozoic carbonate and clastic strata. Adjacent to the eastern limit of the uplift, and within the region underlain by Aptian-Albian flyschoid clastic rocks is the Mount Fitton stock composed of granite of Middle Devonian age.

5. Romanzof Uplift, exposing Proterozoic rocks of the Neruokpuk Formation and unconformably overlain by Cambrian argillite and volcanic agglomerates. The geological map (Fig. 21) excludes localities of

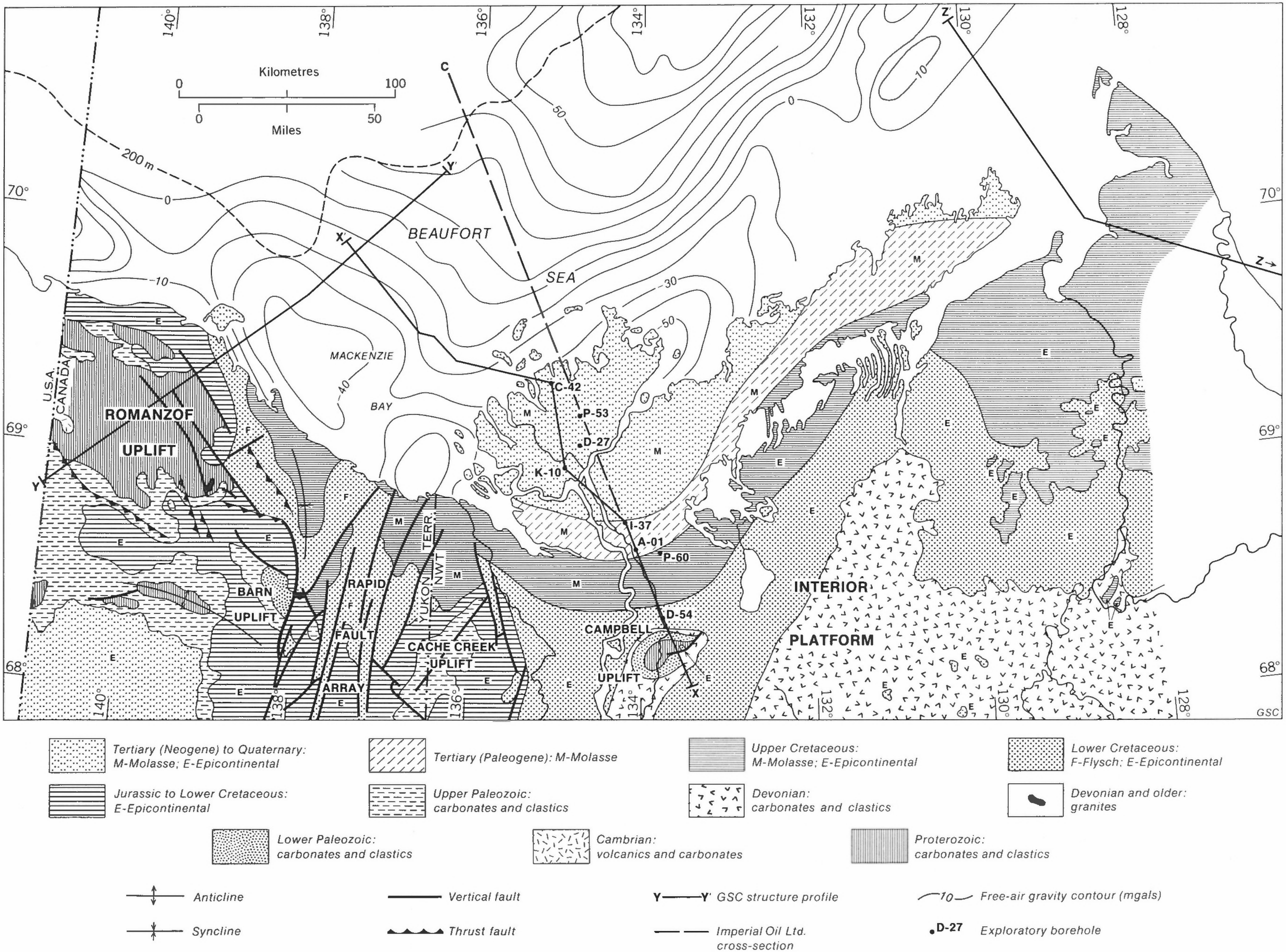


FIGURE 21. Geological map, Beaufort-Mackenzie Basin

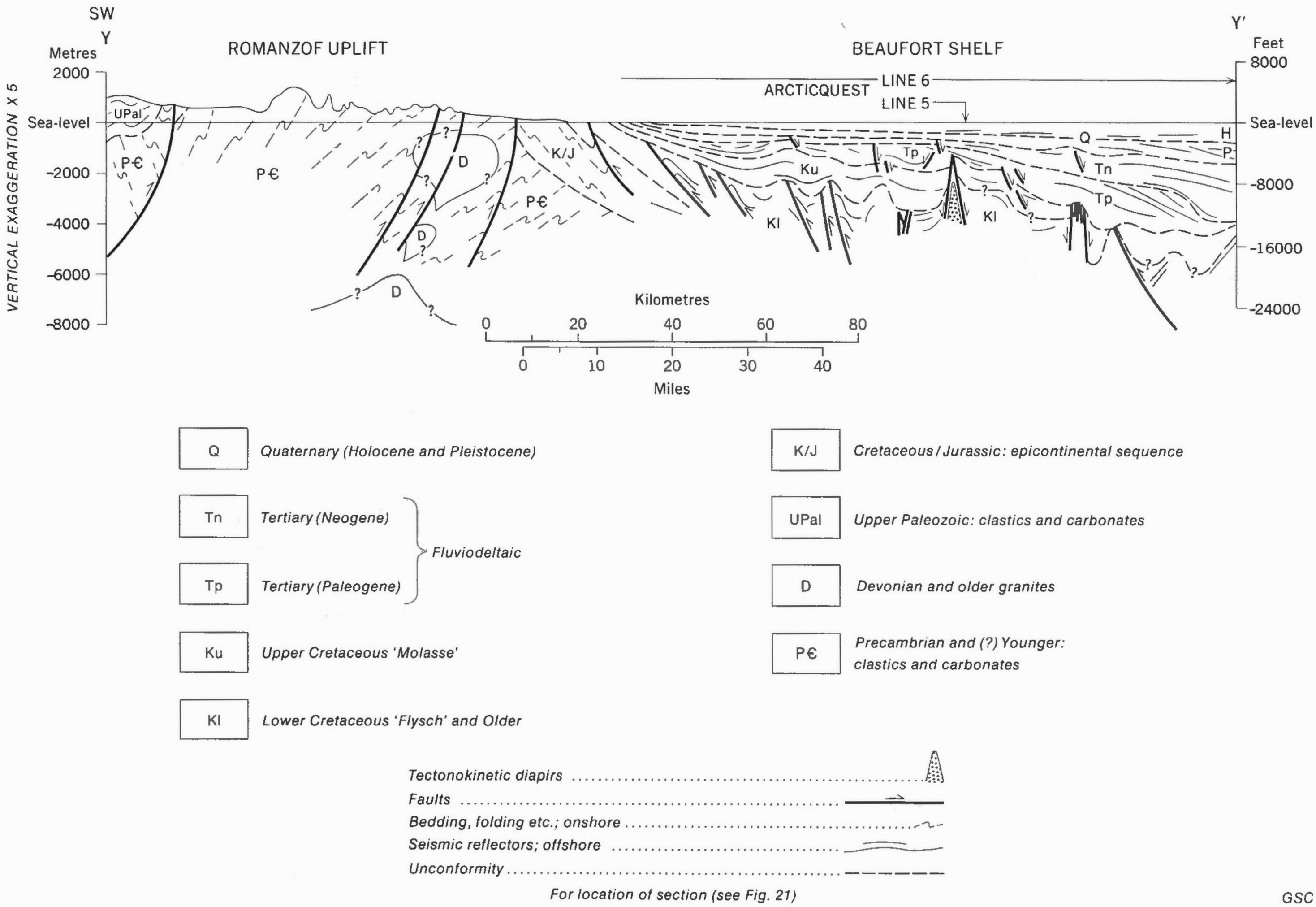


FIGURE 22. Structure section Y-Y', British Mountains to Beaufort Shelf

chert and argillite on the north flank of the uplift which have been dated as latest Silurian and probably are remnant equivalents of the Road River Formation, thus Upper Silurian rocks may occur as a seaward-thickening wedge beneath Beaufort Shelf (Norris, 1976).

6. The Mackenzie Delta, underlain in part by a regressive succession of Late Cretaceous to Holocene age.

7. The continental margin, represented by the northeasterly trending positive free-air gravity anomaly.

The structural geology of this region is best illustrated by a number of cross-sections, whose lines of profile are illustrated in Figure 21.

Structure section Y-Y' (Fig. 22) is located to the west of the Rapid Fault Array and extends from the southwest flank of Romanzof Uplift, near the Yukon-Alaska border, to near the 55 m (180 ft) isobath on Beaufort Shelf. The offshore portion of the section is based on an interpretation of Arcticquest reflection seismic line No. 6.

The Proterozoic Neruokpuk Formation is shown to be folded, faulted and intruded by Devonian and older granites which have yielded radiometric ages of 431 m.y., a few kilometres west of the International Boundary (Reiser, 1970). Upper Paleozoic carbonate and clastic rocks rest with angular unconformity on the Neruokpuk Formation; the unconformity at the base of the Mississippian Kekiktuk Formation represents Ellesmerian movements which resulted in the widespread Upper Devonian flyschoid rocks (Imperial Formation). As pointed out above, rocks assigned to the lower Paleozoic (Road River Formation?) also occur on the north flank of the uplift.

Norris (1974) described two important overstepping relationships on the north flank of Romanzof Uplift. From southwest to northeast, the Triassic Shublik Formation oversteps the upper Paleozoic rocks to rest on the Neruokpuk Formation (Kupsch, 1973) and, in the same direction, the

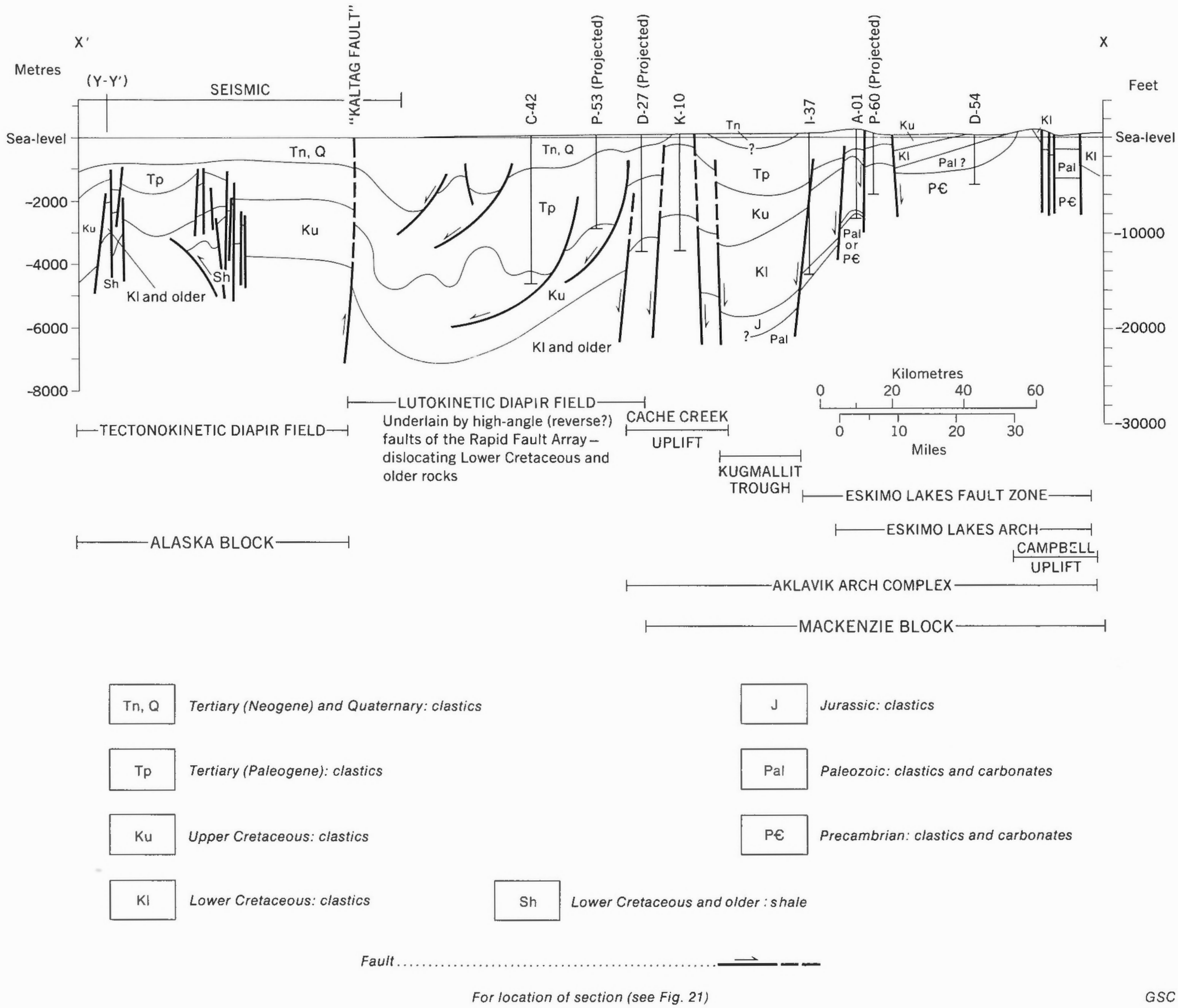


FIGURE 23. Structure section X-X', Mackenzie Delta to Beaufort Shelf

Jurassic Kingak Formation oversteps the Shublik to rest on the Precambrian rocks. These relationships have two important implications.

1. The north flank of Romanzof Uplift, beneath Beaufort Shelf, was expressed as a structural culmination in pre-Late Triassic time and probably represented the southeastward continuation of the Barrow Arch (D.K. Norris, pers. com.)

2. The lateral extension of the Permian and Triassic reservoir rocks at Prudhoe Bay, 385 km (240 miles) along strike to the northwest, has been removed by pre-Jurassic erosion, at least along the axis of the Barrow Arch.

Miall (1973) showed similar relationships on a more regional scale and Bamber and Waterhouse (1971) illustrated facies trends in Carboniferous rocks which become increasingly littoral in the same direction.

These relationships are not illustrated on the structure section.

Along the line of section, on the north flank of Romanzof Uplift, the lower Mesozoic epicontinental sequence is illustrated as resting with angular unconformity on the Neruokpuk Formation which, along with the Road River Formation, is believed to lie deeply buried beneath Beaufort Shelf. These epicontinental clastic rocks are represented by the Jurassic to lower Aptian sandstones, siltstones and shales of the Kingak, Bug Creek and Porcupine Formations as well as the Lower sandstone, Blue-grey shale, Coaly quartzite, Upper shale-siltstone and Upper sandstone divisions.

In the offshore part of the profile, structural discontinuities are suggested by discontinuous, rotated seismic reflectors beneath the sub-Upper Cretaceous unconformity. The geometry of these reflectors suggest southward-directed thrust faults within the Lower Cretaceous and older succession. Similar thrusts with a southward direction of relative tectonic transport have been mapped in northern Yukon by D.K. Norris (Fig. 21). These thrusts probably repeat portions of the Aptian-Albian flysch division and older sequences and are shown in the section to be truncated by the folded sub-Upper Cretaceous unconformity. The northerly dip of the faults probably is controlled by the increasing stratigraphic thickness of the Lower Cretaceous and older rocks in that direction.

Overlying the Lower Cretaceous and older epicontinental sequence is the Upper Cretaceous molassic succession comprising the various components of the Fish River Group and possibly older strata. This succession appears to have been deposited following Columbian compression, uplift, and erosion of the Lower Cretaceous sequence. The Upper Cretaceous and Paleogene sediments were, in turn, folded and faulted during late Laramide deformation, which may have reactivated the earlier thrust faults.

In response to Laramide uplift and erosion over large areas of the adjacent craton, the thick Upper Cretaceous and Tertiary molassic succession prograded seaward toward the continental margin. This thickening was aided by sedimentary growth faults at the distal edges of the prograding sand wedges. The unconformity between the Paleogene and Neogene sequences is identified on the basis of low-angle seismic reflectors within the older succession which appear to be truncated beneath the base of the younger unit. This unconformity may represent the widespread mid-Tertiary uplift of Arctic Canada because Oligocene rocks appear to be largely absent in wells which have penetrated the Tertiary succession on Richards Island (Hawkings and Hatlelid, 1975; Bowerman and Coffman, 1975).

The Pleistocene unit (P) shows reflectors which appear to represent offlapping conditions expressed in low-angle clinoform stratification similar to that observed in the most seaward part of the Paleogene sequence. The overlying, essentially horizontal reflectors may represent the return to marine conditions on the Beaufort Shelf as a result of the Holocene (H) eustatic rise in sea level.

Structure section X-X' (Fig. 23) extends from the Campbell Uplift to the Beaufort Shelf and intersects section Y-Y' at the position indicated. Stratigraphic and structural control for the cross-section is provided by the exploratory wells indicated and by Arcticquest reflection seismic lines 4 and 5. Additional data from Lerand (1973), Hawkings and Hatlelid (1975) and Bowerman and Coffman (1975) were used.

The cross-section illustrates the succession of Mesozoic and Cenozoic rocks extending northwestwards in a thickening lens across the various components of the Aklavik Arch Complex. The intervening structural depressions (Kugmallit Trough and Richards Island Basin) contain thicker sequences than adjacent structural culminations, the flanks of which are dislocated by extension faults of the Eskimo Lakes Fault Zone and the family of vertical faults associated with the Cache Creek Uplift. These faults show non-uniform stratigraphic separation indicating that they are reactivated elements, substantial movements of which occurred during Early Cretaceous time, accounting for the great increase in thickness of Lower Cretaceous strata into Kugmallit Trough. The faults associated with the Cache Creek Uplift are shown to have sustained their principal movement following Late Cretaceous deposition which allowed for the development of the thick Tertiary deltaic complexes beneath Richards Island. Within the Richards Island Basin, rapid deposition of seaward-prograding clastic wedges within the foundered basin caused the development of large-scale detachment structures at the distal ends of the Paleogene and Neogene sand lenses. Strain along rotational growth faults was transferred into the adjacent prodelta shales toward the toes of the faults, resulting in lutokinetic diapirs within the hanging walls.

Beneath the Tertiary and Upper Cretaceous rocks of the Richards Island Basin, the Lower Cretaceous flyschoid sediments and older epicontinental sequence probably are present within a series of northeasterly trending fault blocks of the Rapid Fault Array. Although the array is not shown, its westernmost component, herein referred to for convenience as the "Kaltag Fault", is illustrated as bounding the Richards Island Basin on its seaward side. The presence of this fault is inferred because of the basinal thickening of the succession interpreted to be the Tertiary sequence above and across the fault in Arcticquest seismic line No. 4 (Yorath and Norris, 1975). Beyond this fault, the Tertiary and Upper Cretaceous sequence is considered to be thinner and, in response to continued Laramide right-lateral movements of the Alaska Block, Lower Cretaceous and older shale masses are shown to have intruded the younger successions. These relationships are derived from the interpretation of Arcticquest seismic lines Nos. 5 and 6 (Fig. 22). Therefore, the intruded shale masses are a response to a tectonically induced stress field and are thought, therefore, to be fundamentally different from the gravity-induced diapirs of the Richards Island Basin. More will be said about these contrasting relationships in the section on structural kinematics.

The interpretation described above differs in part from that illustrated by Hawkings and Hatlelid (1975) and from interpretations developed by others in the petroleum industry (Gallup, 1973). To illustrate these differences, section C from Hawkings and Hatlelid (1975, Fig. 9) is included here (Fig. 24). The line of profile is shown on the geological map (Fig. 21) and it can be seen that section C closely approximates the position of section X-X' (Fig. 23) in its southeastern portion.

The principal difference between the two interpretations is illustrated by the absence of Upper Cretaceous rocks beyond the Cache Creek Uplift in section C. In this profile, the detachment structures

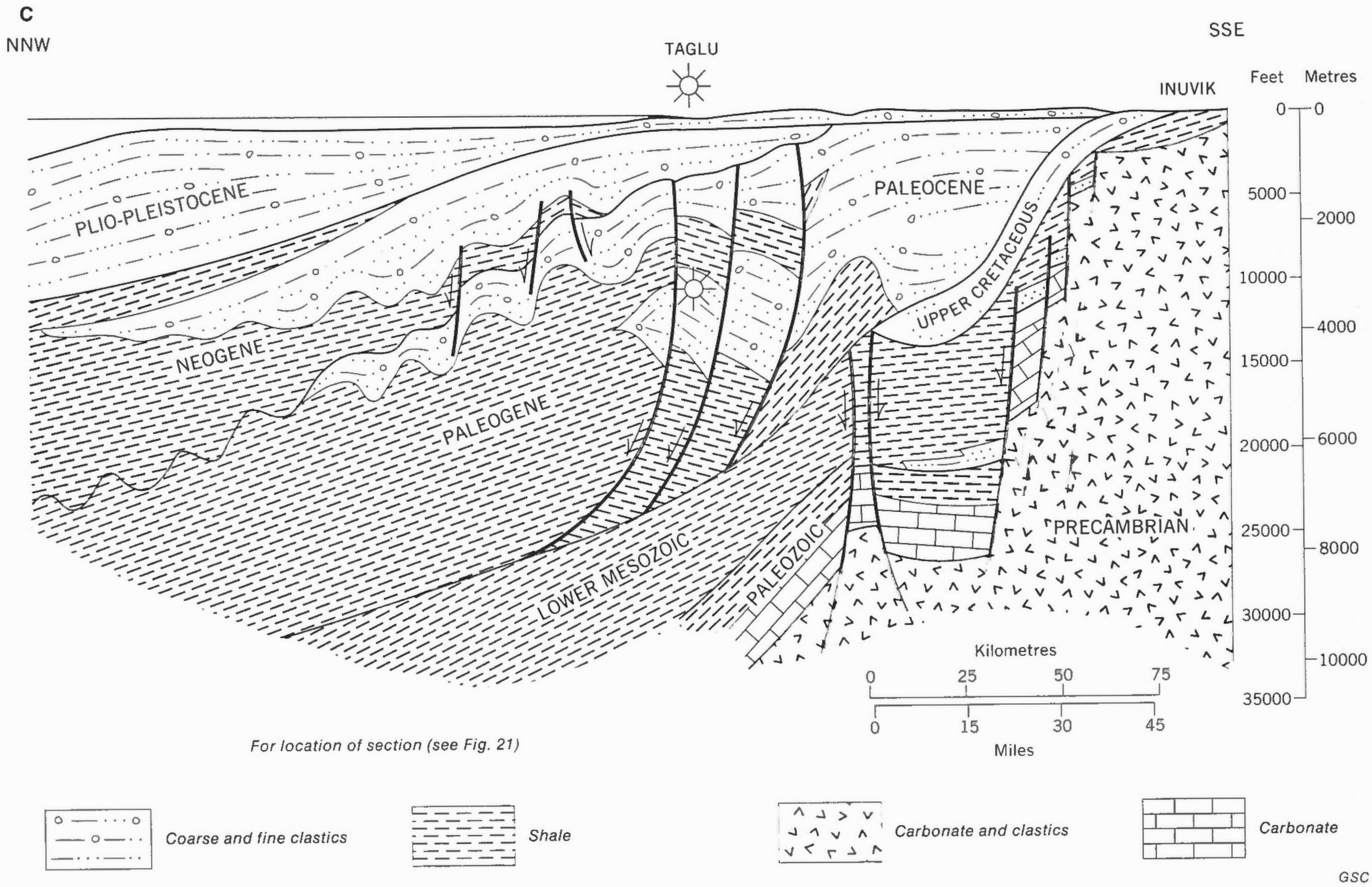


FIGURE 24. Structural profile through the Mackenzie Delta area (after Hawkings and Hatlelid, 1975).

are shown to sole out at the base of the Paleogene, beneath which rocks of early Mesozoic age (presumably Early Cretaceous or older) lie unconformably beneath the Tertiary section. The interpreted absence of Upper Cretaceous rocks beneath Mackenzie Delta by many industrial geologists, on the one hand, and their assumed presence by GSC geologists, on the other, is based largely on differences of opinion among microbiostratigraphers concerning age assignment of fossil taxa. Because the present writers are not proficient in these fields, they do not address themselves to the ongoing biostratigraphic debate. However, if the Upper Cretaceous succession is missing in the region traversed by section C, at least three important implications must be considered.

1. The presence of Upper Cretaceous rocks in northern Yukon (Young, 1975b) and northern Anderson Plain (Yorath and Balkwill, 1970) is widely known and documented and can be assumed reasonably to continue offshore. The absence of Upper Cretaceous rocks along section C implies that a major, northwesterly trending, post-Lower Cretaceous structure separates the northern Yukon and Anderson Plain from Mackenzie Delta. This structure would have to transect orthogonally the principal northeasterly trending Aklavik Arch Complex and associated elements. No such structure is supported by either geological evidence on land (Fig. 21) nor by the gravity field offshore.

2. The presence of such a northwesterly trending element would have had an important effect on the distribution and lithology of the overlying Tertiary sediments. Isopach and isochron trends of at least the Paleogene succession would reflect the presence of the underlying structure to the extent that such trends would not coincide with the regional U-shaped geometry of the Tertiary basin as illustrated by Bowerman and Coffman (1975, Figs. 3, 4).

3. The Late Cretaceous marine transgression was an important, world-wide event. It seems unlikely that such would be unrepresented in a pericratonic situation.

In a recent paper by Evans *et al.* (1975), an identical section to section C of this paper (Fig. 24) is included, within which the succession labeled as Upper Mesozoic and Tertiary in the latter was identified as Paleogene and Neogene by Hawkings and Hatlelid (1975). Thus, the detachment faults presumably sole out in the upper Mesozoic section which more closely agrees with the interpretation illustrated in Figure 23. In any event, the ultimate establishment of the presence or absence of Upper Cretaceous strata will depend on mutually acceptable microbiostratigraphic principles established from cores and cuttings collected at and adjacent to the Tertiary-Late Cretaceous boundary. The writers do not deny the possible absence of Upper Cretaceous strata from specific wells but suggest that such

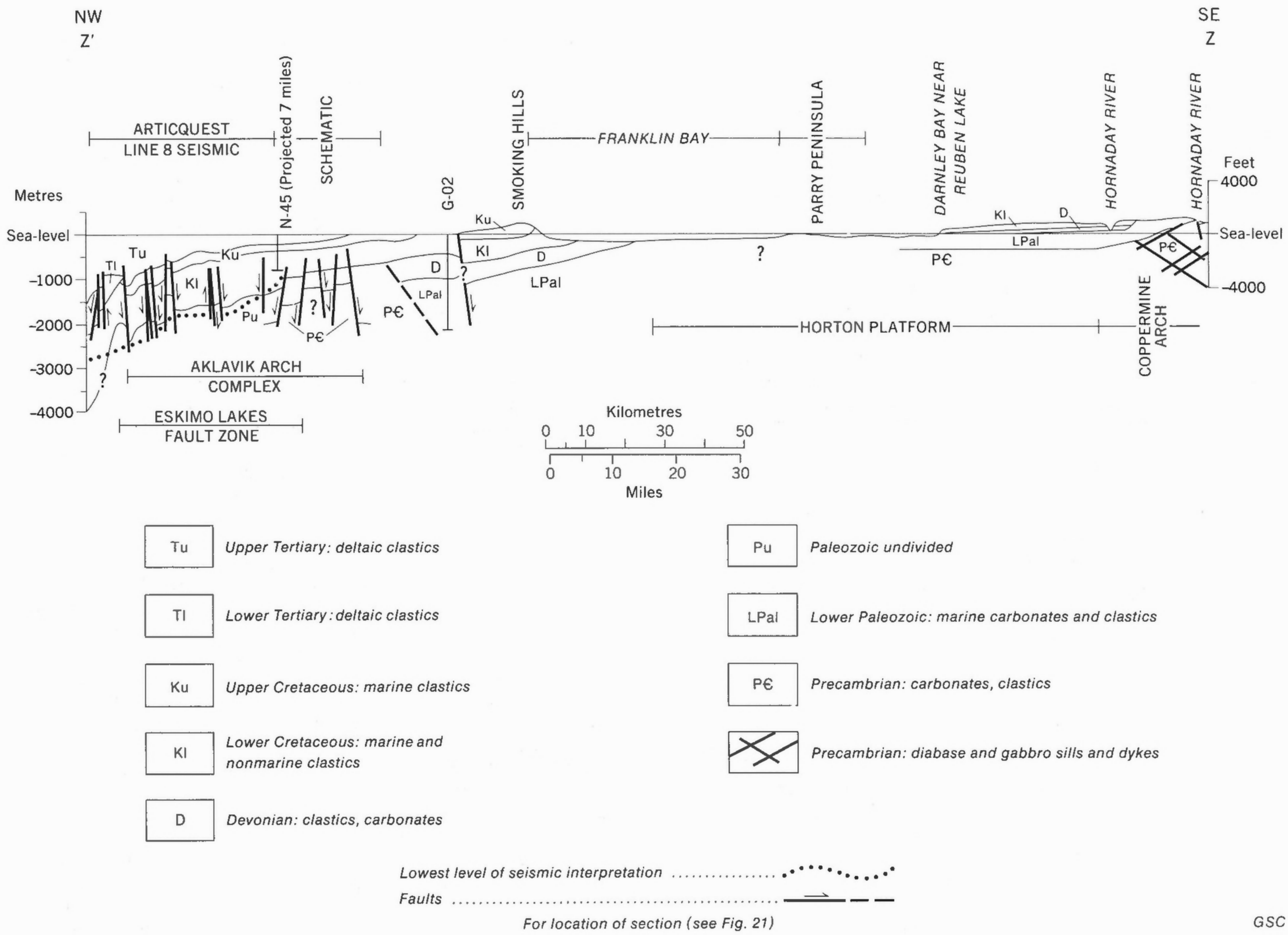


FIGURE 25. Structure section Z-Z', Coppermine Arch to Beaufort Shelf

stratigraphic omissions are due to local extension or detachment (growth) faults.

Section Z-Z' (Fig. 25) is a structure section extending from the Coppermine Arch to the southeast of the report-area across the northern Interior Platform to the Elf Horton River G-02 well and then linking up with Arcticquest seismic line 8 in the Beaufort Sea. The section shows lower and middle Paleozoic clastic and carbonate strata and Mesozoic clastic rocks extending northwestward in an essentially unbroken platform or homoclinal succession from the flank of the Coppermine Arch to the schematically represented Aklavik Arch Complex. Across the complex, the succession is dislocated by numerous faults that have sustained multiple movements as elsewhere along the Eskimo Lakes Fault Zone, and which have thickened the Lower Cretaceous succession as a result of syndepositional strain. A characteristic feature of these faults, as reported elsewhere beneath Tuktoyaktuk Peninsula (Lerand, 1973), is the presence of "roll-over" anticlines on their hanging walls (these structures are not illustrated). Furthermore, as shown in the section, the system of faults reaches progressively higher into the stratigraphic succession in a seaward direction and, since they were active during deposition, the footwall blocks probably acted as local sources of sediment to the adjacent basins above the hanging walls. In addition, the periodicity of movements along these faults resulted in local paleotopographic relief causing variations in thickness and lithology of the enclosing sediments. An example is illustrated beneath the East Reindeer A-01 well in Figure 23. In the most seaward part of section Z-Z', considerable uplift, erosion and downfaulting probably occurred which accounts for the seaward truncation of the Upper Cretaceous rocks beneath Paleogene sediments. The cause probably is related to fault movements on the flanks of another structural culmination of the Aklavik Arch Complex, possibly represented by the 10 mgal anomaly north of Tuktoyaktuk Peninsula (Fig. 21).

STRUCTURAL KINEMATICS

Throughout this paper, much emphasis has been placed on the importance of the Rapid Fault Array with respect to the development of the Beaufort-Mackenzie Basin, particularly during Early Cretaceous time. The Kaltag Fault of Alaska has been identified as a major dextral wrench with between 65 and 130 km (40-80 miles) of observable post-Early Cretaceous to Pleistocene right-lateral separation (Patton and Hoar, 1968). Recent studies by D.K. Norris (1976) have identified a stratigraphic separation from lower Paleozoic to mid-Upper Cretaceous across the fault on Porcupine River. As pointed out previously in this paper, Young (1974) identified substantial sub-Aptian vertical separation across the Blow Fault Zone which is the westernmost component to the array. Although further studies both in Alaska and Canada are needed to identify the kinematic and spatial relationships between the Kaltag-Porcupine and Rapid Fault Array systems, it is assumed here that, because of their proximity and alignment, these systems are related and that initial dextral movements along the systems began in Early Cretaceous time. Hence, right-lateral strain resulting in oblique separation on individual fault components of the Rapid Fault Array has been inferred (Yorath and Norris, 1975).

The important relationship between petroleum occurrence in large pools and wrench tectonics began to receive much new attention during the early part of this decade (Wilcox *et al.*, 1973; Harding, 1973; Yeats, 1973; Moody, 1973). Those papers dealt with both general and specific aspects of wrench faults, and the valuable paper by Wilcox *et al.* (1973) concerned itself with a description of clay-cake experiments, building upon the earlier work of Cloos (1955). An additional paper by Crowell (1974) described the origin of late Cenozoic basins of southern California as the effects of changes in strike of wrench zones. The following discussion is an attempt to rationalize the development of parts of the Beaufort-Mackenzie Basin in terms of the dynamics suggested by the Kaltag Fault and its northern Yukon continuation, the Rapid Fault Array.

Figure 26 illustrates the principal structures of the study-area. The faults of the Eskimo Lakes Fault Zone and the "detachment" structures (presumably growth faults) are taken from Hawkings and Hatlelid (1975). The Kaltag Fault and Yukon Fault trends were provided by D.K. Norris (pers. com.) and the remaining faults on land are the same as those which appear in Figure 21. The offshore extension of the Rapid Fault Array was extrapolated on the basis of the overall trends on shore to coincide with the axis of the large, elliptical positive free-air anomaly ("Kaltag Fault") and the position of steepest gradient on the southeast flank of the anomaly. It should be noted that, whereas Yorath and Norris (1975) suggested that this anomaly represents the uplifted rim of the continental margin and, thus, is in agreement with earlier interpretations by Wold *et al.* (1970), Sobczak (1975) presented arguments suggesting that much of the anomaly is due to uncompensated sediment load beneath the continental slope. The fact that the Bouguer gravity field in this region shows no anomaly beneath the slope lends support to the Sobczak thesis; however, one of the present writers (Yorath) is of the opinion that a free-air anomaly of this magnitude (in excess of 100 mgals adjacent to the Queen Elizabeth Islands) cannot reflect uncompensated clastic sediments entirely. Thus, until additional crustal refraction data are obtained across the anomaly, the writers maintain that at least part of the anomaly represents the present structural edge of the North American plate as represented by the rise in the crust-mantle boundary. Such an interpretation is supported (but not proven) by Overton (1970).

The sharp bend in strike between the Kaltag Fault and the Rapid Fault Array is identified as a "restraining bend" in the manner of Crowell (1974). Along right-lateral strike-slip faults, restraining double bends, resulting in compression of the adjacent terrain, occur when the fault trace curves to the left (counter-clockwise) when viewed along strike. The sharper the bend, the greater the degree of compression and the greater the elevation of one block (in this case the Alaska Block) over the other (Mackenzie Block). As Crowell (*ibid.*) has shown, sharp restraining bends can result in the development of thrust faults and folds in the adjacent parts of the blocks. In cases where splays develop, wedge-shaped culminations and depressions form between the various anastamosing components of the splays. These wedge-shaped components are bounded by vertical faults along which both dextral strike-slip and, in the case of restraining geometry, high-angle reverse separation occurs. Thus, the Rapid Fault Array is interpreted as a splay system of high-angle, reverse and right-lateral strike-slip faults that developed in response to dextral movement along the regional trend of the main wrench system and results from a compressive stress field created at the restraining bend. This deformation is believed to have been initiated at least as early as Neocomian time and possibly continues at present [e.g. the 1963 Prince Patrick Island earthquake swarm (Milne and Smith, 1966)]. The high-angle reverse displacements of the components within the array resulted in several wedge-shaped basins, comprising the Blow Trough, within which the Aptian-Albian flysch division was deposited syntectonically. The development of the trough was aided by Columbian oblique deformation along reactivated components of the Eskimo Lakes Fault Zone and the bounding faults of the Cache Creek Uplift. Additional movements along both systems resulted in continued (Laramide) depression of the Richards Island Basin, allowing for the accumulation of the thick Upper Cretaceous and Tertiary deltaic molassic sequence (Fig. 27).

Additional implications of the proposed wrench tectonic history of the region relate to the expected strain in the offshore portion of the Alaska Block. As illustrated in Figure 26, Hawkings and Hatlelid (1975) indicated a large number of detachment faults within the Beaufort-Mackenzie Basin, both within and adjacent to the bounding limits of the Rapid Fault Array. The writers agree that the faults beneath Richards Island and beneath the Beaufort Shelf between the offshore extension of the

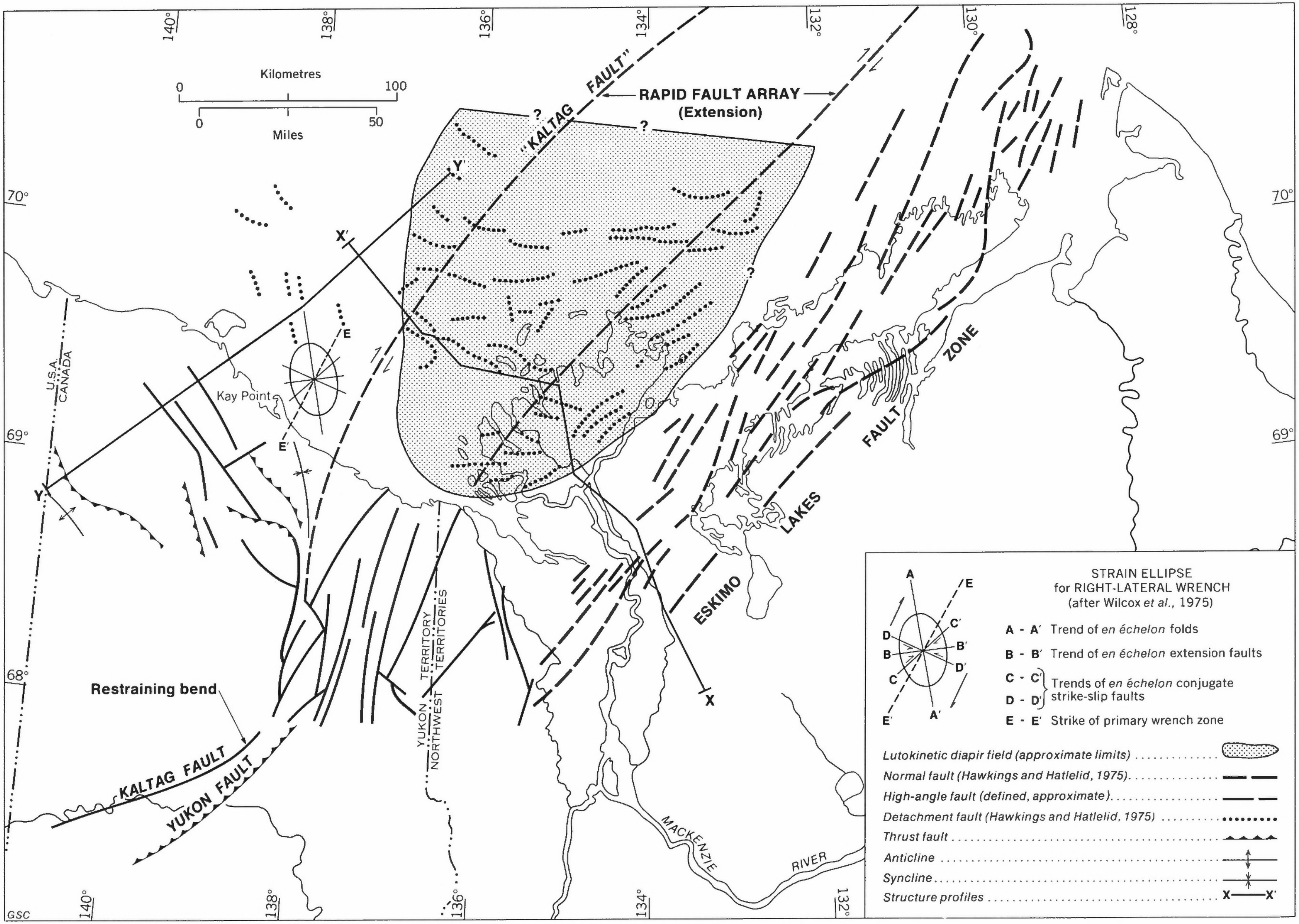


FIGURE 26. Structural dynamics map of Beaufort-Mackenzie Basin

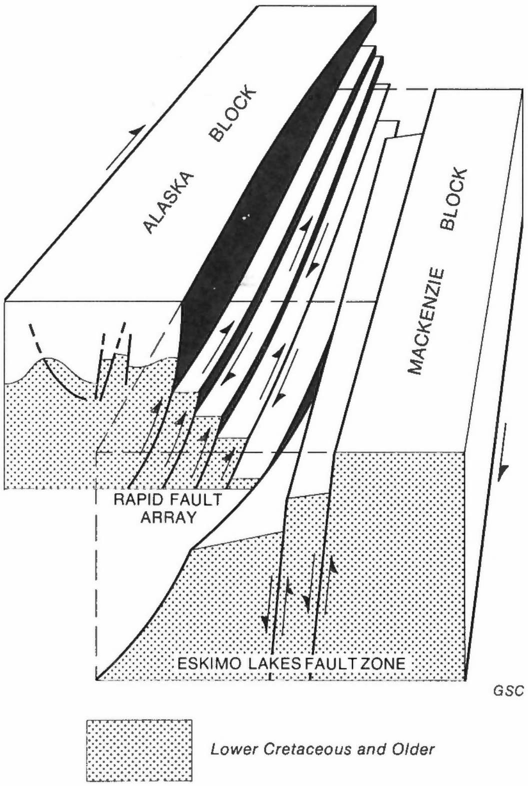


FIGURE 27. Schematic block diagram showing kinematic relationships between the Alaska Block and Mackenzie Block across the Rapid Fault Array

"Kaltag Fault" and the Eskimo Lakes Fault Zone are indeed detachment (growth) faults associated with the thick Tertiary and Upper Cretaceous deltaic successions. However, we believe that those "detachment" structures shown beneath the shelf of the Alaska Block represent faults of the tectonokinetic diapir field and are entirely different from those of the lutokinetic field of Richards Island and adjacent offshore area.

The wrench fault clay-cake experiments described by Wilcox *et al.* (1973) illustrate the nature and style of structures associated with right-lateral strike-slip displacement. Figure 26 includes a strain ellipse oriented in the appropriate manner relative to the trend of the main wrench system in the Beaufort Sea. E-E' is the strike of the reoriented primary wrench zone. A-A', identified in the legend of the figure wherein the strain ellipse has the same orientation as that shown on Beaufort Shelf, is the trend of *en echelon* folds and thrusts that is predicted by the stress field associated with the wrench system. The reader will note that the trend of the "detachment" structures of Hawkings and Hatlelid (1975) is that predicted by the strain ellipse. In addition, the trend of the syncline axis and adjacent thrust fault southeast of Kay Point also is in accordance with the strain predicted. Likewise, the strain ellipse predicts that B-B', C-C' and D-D' will be the trends of *en echelon* extension faults and conjugate strike-slip faults, respectively. In Figure 22, which is a section within the Alaska Block, the thrust faults and later folds are predicted by the strain ellipse and are interpreted to be observable within Arcticquest seismic line 6. Both Figures 22 and 23 illustrate the emplacement of older shale masses into the Lower Cretaceous and younger successions. These tectonokinetic diapirs probably have the orientation of A-A' of Figure 26 and their associated vertical faults may represent the predicted extension and conjugate strike-slip faults. Thus, the writers believe that the detachment structures shown beneath the shelf of the Alaska Block are thrust faults and folds associated in part with the wrench system of the Kaltag-Rapid Fault Array. The petroleum implications of this interpretation will be discussed in the following section.

An attempt is made to illustrate (*see* Fig. 27) the strain relationships expressed above. Within the Alaska Block, the Lower Cretaceous and older succession is separated from the overlying sequence by an unconformity which resulted from uplift and erosion consequent upon right-lateral motion along the several components of the Rapid Fault Array. This early (Columbian) deformation was manifest in folds and thrust faults within the Alaska Block and probably within the Lower Cretaceous and older rocks underlying the array (not shown). Subsequent Laramide movements resulted in the folding of the unconformity and possible reactivation of the older structures, in addition to reactivation of the ancient faults of the Eskimo Lakes Fault Zone. These latter faults probably were extension structures originally, but later also sustained Columbian and Laramide oblique wrench movements as suggested by the right-lateral separation along the Donna River Fault (Jeletzky, 1975a).

As stated earlier, the kinematics of wrench tectonics associated with the Kaltak-Rapid Fault Array explains the Columbian downwarp of Blow Trough, the Laramide development of Richards Island Basin, and the motivation and orientation of thrust faults and shale intrusions in the offshore tectonokinetic diapir field. It does not, however, explain many other structural phenomena associated with the Laramide and Eurekan tectonism in the study-area. For example, the change in sedimentary "style" and depositional trends from the mid-Cretaceous flysch trough to the later wedges of molassic clastic rocks, which strike generally perpendicular to the former, cannot be accounted for simply by wrench kinematics. These gradual, but profound changes probably are related to the vertical uplift [at least 1.5 km (0.9 mile)] of northern Richardson Mountains which were formerly the site of the Blow Trough. Considerable topographic relief along the uplifted parts of the Eskimo Lakes Fault Zone also is indicated by the coarse, alluvial nature of associated mid- to upper Tertiary sediments. These uplifts presumably are related to more regional stresses, possibly associated with late Cordilleran deformation and the opening of the Canada Basin. Hence, stress relationships during the Tertiary still are poorly understood, although a thread of continuity from the Columbian Orogeny to the present is provided by certain ancient, intermittently active faults, the persistence of positive crustal blocks, and the gradual change in depositional trends and paleogeography.

PETROLEUM POTENTIAL

The petroleum potential of the Beaufort-Mackenzie Basin has been rated very good in analyses by Lerand (1973) and King (1973). In this paper, the potential of each structural element (Fig. 2) is reviewed briefly and summarized with respect to major lithofacies (Table 2). The status of the geoscience base (non-confidential) and petroleum potential for each area is indicated on the diagram.

NORTHERN YUKON-RICHARDSON MOUNTAINS AREA

In northern Yukon and northern Richardson Mountains, structural deformation and widespread breaching of potential source and reservoir rocks have reduced the prospects of finding significant amounts of hydrocarbons (Young, 1975b; Norris, 1974). Jurassic and Lower Cretaceous clastic strata were deposited in shallow-marine and nearshore environments on the flanks of Cache Creek High and Blow Trough (Fig. 6). These sand bodies may exist in the subsurface of Yukon Coastal Plain and are potential reservoirs provided that primary porosity survived structural deformation and diagenetic changes. Liquid hydrocarbons are unlikely to have sustained known thermal metamorphism related to Laramide tectonism in the Kaltag-Rapid Fault Array, and only supermature gas is expected.

To date, only three boreholes have been drilled in the Yukon Coastal Plain. The deepest one, IOE Blow River YT E-47, penetrated 4256 m (14 000 ft) of Cretaceous sediments. Fresh water was recovered from a drillstem test of a conglomeratic unit believed to be the Upper Cretaceous Cuesta Creek Member (Young, 1975b).

MACKENZIE DELTA-RICHARDS ISLAND AREA

In the central and northern parts of the Mackenzie Delta and the Richards Islands area, the potential for finding hydrocarbons in sedimentary rocks of Paleogene and older ages is fair to excellent. Structures associated with the lutokinetic diapir field and Laramide or older tectonism may provide excellent structural traps. These structures may combine with stratigraphic traps in porous nearshore and deltaic sand bodies. One such example is the Taglu Field, which may have resulted from a combination of shale diapirism in a delta-front environment (Bowerman and Coffman, 1975; Figs. 14, 15, 23). Here, hydrocarbons are trapped in thick deltaic cycles that consist of impermeable pelites at their bases and grade upward into porous sandstone units of delta-front and delta-plain origins (Shawa *et al.*, 1974). Shale diapirism and antithetic faults provide the closure (Bowerman and Coffman, 1975) (Fig. 24). Proven reserves in this region to date are restricted to reservoirs of Paleogene and possibly Late Cretaceous age. Potential source-rocks in the area probably exist in the pelitic parts of the Paleogene section. Powell and Snowdon (1975) favour a mixed marine and terrestrial origin for the discovered oils which are mainly Tertiary in age. Evans *et al.* (1975) prefer a nonmarine origin and suggest that the hydrocarbons may have been derived from stratigraphically equivalent, off-structure beds, or from older strata of early Tertiary to Late Cretaceous age. They also suggest that "pressure seals" are important for causing horizontal fluid migration and in delaying the expulsion of compaction water until hydrocarbon generation has taken place. These are phenomena that would be expected in a rapidly subsiding basin receiving deltaic sediments, and may contribute to overpressuring and shale diapirism.

Pre-molassic strata in the lutokinetic diapir field are too deep to be considered for their hydrocarbon potential, but they may contain source-rocks for hydrocarbons which could have migrated upward and become trapped in younger strata.

South and west of the lutokinetic field in the subsurface of central Mackenzie Delta, rocks of Jurassic to Paleogene age have poor to good potentials for entrapping hydrocarbons. Boreholes in this area have penetrated porous sandstones in nearshore and deltaic lithofacies. Petroleum was discovered in the Lower Cretaceous "Parsons" sandstone in the Shell Kugpik O-13 borehole, which is located on a northeastern extension of the Cache Creek Uplift (Fig. 3). The trapping mechanism may be related to episodic movements of the Cache Creek High, which culminated during late Laramide tectonism into the Cache Creek Uplift. Evidence for paleostructure of pre-Albian age in this borehole is indicated on Figure 6. Other stratigraphic-structural traps related to this uplift probably exist.

BEAUFORT SHELF-TECTONOKINETIC FIELD

The prospects for future discoveries of petroleum within the tectonokinetic diapir field of the offshore Alaska Block appear very good. The development of large-amplitude structures syntectonically with Late Cretaceous and Tertiary sedimentation (Fig. 23) assures that the migration of hydrocarbons into potential traps is appropriate for large pools, assuming that other requirements such as adequate reservoirs, seals, and source rocks are available.

Insofar as the source directions for the Paleogene reservoir sands of the Taglu Field of Richards Island were from the south and west (Bowerman and Coffman, 1975), clinoform stratification, evident in the Paleogene succession of Figure 22, suggests that a southwestern source provided at least part of the sedimentary wedge beneath the Beaufort Shelf of the Alaska Block. Such a source would have been available within the Romanzof Uplift, due to both Columbian and Laramide deformation. Thus, notwithstanding the inadequacy of the geoscience base in the region and although the sand content within much of the lutokinetic field may rapidly decrease seaward, the presence of clinoform (progradational) stratification near the shelf edge (Fig. 22) suggests that adequate reservoir rocks may extend farther seaward in the tectonokinetic field.

The thesis proposed concerning the relationship between wrench tectonics and basin development has important implications for the subject of petroleum potential. Many examples in the literature illustrate fundamental cause and effect relationships

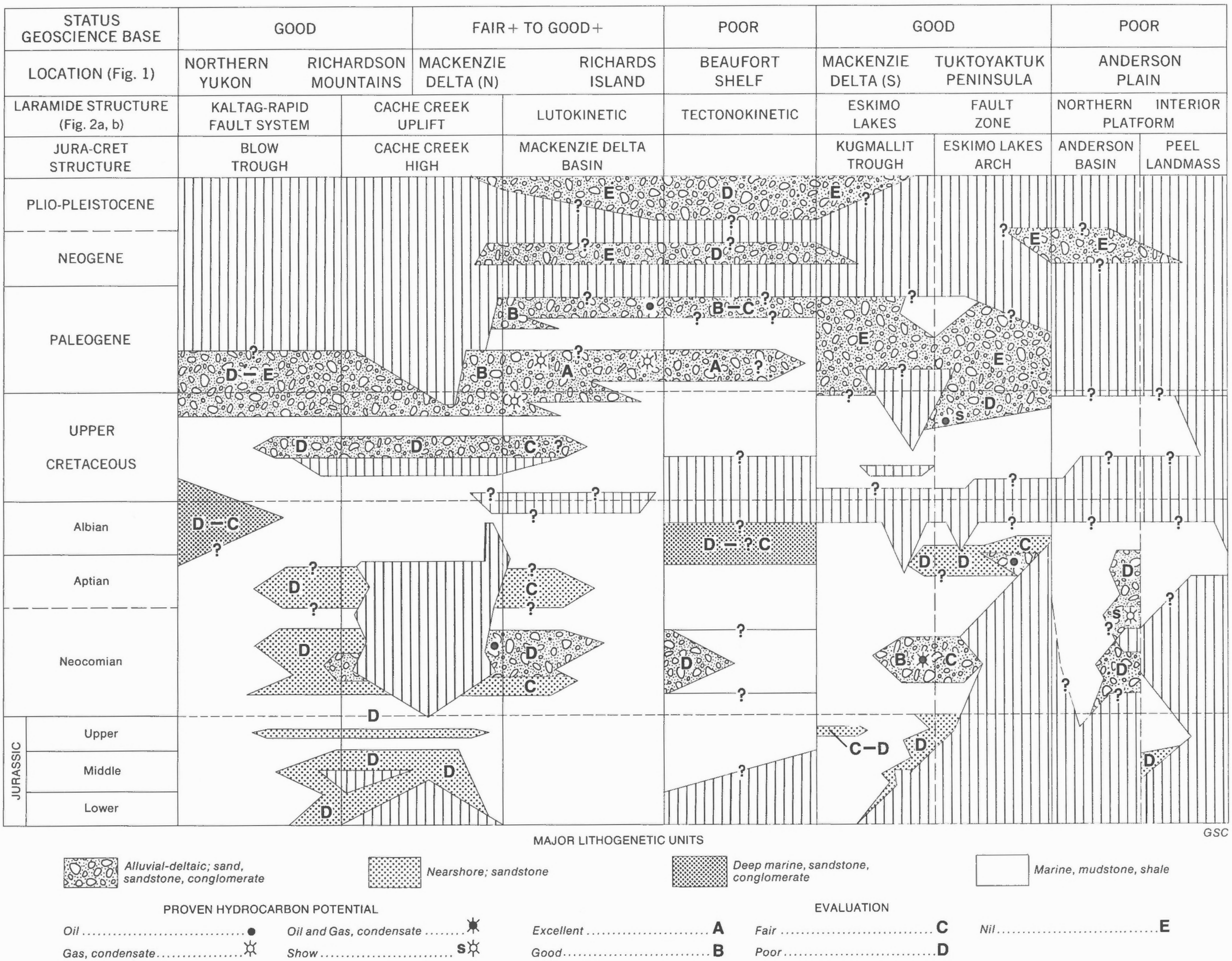


TABLE 2. Chart showing areas of relative potential for petroleum by comparison of structural elements and stratigraphy

pertaining to the occurrence of large hydrocarbon pools adjacent to and within major wrench zones, not the least of which are the Los Angeles and Ventura Basins of California (Crowell, 1974; Harding, 1973; Yeats, 1973). Moody (1973) discusses the importance of wrench tectonics to petroleum occurrence on a world-wide basis and further alludes to its possible significance in northern Alaska and Mackenzie Delta.

The wrench tectonics thesis herein described is offered as an exploration concept for the offshore area of northern Yukon. The associated structures, including large-amplitude, northwesterly trending, *en echelon* folds and contraction faults, involving Lower Cretaceous and older shale masses which intruded into the younger successions, could contain large hydrocarbon reserves. The availability of adequate source and reservoir rocks and a favourable geothermal history will ultimately be decided by the drill.

MACKENZIE DELTA-TUKTOYAKTUK PENINSULA AREA

In southern Mackenzie Delta and Tuktoyaktuk Peninsula, the potential for future hydrocarbon discoveries ranges from nil to good (Table 2). The Neocomian "Parsons" sandstone of nearshore and deltaic origin appears to have the best potential, whereas the Paleogene section has the least, owing to shallow depths of burial and the abundance of sand. Laramide normal faults and older structures of the Eskimo Lakes Fault Zone, in conjunction with the Eskimo Lakes Arch and the associated, porous nearshore and alluvial sandstones (Figs. 6, 9), provide a multitude of combination-type traps. The Lower Cretaceous units have the best potential because of their deeper burial and abundance of reservoir and possible source-rocks.

Two significant discoveries of hydrocarbons within the Eskimo Lakes Fault Zone occur within roll-over structures associated with down-to-basin normal faults of possible Cretaceous to Tertiary age. These include the Parsons structure (Coté *et al.*, 1975) which contains gas, condensate, and light oil in Neocomian shallow-marine and deltaic sandstones, and the "Atkinson" structure in which oil is trapped in upper Lower Cretaceous alluvial sandstones (Grieve *et al.*, 1972).

Jurassic sandstones in the subsurface have yielded either fresh water or waters of low salinity. This may be due to the proximity of these sandstones to the eastern front of the Richardson Mountains and the Treeless Creek-Trevor fault systems (Norris, 1975), allowing the escape of hydrocarbons and/or the penetration of meteoric waters into potential reservoirs. This factor, together with the limited distribution of Jurassic sandstone in the subsurface (Figs. 4, 5), greatly reduce the chances of finding significant amounts of hydrocarbons in Jurassic rocks.

ANDERSON PLAIN AREA

In the Anderson Plain area, the petroleum potential in the Mesozoic succession is nil to poor. Small traps related to fault closures on the eastern flank of the Eskimo Lakes Fault Zone, gentle undulations of the pre-Mesozoic unconformity surface, or stratigraphic traps in shallow-marine and deltaic sandstone bodies may exist. Some potential exists in the relatively unexplored Anderson Basin, where both stratigraphic and structural traps may occur in rocks of Aptian and older ages.

HISTORICAL SUMMARY

TRIASSIC (195-230 m.y.)

Northern Yukon and Mackenzie Delta appear to have been emergent during Early and Middle Triassic time and probably formed a lowland on the south flank of Barrow Arch, a structural culmination beneath the Beaufort continental shelf. In Late Triassic time, a transgression of the sea from the west occurred, accompanied by very slow sedimentation of siltstone, limestone and sandstone on a stable platform. This transgression marks the commencement of deposition in the Beaufort-Mackenzie Basin, which continued with sporadic, tectonically induced interruptions into Tertiary time. A relatively brief regression may have occurred in latest Triassic time, and the earliest Jurassic shoreline probably transgressed again over much the same areas as did the Late Triassic sea.

EARLY JURASSIC (176-195 m.y.)

Lower Jurassic black, marine shale of the Kingak Formation was deposited over Romanzof Uplift and eastward in the Beaufort-Mackenzie Basin, the southern shoreline of which probably coincided with the northern margins of the Eskimo Lakes Arch, Rat High, and Eagle Arch. Sandstone units of the lower part of the Bug Creek Formation comprise an eastern nearshore facies which shales out in northwestern Richardson Mountains and Kugmallit Trough. The Beaufort-Mackenzie Basin was still bounded on the north by the low-lying Barrow Arch.

Uplift and erosion of the southern part of Cache Creek High occurred in late Early Jurassic time.

MIDDLE JURASSIC (162-176 m.y.)

In early Middle Jurassic time, the Beaufort-Mackenzie Basin expanded eastward, southward and southwestward. A strait formed along the axis of the present-day Dave Lord Ridge and Keele Range (Keele-Kandik Trough) and connected the Beaufort-Mackenzie Basin with the Kandik Basin (Fig. 4). A northern landmass or stable submerged platform may have persisted in the Beaufort Sea area.

Three major clastic facies are recognized in Middle Jurassic sediments: mature quartzose sandstone in northern Richardson Mountains; marine siltstone westward and northeastward of the sand; and black shale in the region northwest of Blow River. The presence of carbonaceous debris, conglomerate and less mature sandstone in the Vittrekwa Embayment indicates that a major river flowed from the southeast and emptied there. Sands from this source were spread northerly by marine currents and were deposited over and around Cache Creek High.

Middle Jurassic siltstone attained a thickness of over 1000 m (3300 ft) in the axis of Blow Trough west of Bell River, whereas immediately west the shale facies is only 400 m (1200 ft) thick. This suggests that the shale originated in a deep basin while the siltstone was deposited on a rapidly subsiding slope and marginal shelf.

LATE JURASSIC (141-162 m.y.)

In Late Jurassic time, the eastern shoreline of the Beaufort-Mackenzie Basin transgressed farther onto the Eskimo Lakes Arch, the Keele-Kandik Trough widened, and the Vittrekwa Embayment in the region of the present central Richardson Mountains enlarged (Fig. 5). The Old Crow Landmass, an eastward projection of the Brooks Range Geanticline, continued to expand and may have shed terrigenous clastics into the area of the present-day Old Crow Village.

Black shale, burrowed siltstone, and quartzose sandstone were still the dominant facies, but their areal distribution shifted somewhat during the epoch. Sands were deposited considerably to the southwest of those of the Middle Jurassic, mostly in Yukon Territory north of Eagle Plain.

Thin, marine sandstone is presumed to be present beneath Mackenzie Delta and thin, littoral sandstone occurs along the flanks of the Peel Landmass and southern Eskimo Lakes Arch. Sand distribution, paleocurrent indicators and thickness variabilities suggest that terrigenous clastics were still entering the head of Vittrekwa Embayment, as well as the eastern shore of Keele-Kandik Trough. A dominant northeasterly flowing current in the strait reworked sands into offshore bars and, where this current converged with a clockwise current flowing around the perimeter of Beaufort-Mackenzie Basin, resulted in a 700 m (2300 ft) thick succession of shallow-water sandstone near Porcupine River.

Broadening of the Beaufort-Mackenzie Basin in the Late Jurassic contributed to the wide dispersal of clastic detritus and a general shoaling effect, which may have eradicated largely the probable basin-slope-shelf configuration developed in the Middle Jurassic.

EARLY CRETACEOUS (NEOCOMIAN) (118-141 m.y.)

Soon after the beginning of Cretaceous time, further shoaling around the southern margin of Beaufort-Mackenzie Basin induced the widespread deposition of sandy sediments (Fig. 7). Progradational deltaic wedges, derived from Peel Landmass, were deposited in the area of northern Richardson Mountains and Mackenzie Delta, while marine facies, similar to those of the underlying Jurassic succession, continued to be deposited marginal to the deltaic complexes. Biostratigraphic and lithostratigraphic evidence suggests that the main depocentre of late Berriasian and Valanginian time was in the Kugmallit Trough north of Inuvik, resulting in the gas-bearing "Parsons" sandstone. In approximately Hauterivian time, however, the main deltaic depocentre shifted to the northern Yukon area, while a thick, shallow-marine facies accumulated in the Kugmallit Trough. During this time, the southern shoreline gradually transgressed over northern Eagle Plain, while the Keele-Old Crow Landmass, or eastern nose of the Brooks Range Geanticline, expanded so that its shoreline and associated nearshore sediments moved basinward toward the northeast. Deposition of deltaic and shallow-marine sediments also began in the Anderson Basin in Neocomian time.

The first movements along the Yukon and Kaltag-Porcupine Faults in late Hauterivian time are indicated by great contrasts in thickness and facies of Neocomian sediments across the northward extension of these faults in the Blow Fault Zone. The northward-constraining bend in these right-lateral wrench faults caused downwarping of the crust in the Blow Trough and uplift immediately west of the fault zone. Fault dislocations and tectonic upheaval also occurred in late Hauterivian time along Cache Creek and Rat Highs and the central Eskimo Lakes Arch, resulting in truncation of the lower Neocomian succession in much of the area.

LATE EARLY CRETACEOUS (BARREMIAN-ALBIAN) (98-118 m.y.)

Following the brief interval of late Hauterivian tectonism and uplift along the Aklavik Arch Complex and west of the Kaltag-Blow Fault Zone, a marine transgression occurred, resulting in the deposition of the widespread Upper shale-siltstone division. This pelitic marine unit onlaps older deltaic wedges and uplifted areas exposed by the late Hauterivian tectonic episode. By the end of Barremian time, the southern shoreline probably had shifted far enough southward to incorporate most of Eagle Plain into Beaufort-Mackenzie Basin. The western margin, however, probably remained static owing to the positive nature of the Brooks Range Geanticline. In fact, the foredeep (Blow Trough) axis apparently migrated slightly eastward from its former position because the Upper shale-siltstone division attains its greatest thickness in a line through upper Rapid Creek and a zone a few miles west of Bell River. This axis is similar in location and trend to that of the later Aptian-Albian flysch division. Arenaceous sediments were deposited along the southeastern margin of the basin in the Vittrekwa Embayment while pelites accumulated in Kugmallit Trough during Barremian time.

With the approach of Aptian time, shoaling of the basin accompanied by shoreline regression occurred, resulting in the deposition of the Upper sandstone division of early Aptian age. Shallow-marine sandstone and siltstone of this unit occur widely throughout northern Richardson Mountains and grade laterally northward and northeastward into shale (Fig. 10). The Cache Creek High again became emergent and appears to have influenced the distribution of sediments, although late Aptian tectonic movements and erosion there and on parts of the Aklavik Arch Complex obscured the original depositional record. For example, the basal sandstone-conglomerate unit of general Aptian-Albian age of northeastern Eskimo Lakes Arch unconformably overlies Paleozoic or older rocks; the Barremian or older Mesozoic sediments may have been deposited and later eroded. The western margin of the basin was greatly influenced by Aptian tectonic activity in the eastern Brooks Range Geanticline and along the Kaltag-Blow Fault Zones. An uplifted block west of the fault zone probably shed lithic and carbonate detritus eastward into the basin in mid-Aptian time, but probably was downwarped and formed part of the Blow Trough by late Aptian time. Upper Aptian marine shale occurs throughout central and southern Beaufort-Mackenzie Basin, but its original distribution is unknown due to late Aptian to Early Albian tectonic uplift and erosion. At this time, the Mackenzie Valley first formed a marine embayment extending southeastward from the main basin. The Eagle Plain area was probably emergent during Aptian time.

By Early Albian time, the Blow Trough became a flyschoid foreland depression. This depression was, in part, the result of movement of the Rapid Fault Array, a series of splay faults resulting from the abrupt bend in the Kaltag-Porcupine wrench fault. The trough axis lies parallel to and just east of the Kaltag-Blow Fault Zone, and includes a northwesterly trending branch north of Barn Mountains. This trough was filled predominantly by marine shale, as well as by lesser volumes of turbiditic sandstone, siltstone, and conglomerate, derived from highlands to the west of the trough (Fig. 11). The coarse clastic sediments are texturally and chemically immature and consist of chert, volcanic fragments, carbonates, feldspar and quartz. Their localized areal and vertical distribution, paleocurrent indicators, and grain-size variations suggest deposition in submarine canyons and on associated fans. Strong, axial, bottom-currents prevented much sediment from reaching the eastern side of the trough. On the raised submarine platforms along the eastern side (Cache Creek High), a thin sequence of phosphatic iron carbonate and shale was deposited. By mid-Albian time, the Blow Trough was filled by as much as 3000 m (9800 ft) of sediments and the southern shoreline of the basin had transgressed over the craton far to the south and southeast.

An elongated island is believed to have remained emergent over the Eskimo Lakes Arch during Early Albian time and was surrounded by a shallow sea (Fig. 11).

LATE CRETACEOUS (65-98 m.y.)

Most of Late Cretaceous time is represented by a relatively thin shale formation, deposited widely over Beaufort-Mackenzie Basin. Stratigraphic gaps occur at the base in the eastern half and, internally, in central parts of the basin. In these areas, the shale is bituminous and bentonitic while, in the west, it is siltier and relatively thick. Sandstone apparently flanks the western shoreline along the Keele-Old Crow Landmass (Fig. 12).

The Upper Cretaceous shale is thin over Eskimo Lakes Arch and Cache Creek High, but thickens between those elements to 500 m (1650 ft) in Kugmallit Trough. West of Cache Creek High, the Boundary Creek Formation thickens markedly into Blow Trough which, by the beginning of the Late Cretaceous, extended southward into Eagle Plain Basin.

This pelitic sequence was derived in large degree from the final erosional phase of the Columbian Brooks Range Geanticline which lay west of the basin. Similar deposits in nearby Banks Island (Miall, in press) and northeastern Alaska (Detterman *et al.*, 1975) attest to generally quiescent tectonic conditions, except for vulcanism indicated by the presence of bentonite beds.

In late Campanian time, tectonic stability was terminated with the beginning pulses of the Laramide Orogeny. Some of the major faults were reactivated and upthrown blocks became highlands that shed coarse terrigenous detritus into basinal areas. Also, subsidence of most negative areas greatly increased, with the result that the Tent Island and Mason River Formations, representing only parts of Campanian and Maastrichtian time, are generally much thicker than the underlying, long-ranging Boundary Creek-Smoking Hills Formation. During the Laramide Orogeny, former negative areas in the southern part of the basin, such as Dave Lord Arch and Richardson Mountains, were deformed and uplifted into geomorphologically high areas.

A marine transgression followed localized mid-Campanian tectonism in northern Yukon, resulting in the deposition of a thick mudstone unit, the Tent Island Formation. Its eastern equivalent, the Mason River Formation, is a soft, pale grey clay-shale unit with some bentonite beds which grades laterally westward into the non-bentonitic siltstone and mudstone of the Tent Island Formation.

Molassic sedimentation was initiated with the deposition of a regressive arenaceous wedge, the Moose Channel Formation, which prograded basinward in Maastrichtian time as a result of increased sediment supply on a coastal plain flanking rejuvenated uplands to the west and south of the basin (Fig. 13). This wedge consists of clastic rocks and coal seams deposited in interfingering fluvial, delta-plain, littoral, and shallow-marine environments. Sandstone and conglomerate of the Moose Channel Formation are rich in chert, volcanic and metamorphic lithic fragments and, together with paleocurrent and dispersal trends, indicate source-areas lying west and south of the present coastal plain. Deltaic depocentres appear to be concentrated in the outer Yukon coastal plain and in the subsurface of the northwestern margin of the modern Mackenzie Delta.

Toward the end of Cretaceous time, the Caribou High, together with parts of northern Richardson Mountains, were tectonically uplifted and eroded.

TERTIARY (2-65 m.y.)

The Tertiary Period began with a second major clastic wedge, the Reindeer Formation, which prograded seaward from uplands ringing the western and southern margins of the basin (Fig. 16). The major source-area was still the western tectonic highland, but uplifts along the Eskimo Lakes Fault Zone also were starting to shed coarse debris into Richards Island Basin. Thus, a wide, fringing coastal plain was formed, consisting of paludal, fluvial and alluvial fan lithofacies. Deltaic depocentres developed in the Richards Island and northern Tuktoyaktuk Peninsula areas.

By late Paleocene-early Eocene time, clastic influx into the Richards Island Basin was waning, resulting in marine transgression and the deposition of pelites over the former deltaic deposits. The upper part of the shale unit is probably prodeltaic in origin, comprising the northeastward-migrating toe of the succeeding clastic wedge.

The upper Paleogene clastic wedge thickens markedly toward the northeast side of Richards Island (Fig. 18) and probably resulted from late Laramide tectonic activity in northern Yukon and, possibly, within the Eskimo Lakes Fault Zone. Fluvial sediments in this and succeeding Neogene clastic wedges are coarse grained and largely unconsolidated in the subsurface of Richards Island and adjacent areas. Older basinal areas south of the presence coastline were being converted into tectonic uplands which were composed in part of previously deposited molassic sediments.

The upper Paleogene wedge is terminated by a disconformity in much of the lower Mackenzie Delta area. This could be the time of tectonic intrusion of shale masses into molassic sediments in the Beaufort Shelf subsurface (Alaska Block). Following the hiatus, a series of Neogene and Quaternary clastic wedges prograded far out onto the continental shelf of the Beaufort Sea. Alluvial equivalents of the Neogene wedges are preserved as coarse gravels and sands (Beaufort Formation) on Tuktoyaktuk Peninsula and in the lower Anderson River area. Deltaic and littoral sands of Quaternary age crop out on the outer islands of Mackenzie Delta. Part of the clastic detritus presumably was delivered by the ancient Mackenzie River, which was gradually becoming a large continental river during Neogene-Quaternary time.

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APPENDIX

NAMES AND LOCATIONS OF BOREHOLES REFERRED TO IN TEXT AND ON ILLUSTRATIVE PROFILES

No.	Name	Latitude	Longitude	K.B. Elevation	Total Depth
1	Imperial Atkinson H-25	69°44'20"	131°50'06"	28	5941
2	Imperial Atkinson M-33	69°42'48"	131°54'43"	42	6327
3	Gulf Mobil East Reindeer A-01	68°40'13"	134°00'31"	625	9693
4	Gulf East Reindeer C-38	68°47'10"	133°39'15"	235	8512
5	Gulf Mobil East Reindeer G-04	68°53'16"	133°46'03"	171	12 250
6	Gulf East Reindeer P-60	68°39'45'	133°43'60"	380	6300
7	IOE Ellice O-14	69°03'56"	135°48'16"	17	9531
8	Elf Horton River G-02	69°51'22"	127°15'56"	125	8130
9	Gulf Mobil Ikhil I-37	68°46'34"	134°07'50"	432	15 432
10	Imperial Ivik N-17	69°36'51"	134°19'16"	116	10 004
11	Imperial Ivik J-26	69°35'42"	134°20'38"	100	11 969
12	Imperial Kanguk I-24	69°53'40"	131°05'12"	37	5254
13	Shell Kugpik O-13	68°52'50"	135°18'15"	34	12 103
14	Shell Kumak C-58	69°17'06"	135°13'53"	36	11 582
15	Imperial Magak A-32	69°31'09"	132°07'32"	115	5160
16	IOE Natagnak K-23	69°42'31"	131°36'44"	88	4977
17	Texcan C&E Nicholson N-45	69°59'50"	128°59'50"	55	2833
18	IOE Nuvorak O-09	69°58'55"	130°30'56"	36	3789
19	Gulf Mobil Parsons F-09	68°58'34"	133°31'33"	207	11 638
20	Gulf Mobil Parsons N-10	68°59'49"	133°31'50"	222	10 515
21	Imperial Pikiolik E-54	69°23'15"	132°44'35"	80	10 230
22	Shell Unak B-11	68°40'10"	135°18'40"	33	10 975
23	Shell Unipkat I-22	69°11'37"	135°20'27"	32	14 309
24	Banff Aquitaine Arco Rat Pass K-35	67°54'43"	135°21'57"	81	6004
25	B.A. Shell Imperial Reindeer D-27	69°06'05"	134°36'54"	109	12 668
26	Gulf Mobil Siku C-55	69°04'05"	133°44'58"	129	14 785
27	Imperial Spring River YTN-58	69°07'53"	138°44'05"	318	7009
28	Imperial Taglu C-42	69°21'05"	134°56'50"	40	16 060
29	Imperial Tuk F-18	69°17'29"	133°04'01"	85	10 322
30	Imperial B.A. Shell Tununuk K-10	68°59'44"	134°46'34"	36	12 326
31	Imperial Wagnark G-12	69°11'21"	133°18'14"	126	11 718
32	Gulf Mobil Ya Ya P-53	69°12'50"	134°42'45"	136	9950
33	IOE Natagnak H-50	69°49'27"	131°40'11"	21	6402
34	Imperial Ivik K-54	69°33'36"	134°29'01"	139	10 339
35	Imperial Mallik P-59	69°28'49"	134°42'45"	27	8636