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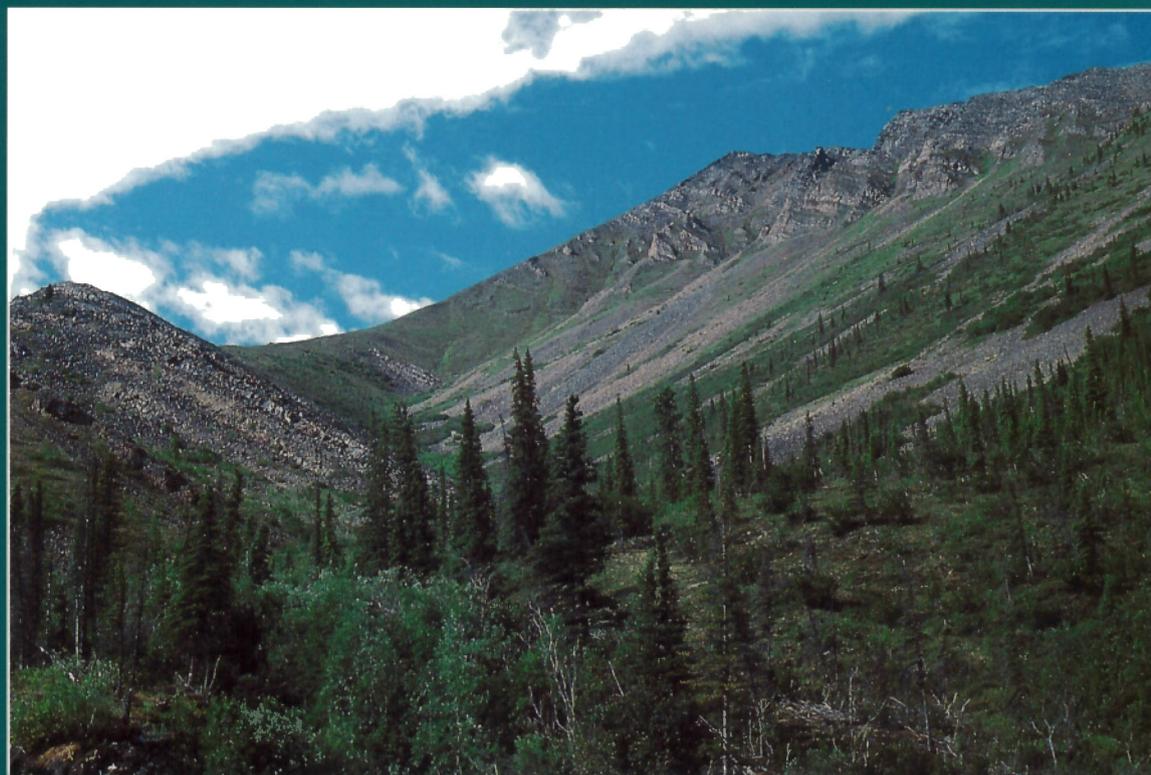
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GEOLOGICAL SURVEY OF CANADA  
BULLETIN 528

# PERMIAN AND TRIASSIC STRATIGRAPHY OF MACKENZIE DELTA, AND THE BRITISH, BARN, AND RICHARDSON MOUNTAINS, YUKON AND NORTHWEST TERRITORIES

J. Dixon



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DELTA, AND THE BRITISH, BARN, AND RICHARDSON  
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**Cover illustration**

Typical outcrop character of Permian strata on the north flank of Rat Uplift, just west  
of Sheep Creek.

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## **PREFACE**

Only initial reconnaissance-level data are available for Permian and Triassic strata of the British, Barn, and Richardson mountains, and the subsurface of Mackenzie Delta. This report presents more details about these strata and helps fill a gap in our geological knowledge of the area. Details of the lithological succession, lithostratigraphic nomenclature, facies analysis, correlations, and depositional history are presented, along with a review of the economic potential of the strata.

M.D. Everell  
Assistant Deputy Minister  
Earth Sciences Sector

## **PRÉFACE**

Seules des données de reconnaissance sont disponibles pour les strates permiennes et triasiques des monts British, Barn et Richardson et en subsurface du delta du Mackenzie. Le présent bulletin fait état d'autres détails sur ces strates et comble en partie une lacune dans les connaissances géologiques sur la région. Il fournit des données sur la succession lithologique, la nomenclature lithostratigraphique, les faciès, l'équivalence des lithologies et l'évolution sédimentaire, ainsi qu'un bilan du potentiel économique des strates en question.

M.D. Everell  
Sous-ministre adjoint  
Secteur des sciences de la Terre



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# Permian and Triassic stratigraphy of Mackenzie Delta, and the British, Barn, and Richardson mountains, Yukon and Northwest Territories

## *Abstract*

*Permian strata in the British and Richardson mountains and in the subsurface of Mackenzie Delta have a similar, threefold division. A variably thick, basal, generally sandstone-dominant interval is abruptly overlain by a thick, shale-dominated succession, which is in turn gradationally to abruptly overlain by a sandstone-rich succession. In the British Mountains, these beds are correlated with the Echooka Formation of the Sadlerochit Group, whereas in the Richardson Mountains and Mackenzie Delta, the lower two successions are correlated with the Jungle Creek Formation and divided into a Lower and Upper member. The upper, sandstone-rich succession in the Richardson Mountains and adjacent subsurface, is herein named the Longstick Formation.*

*Most of the Permian succession is of marine shelf origin, with the exception of parts of the Lower member, especially in the eastern Richardson Mountains and parts of the adjacent subsurface, where nonmarine, alluvial fan, fan-delta, and braided river deposits are present.*

*Triassic strata generally are thin, areally restricted, and are present at scattered locations. In the British Mountains, the upper part of the succession previously identified as the Sadlerochit Group is inferred to be part of the Lower Triassic Ivishak Formation. The only other known occurrence of Lower Triassic strata is an isolated exposure in the northern Richardson Mountains. The bulk of the known Triassic strata is Carnian and Norian (Upper Triassic) in age, with the latter being more common. These Upper Triassic strata are correlated with the Shublik Formation and are present primarily in the British Mountains, in a few scattered outliers in the Barn Mountains, and to the east of the central Richardson Mountains, at Salter Hill. The Triassic consists of a mixture of siliciclastic and carbonate beds, and is marine at all of its known occurrences.*

*Major discontinuities in the Permian succession are not readily identified, although there is some minor physical evidence to suggest that, locally, the lower contact of the Longstick Formation may be disconformable. On the other hand, the Triassic can be divided into a number of unconformity-bounded successions.*

*The economic potential of Permian and Triassic strata is considered to be minimal. No mineral showings are known in either succession. Although thermal indicators indicate oil generation is possible in the subsurface succession of Mackenzie Delta, no Permian source rocks have been identified. Reservoir-quality beds are not very common in the Permian.*

## *Résumé*

*Les strates permienes dans les monts British et Richardson et en subsurface du delta du Mackenzie présentent une division ternaire semblable. Un intervalle de base d'épaisseur variable où dominant en général les grès passe abruptement vers le haut à une épaisse succession composée essentiellement de shales, laquelle est recouverte à son tour de manière progressive à abrupte d'une succession riche en grès. Dans les monts British, la Formation d'Echooka du Groupe de Sadlerochit correspond à ces strates. Dans les monts Richardson et la subsurface du delta du Mackenzie, la Formation de Jungle Creek, divisées en un membre supérieur et un membre inférieur, est équivalente aux deux successions inférieures. Dans les monts Richardson et en subsurface de la région adjacente, la succession supérieure riche en grès est dénommée «Formation de Longstick».*

*La succession permienne a été formée pour l'essentiel dans un milieu marin de plate-forme continentale, à l'exception de certaines parties du membre inférieur, surtout dans la partie orientale des monts Richardson et certaines zones de la subsurface adjacente, où sont présents des dépôts non marins de cônes alluviaux, de cônes de déjection et de cours d'eau anastomosés.*

*En général, les strates triasiques sont minces, à répartition restreinte et s'observent sporadiquement. Dans les monts British, la partie supérieure de la succession, antérieurement associée au Groupe de Sadlerochit, est par déduction plutôt corrélée à la Formation d'Ivishak du Trias inférieur. Les seules autres strates connues du Trias inférieur s'observent dans un affleurement isolé de la partie nord des monts Richardson. Les strates triasiques connues sont en général d'âges carnien et norien (Trias supérieur), ce dernier étant le plus courant. Les strates du Trias supérieur sont associées à la Formation de Shublik et s'observent essentiellement dans les monts British, dans quelques buttes-témoins dispersées des monts Barn et à l'est de la partie centrale des monts Richardson, dans la région de la colline Salter. Les lithologies triasiques se composent d'un mélange de couches silicoclastiques et carbonatées et sont d'origine marine partout où leur présence est connue.*

*L'identification de discontinuités importantes dans les strates permienes est délicate, bien que certains indices physiques mineurs laissent supposer que, localement, le contact inférieur de la Formation de Longstick est peut-être en disconformité. Par contraste, les strates triasiques se divisent en un certain nombre de successions limitées par des discordances.*

*Le potentiel économique des strates permienes et triasiques est considéré comme faible et, à ce jour, aucun indice affleurant n'y a été signalé. Malgré que des indicateurs thermiques révèlent la présence possible de pétrole dans la succession de subsurface du delta du Mackenzie, aucune roche mère permienne n'a encore été identifiée. Les couches pouvant être des réservoirs ne sont pas très courantes dans le Permien.*

## Summary

Permian and Triassic strata of the northern Yukon and adjacent Northwest Territories outcrop in two principle areas, the British Mountains and northern Richardson Mountains. Lesser areas of outcrop are found in the Barn Mountains and the eastern and western slopes of the central Richardson Mountains. In the subsurface of Mackenzie Delta, Permian strata are limited to a relatively small area under the southwestern part, contiguous with the adjacent outcrops of the northern Richardson Mountains. Triassic strata are less widespread than Permian beds and are not known from the subsurface. Between the northern Richardson Mountains and the Barn Mountains, Permian and Triassic strata are absent and Jurassic beds rest directly on lower Paleozoic rocks.

In the British Mountains, Permian strata are present in the Ehooka Formation of the Sadlerochit Group, and in the northern Richardson Mountains they are present in the Jungle Creek and Longstick (new name) formations. Ehooka strata occur mostly on the southern flank of the British Mountains and consist of a generally thin basal sandstone overlain by shale, in turn gradationally overlain by a sandstone interval. The latter locally contains interbedded limestone. The basal sandstone and overlying shale are correlative with the Joe Creek Member, and the sandstone interval with the Ikiakpaurak Member of the Ehooka Formation of adjacent northeastern Alaska. Ehooka strata are generally poorly exposed and range from 80 to 176 m in thickness. In the Mount Sedgwick area of the British Mountains there is some evidence to suggest that the Ikiakpaurak Member overlaps lower beds in a northward direction. However, the age and correlation of these outcrops remains speculative. The presence of marine microfossils, brachiopod-bearing limestone, and extensive bioturbation point to a marine shelf origin for the Ehooka strata. Fossils are scarce but those found indicate an age range of at least Sakmarian to Kungurian. In adjacent Alaska, correlative beds range from the Sakmarian to Kazanian (Wordian).

Permian strata in the northern Richardson Mountains and adjacent subsurface of Mackenzie Delta consist of a similar succession to that of the Ehooka Formation: a lower unit dominated by coarse grained siliciclastics, with some locally occurring carbonate beds, abruptly overlain by a shale-dominated succession, in turn gradationally, to locally abruptly, overlain by a sandstone-dominated interval. The lower two units are part of the Jungle Creek Formation and the upper unit the Longstick (new name) Formation. Permian strata in the Richardson Mountains and Mackenzie Delta are considerably thicker than in the British Mountains, ranging up to about 1300 m in the mountains and up to 910 m in the subsurface.

Jungle Creek strata are divided into Lower and Upper members. The Lower member contains three lithofacies assemblages. At the basin margin are red interbeds of breccia, breccio-conglomerate, conglomerate, mudstone, and fine to coarse grained sandstone. In a slightly more basinward position is the second lithofacies assemblage, which consists of interbedded very fine to coarse grained sandstone, conglomerate, and local limestone beds. The third lithofacies assemblage consists of interbedded limestone, sandy limestone, and calcareous sandstone, commonly capped by a *Paleoaplysina*-bearing limestone. These lithofacies assemblages represent a lateral transition from a basin margin facies dominated by fan-delta and coastal alluvial fan deposits, to coastal braidplain and shoreline facies, and marine, inner shelf facies.

The Upper member is a shale-dominated succession with scattered interbeds of siltstone and sandstone, commonly present in thin, coarsening-upward intervals. The contact with the Lower member tends to be abrupt, and the upper contact is mostly gradational with the Longstick Formation, although locally a more abrupt contact appears to be present. In the northernmost Richardson Mountains, the Upper member is unconformably overlain principally by the Jurassic Bug Creek Group and locally by a remnant of an unnamed Triassic unit. A very distinct limestone bed is present in the upper part of the member in the northernmost outcrops. This bed consists of almost completely disarticulated bivalve debris and in thin section is composed of calcite prisms and some quartz sand. Based on the fossil content, dominance of shale, and the ubiquitous bioturbation of the coarser grained siliciclastic beds, the Upper member is interpreted as mostly low-energy, middle shelf deposits, entirely marine in origin.

The age of the Jungle Creek Formation in the northern Richardson Mountains is probably Sakmarian to Artinskian, possibly as young as Kungurian (Wordian).

Longstick strata consist of bioturbated and crosslaminated, very fine to fine grained sandstone, and locally occurring limestone beds in the lower part of the formation. Away from the basin margin, shale interbeds become more common. A dominant feature of the Longstick Formation is the abundance of the trace fossil *Zoophycus*. Longstick facies are interpreted as representing nearshore to inner shelf deposits. Fossils are very scarce within the formation, consequently age control is poor. The few fossils that have been dated indicate a Kungurian to Kazanian age. Longstick strata are disconformably overlain by the Jurassic Bug Creek Group.

Triassic strata are thin and are present as scattered outcrops in the British, Barn and Richardson mountains. Most of the dated Triassic strata range from the Carnian to the Norian and correlate with the Shublik Formation. Lower Triassic strata are presumed to be present in the undated strata identified as the Ivishak Formation of the Sadlerochit Group in the British Mountains. A possible Lower Triassic succession is present in an outlier in the northern Richardson Mountains. The thickest and best exposed Triassic strata occur along Fish Creek and in Loney Syncline of the northern British Mountains, where the Shublik Formation is present. Triassic strata rest unconformably on a number of older units, ranging from the lower Paleozoic Neruokpuk Formation to the Permian Echooka Formation, and are disconformably overlain by Jurassic strata, mostly the Kingak Formation, but in the northern Richardson Mountains, by the Bug Creek Group. Lithofacies are highly variable within the Triassic and include shale, mudstone, siltstone, very fine grained sandstone, granulestone, and sandy bioclastic limestone. At the northwest outcrops of Loney Syncline, limestone breccia is present as a fill of vertical to subhorizontal fissures. The Triassic succession can be shown to contain a number of internal unconformities, and in the British Mountains, older Triassic strata are overlapped northward to northeastward by younger Triassic strata.

No mineral showings were noted in Permian and Triassic strata and the petroleum potential is considered low to moderate. High levels of thermal maturity characterize the Triassic succession of the British Mountains. The Permian under Mackenzie Delta appears to lack potential source rocks and the sandstones have low porosity and permeability. However, thermal maturity in the subsurface occurrences of Permian strata is within the zone of oil generation.

### *Sommaire*

Dans le nord du Yukon et les secteurs limitrophes des Territoires du Nord-Ouest, les strates permiennes et triasiques affleurent principalement dans deux régions, les monts British et la partie nord des monts Richardson. Des zones d'affleurement moins étendues s'observent dans les monts Barn et sur les versants est et ouest des monts Richardson dans leur partie centrale. En subsurface du delta du Mackenzie, les strates permiennes sont restreintes à une aire relativement peu étendue sous la partie sud-ouest de cette masse d'eau, laquelle est adjacente aux affleurements de la partie nord des monts Richardson. Les strates triasiques sont moins répandues que les couches permiennes et n'ont pas été identifiées en subsurface. Entre la partie nord des monts Richardson et les monts Barn, les strates permiennes et triasiques sont absentes et les couches jurassiques reposent directement sur des roches du Paléozoïque inférieur.

Dans les monts British, les strates permiennes sont présentes dans la Formation d'Echooka du Groupe de Sadlerochit; dans la partie nord des monts Richardson, elles le sont dans les formations de Jungle Creek et de Longstick (nouvelle appellation). Les strates de la Formation d'Echooka s'observent surtout sur le flanc sud des monts British; elles consistent, de la base au sommet, en du

grès (généralement mince) qui passe à du shale et, ensuite, de manière progressive, à un intervalle de grès. Ce dernier intervalle renferme localement des interlits de calcaire. Le grès basal et le shale sus-jacent sont corrélatifs du Membre de Joe Creek; l'intervalle de grès est, quant à lui, équivalent au Membre d'Ikiakpaurak de la Formation d'Echooka (partie nord-est de l'Alaska adjacent). En général, les strates de la Formation d'Echooka, dont l'épaisseur varie de 80 à 176 mètres, affleurent peu. Dans la région du mont Sedgwick, qui fait partie des monts British, certaines observations indiquent que le Membre d'Ikiakpaurak est en chevauchement vers le nord sur les lits inférieurs. Toutefois, l'âge de ces affleurements et les équivalences établies demeurent des suppositions. La présence de microfossiles marins, de calcaires renfermant des brachiopodes et d'une intense bioturbation indiquent que les strates de la Formation d'Echooka ont été déposées dans un milieu marin de plate-forme continentale. Les fossiles sont rares, mais ceux qui ont été observés témoignent d'un intervalle d'âges qui va au moins du Sakmarien au Koungourien. Dans les secteurs adjacents de l'Alaska, les couches corrélatives datent du Sakmarien au Kazanien (Wordien).

Dans la partie nord des monts Richardson et en subsurface du delta adjacent du Mackenzie, les strates permienes se composent d'une succession semblable à celle de la Formation d'Echooka : une unité inférieure où dominant des silicoclastites à grain grossier et dans laquelle s'observent localement des couches carbonatées est recouverte sans transition d'une succession composée essentiellement de shales, laquelle est recouverte à son tour progressivement, mais par endroits sans transition, d'un intervalle à dominante gréseuse. Les deux unités inférieures font partie de la Formation de Jungle Creek et l'unité supérieure, de la Formation de Longstick (nouvelle appellation). Les strates permienes dont il est question dans le présent paragraphe sont beaucoup plus épaisses que celles dans les monts British, leur épaisseur atteignant 1 300 mètres dans les monts Richardson et 910 mètres en subsurface du delta du Mackenzie.

Les strates de la Formation de Jungle Creek se divisent en un membre inférieur et un membre supérieur. Le membre inférieur contient trois assemblages de lithofaciès dont les caractéristiques varient selon la position dans le bassin. Le premier, en marge du bassin, se compose d'interlits rouges de différentes lithologies, en l'occurrence des brèches, des conglomérats bréchiques, des conglomérats, des mudstones et des grès, ces derniers étant de granulométrie fine à grossière. Légèrement plus près du centre du bassin, le deuxième assemblage de lithofaciès consiste en des interlits de grès (granulométrie très fine à grossière), de conglomérat et, localement, de calcaire. Le troisième assemblage de lithofaciès est, quant à lui, constitué d'interlits de calcaire, de calcaire gréseux et de grès calcareux, en général coiffés d'un calcaire à *Paleoaplysina*. Ces assemblages de lithofaciès représentent une transition latérale d'un faciès de marge de bassin (où dominant des dépôts de cônes de déjection et de cônes alluviaux côtiers) à des faciès de plaine anastomosée côtière et de littoral et, enfin, à des faciès marins de plate-forme continentale interne.

Le membre supérieur est une succession à shales dominants contenant des interlits sporadiques de siltstone et de grès, généralement présents en minces intervalles à granoclassement inverse. Le contact à sa base, donc avec le membre inférieur, a tendance à être abrupt, tandis que celui à son sommet, donc avec la Formation de Longstick, est généralement progressif; il est cependant à noter que, localement, ce dernier semble être plus abrupt. Dans l'extrême nord des monts Richardson, le membre supérieur est en contact discordant principalement avec le Groupe de Bug Creek du Jurassique, mais localement avec un lambeau d'érosion d'une unité triasique non désignée. Une couche calcaire très distinctive s'observe dans les affleurements les plus septentrionaux de la partie supérieure du membre dont il est question dans le présent paragraphe. Cette couche se compose presque uniquement de débris de bivalves désarticulés; en lame mince, on y voit des prismes de calcite et, en faible proportion, du sable quartzeux. En se fondant sur la nature des fossiles, la prédominance du shale et l'omniprésence de la bioturbation des couches silicoclastiques à grain grossier, on interprète le membre supérieur comme étant essentiellement un dépôt entièrement d'origine marine qui a sédimenté sur une plate-forme continentale (partie médiane) de basse énergie.

Dans la partie nord des monts Richardson, la Formation de Jungle Creek date probablement de l'intervalle du Sakmarien à l'Artinskien, voire même peut-être du Sakmarien au Kougourien (Wordien).

Les strates de la Formation de Longstick sont constituées de grès de granulométrie très fine à fine dans lesquels s'observent des structures de bioturbation et des laminations obliques; des lits calcaires sont présents localement dans la partie inférieure de la formation. À plus grande distance de la marge du bassin, les interlits de shale deviennent plus nombreux. Une caractéristique dominante de la Formation de Longstick est l'abondance de l'ichnofossile *Zoophycus*. Les faciès de la Formation de Longstick sont interprétés comme étant des dépôts littoraux passant à des dépôts de plate-forme continentale interne. Les fossiles y sont très rares; aussi la datation est-elle incertaine. Les quelques fossiles datés indiquent un âge kougourien à kazanien. Une disconformité sépare les strates de la Formation de Longstick de celles sus-jacentes du Groupe de Bug Creek (Jurassique).

Les strates triasiques sont minces et affleurent sporadiquement dans les monts British, Barn et Richardson. La plupart des strates triasiques datées remontent à l'intervalle du Carnien au Norien et sont corrélatives de la Formation de Shublik. Il est présumé que, dans les monts British, parmi les strates non datées associées à la Formation d'Ivishak (Groupe de Sadlerochit), certaines sont du Trias inférieur. Une succession datant peut-être du Trias inférieur s'observe dans une butte-témoin de la partie nord des monts Richardson. Les meilleurs affleurements et les plus grandes épaisseurs de strates du Trias se trouvent le long du ruisseau Fish et dans la région du synclinal de Loney, dans la partie nord des monts British, là où est présente la Formation de Shublik. Les strates triasiques reposent en discordance sur diverses unités plus anciennes, passant de la Formation de Neruokpuk du Paléozoïque inférieur, à la Formation d'Echooka du Permien. Elles sont cependant séparées des strates sus-jacentes du Jurassique par une disconformité. Les strates du Jurassique appartiennent principalement à la Formation de Kingak, sauf dans la partie nord des monts Richardson où elles sont associées au Groupe de Bug Creek. Les lithofaciès triasiques sont très variables; ils comprennent notamment des shales, des mudstones, des siltstones, des grès à grain très fin, des granulestones et des calcaires bioclastiques gréseux. Aux affleurements nord-ouest du synclinal de Loney, une brèche calcaire apparaît sous forme de remplissage de fissures verticales à subhorizontales. Il est possible de démontrer que la succession triasique contient un certain nombre de discordances internes; dans les monts British, des strates triasiques sont chevauchées vers le nord et vers le nord-est par d'autres strates triasiques plus récentes.

Aucun indice affleurant n'a été signalé dans les strates permiennes et triasiques et le potentiel en hydrocarbures y est considéré comme faible à moyen. La succession triasique des monts British se caractérise par une très grande maturité thermique. Il ne semble pas y avoir de roches mères dans les lithologies permiennes en subsurface du delta du Mackenzie et les grès y ont une porosité et une perméabilité faibles. Toutefois, la maturité thermique des strates permiennes en subsurface du delta se situe à l'intérieur de la fourchette de genèse du pétrole.

## INTRODUCTION

The area investigated extends from the British Mountains of northwesternmost Yukon eastward into the Richardson Mountains and under Mackenzie Delta (Fig. 1). In the Richardson Mountains, the principle area of study extends as far south as Mount Millen, about 30 km south of McDougall Pass. However, isolated outliers of Triassic strata are present farther to the south, in the Salter Hills area, on the east flank of the Richardson Mountains (Norris, 1981h) near Caribou River.

In the British Mountains, poorly exposed Permian strata are present principally in the southern ranges, in the upper reaches of Babbage River, Muskeg Creek, and Timber Creek (Fig. 1). South of Joe Creek, near the Yukon-Alaska border, the Permian to Triassic Sadlerochit Group has been mapped by Norris (1981b). A few isolated and very thin successions of either Permian or Triassic strata may be present between Malcolm River and Fish Creek, in the northern British Mountains. However, most of these strata remain undated except for Triassic strata at Fish Creek (Dixon et al., 1996).

Between the British Mountains and northern Richardson Mountains no known Permian strata have been identified. Here, Jurassic, and locally Triassic, strata rest directly on Carboniferous or older beds (Norris, 1981b). Between the headwaters of Black Fox Creek and Babbage River there are a few thin successions of sandstone overlying the Carboniferous Lisburne Group. These were mapped as Triassic by Norris (1981b). They could be Permian in age, but like similar outcrops in the British Mountains, they remain undated.

The core of the northern Richardson Mountains (Norris, 1981b, e, f) contains the largest area of Permian outcrop in the study area. Outcrop quality is highly variable; it is poor to moderate in the north, in the vicinity of Little Fish River and Almstrom Creek, and generally good around the White Mountains and immediately north and south of McDougall Pass. However, these latter two areas are difficult to access because of the ruggedness of the terrain. Previously unrecognized Lower or Middle Triassic strata have been identified in the northern Richardson Mountains, occurring as a thin interval between Permian and presumed Jurassic beds, between Almstrom Creek and Little Fish River (section DFA92-12; J. Utting, unpublished GSC paleontological report 6-JU-1994).

The easternmost exposures of Permian strata are in the Aklavik Range (principally at Jurassic Butte) of the

Richardson Mountains, overlooking the western edge of Mackenzie Delta. Here the exposures are generally of good quality, but only a thin succession is present.

The subsurface occurrence of Permian strata is limited to the southwestern part of Mackenzie Delta (Fig. 1); as far south as the Aklavik F-38 well, as far north as the Kugpik L-24 well, and as far east as the Napoiak F-31 well. Erosional edges define the eastern and southern limits, but it is probable that Permian strata extend north of Kugpik L-24. However, isopach and erosional trends indicate northward truncation of Permian strata and the northern limit is probably not too far north of Kugpik L-24. To date, no Triassic strata have been identified in the subsurface.

The remoteness of the British, Barn, and Richardson mountains requires helicopter and/or fixed-wing aircraft support for fieldwork. Inuvik is the nearest populated centre with aircraft charters. Most field operations were conducted in late June and July when weather conditions tend to be optimum.

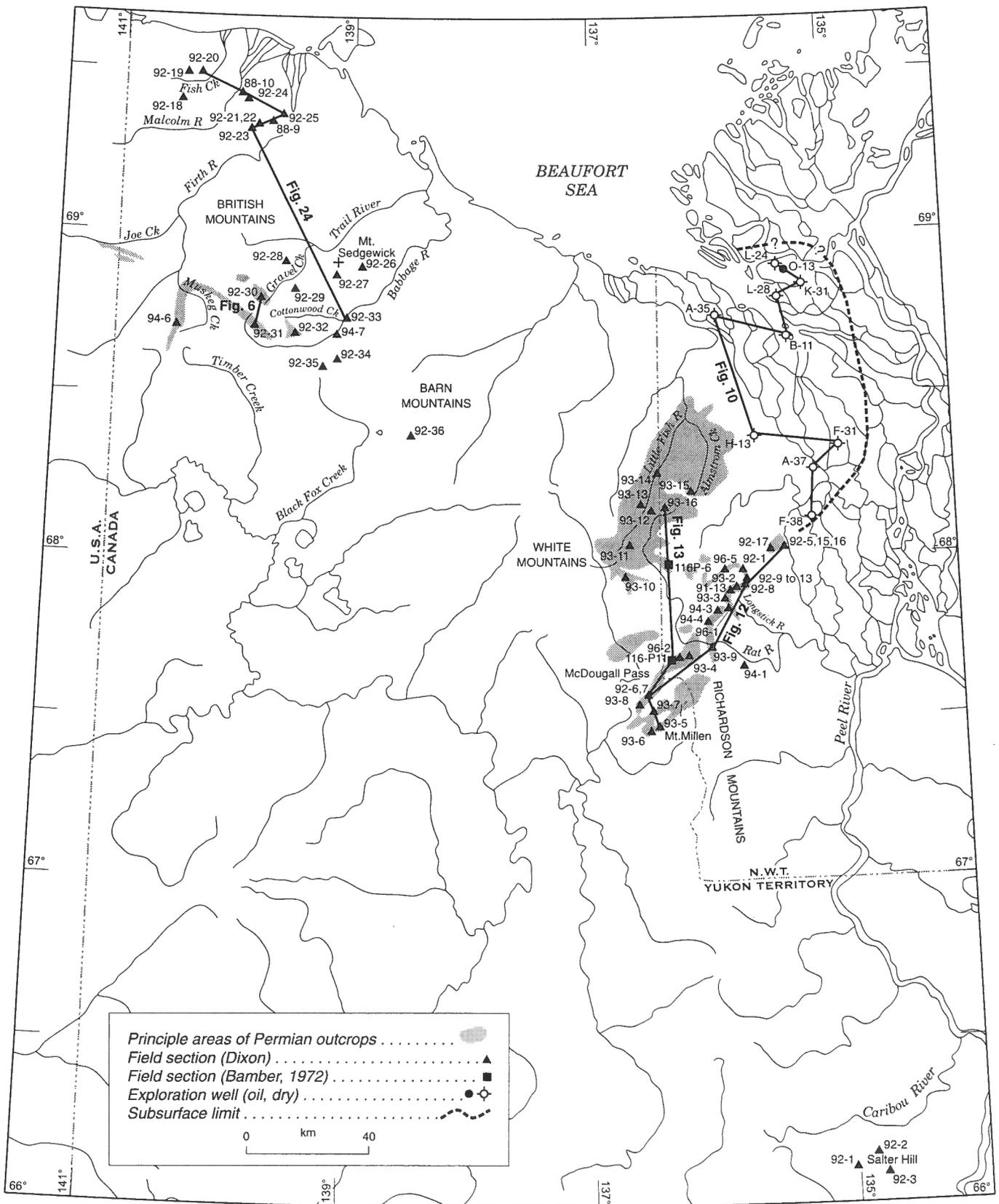
The terrain is rugged, with relief varying from about 600 to 1200 m. Because these mountain areas were not glaciated during the final ice advance of the Pleistocene there is much talus and felsenmeer, generally making for poor to moderately good outcrop quality. However, well exposed successions can be found in places.

## OBJECTIVES

This investigation aims to expand upon previous stratigraphic studies and proposes formal nomenclature for the unnamed parts of the Permian succession. Correlations between the various occurrences in the study area are attempted as well as more regional correlations with Permian and Triassic strata in the Yukon, mainland Northwest Territories (NWT), and adjacent Alaska. Paleogeographic reconstructions and the economic potential of Permian and Triassic strata are discussed. The surface and subsurface sections containing Permian strata measured and/or examined for this study have been published by Dixon (1996).

## PREVIOUS WORK

Although Permian strata in the northern Yukon and adjacent NWT had been identified early in the 20th century (Maddren, 1912; Cairnes, 1914) it was not until the latter half of the century that more comprehensive accounts of the stratigraphy and paleontology began to



**Figure 1.** Geographic names, section locations, and the distribution of Permian strata. Areas of Triassic strata are too small to include at this scale.

appear. Martin (1959, 1961) presented a regional outline and Knipping (1960) discussed the late Paleozoic tectonic development. The first regional map incorporating the Permian was produced by Norris et al. (1963), followed almost two decades later by more detailed maps (Norris, 1981a to h, 1982a to c, 1985).

During the 1960s some of the first paleontological studies of Permian strata began to be published (Nelson, 1961, 1962; Nelson and Johnson, 1968; Nassichuk et al., 1965; Bamber and Barss, 1969). The next decade saw some major regional studies produced, the most notable being that of Bamber and Waterhouse (1971), the first truly comprehensive account of Carboniferous and Permian strata in the northern Yukon and adjacent Northwest Territories. The detailed descriptions of the sections used to compile their synthesis were published later (Bamber, 1972, 1982). Bell (1973) expanded upon Knipping's (1960) work on the late Paleozoic Ellesmerian Orogeny, with Richards et al. (1997) adding more information on the orogeny and tectonic development. Miall (1973) incorporated data on the Permian into a regional geological study of the northern Yukon. More detailed local studies also were produced, such as those for the Eagle Plain area (Martin, 1973; Graham, 1973). Paleontological reports and site-specific details continued to be published (Davies, 1971; Nassichuk, 1971a, b; Nassichuk and Bamber, 1978; Sarytcheva and Waterhouse, 1972; Seo, 1977).

The most recent studies of the Permian have focused on specific topics, local mapping, and new paleontological data (Bamber et al., 1989; Bardoux, 1984; Davies, 1988; Hamblin, 1990; Mamet et al., 1987; Mattner, 1990; Norris, 1980; Pugh, 1983; Waterhouse and Waddington, 1982; Wielans, 1992; Shi and Waterhouse, 1997). Several regional syntheses of the Permian of western and northwestern Canada have been published recently (Henderson et al., 1993; Richards et al., 1997). On a more international scale, Beauchamp (1995) has summarized the Permian of the Arctic regions of North America.

Triassic strata were not recognized in the study area until Tozer (1961) listed some occurrences. Initial mapping of the Triassic was published by Norris et al. (1963). Mountjoy (1967) produced the first detailed outcrop descriptions. It was not until the detailed mapping by Norris (1981a, b, h) that a comprehensive view of the distribution of Triassic strata became available. Norris (1997) summarized the Triassic stratigraphy of northernmost Yukon in some detail. A broad overview has been published by Gibson (1992). Details of a local occurrence of Triassic strata in the

northern British Mountains were published by Dixon et al. (1996).

Studies of the Permian and Triassic in northeast Alaska that have a bearing on the Permian of northern Canada have been best summarized in Detterman (1970), Detterman et al. (1975), and Crowder (1990). The reader is referred to these authors for additional references.

## REGIONAL SETTING

The bulk of the exposed Permian and Triassic strata of the northernmost Yukon and adjacent Northwest Territories occurs in several prominent tectonic elements: the Romanzof, Cache Creek, Rat, and Scho uplifts (Fig. 2; Norris, 1972, 1973; Young et al., 1976). Romanzof Uplift underlies the British Mountains, Barn Uplift underlies the Barn Mountains, and the other uplifts occur in the northern Richardson Mountains. Although the present expression of these uplifts is due principally to Late Cretaceous–Early Tertiary deformation, they have had a long history of tectonic activity, varying in style from uplifts to depressions. Minor outcrops of Triassic strata occur on the western and southwestern flanks of Barn Uplift and on the eastern flank of the central Richardson Mountains, in the vicinity of Salter Hill (Norris, 1981h).

The Permian in the subsurface of Mackenzie Delta occurs in several tectonic features. In the northernmost subsurface occurrence, the Permian sits in, or on the flanks of, the Tununuk High. South of this high, Permian strata rest in the northeastern end of the Canoe Depression. The southeastern extent of the Permian is limited by the Eskimo Lakes Fault Zone (Fig. 2).

The greatest known thickness of Permian strata is present in the core of the Cache Creek Uplift (Fig. 3), and decreases to the east and southeast through erosion and depositional thinning. Thinning to the west is probably due primarily to post-Permian erosion, but cannot be evaluated because of a lack of data. The isopach and facies trends of the Permian succession (see discussion below) indicate that the site of the Cache Creek Uplift was a Permian depocentre. Available data are inadequate for constructing an isopach map of Triassic strata.

Carboniferous and Permian successions rest with marked angular unconformity on Upper Devonian and older beds (Fig. 4), a relationship interpreted as

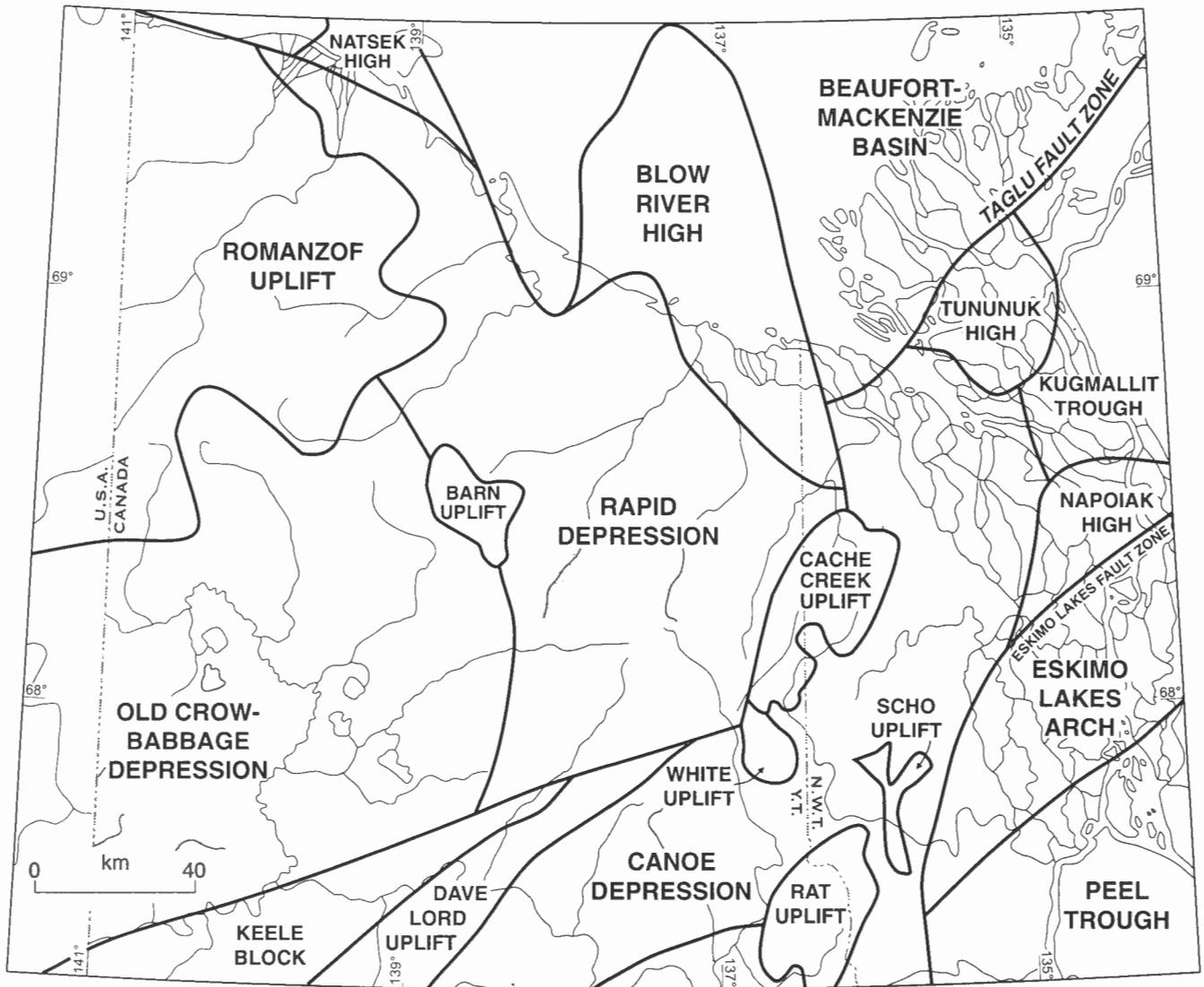


Figure 2. Present-day regional tectonic elements. Modified from Norris (1983) and Dixon et al. (1992)

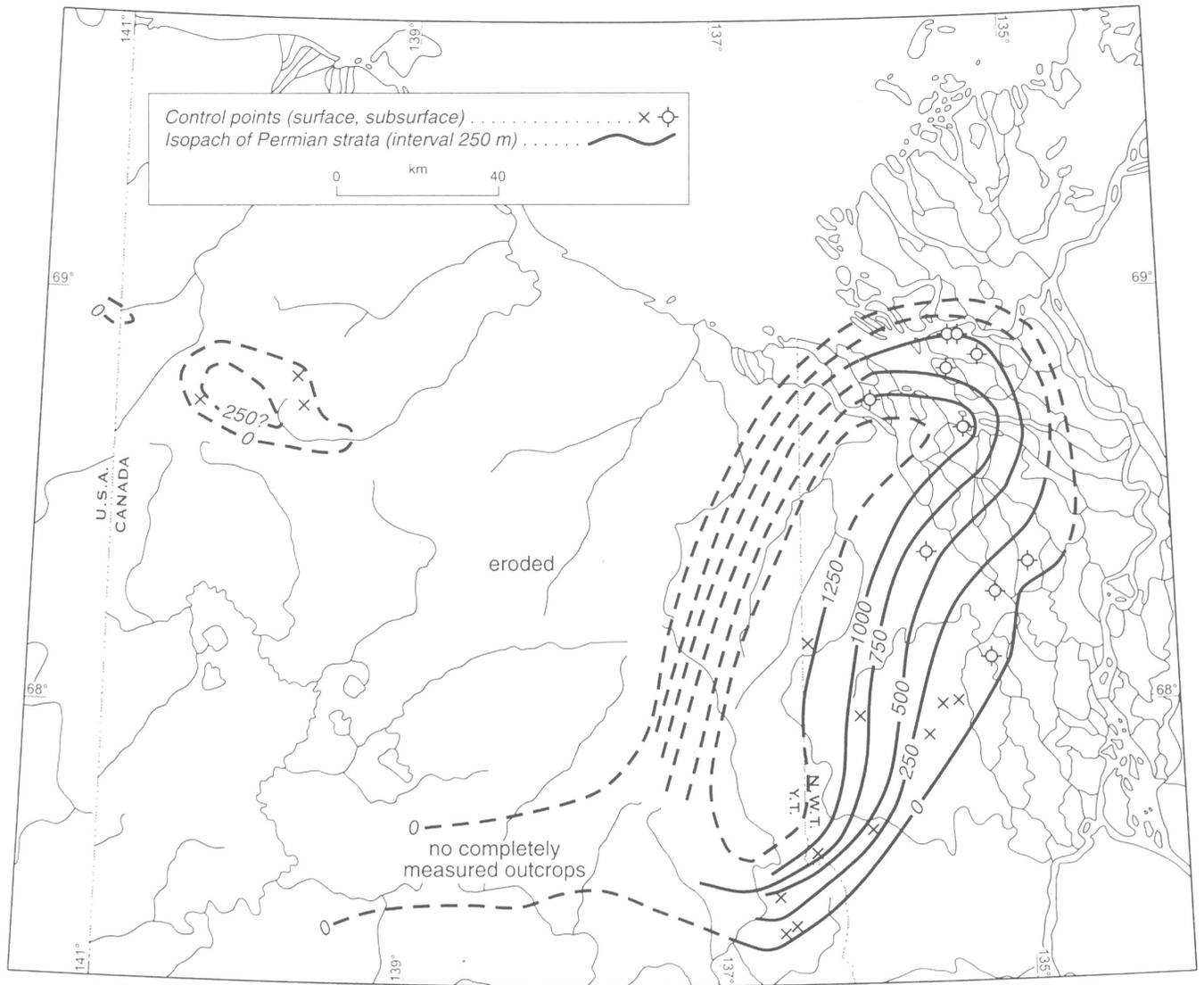
resulting from the major late Paleozoic Ellesmerian Orogeny (Knipping, 1960; Bell, 1973; Richards et al., 1997). In places, Permian strata rest erosionally, but disconformably, on Carboniferous beds, locally overlapping the Carboniferous and resting on older beds. Triassic strata rest disconformably on Carboniferous or Permian beds and are overlain disconformably by Jurassic strata. Tectonism during the Carboniferous to Triassic and continuing into the Early Cretaceous is interpreted to have been dominated by extension (Henderson et al., 1993; Richards et al., 1997; Dixon, 1994).

Permian deposition in western and northern mainland Canada was on a west-facing (present-day coordinates), passive continental margin (Henderson et al., 1993). From east to west, depositional facies change from nearshore to basinal. The northwest-oriented Permian depositional trough extending from western Canada into the Yukon has been called the

Ishbel Trough (Henderson et al., 1993). In the northern Yukon, some authors have identified a positive tectonic element that influenced local depositional patterns and facies - the Ancestral Aklavik Arch (Bamber and Waterhouse, 1971; Henderson et al., 1993).

## STRATIGRAPHY

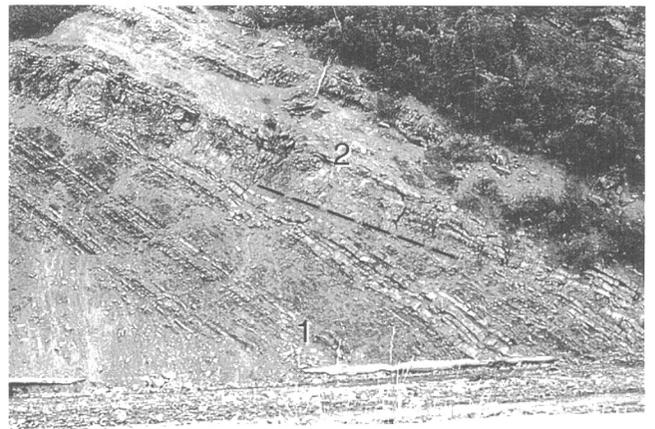
Informal names for the Permian of parts of the northern Yukon were first used by Nelson (1961). Formal names for some Permian strata of the northern Yukon and adjacent Northwest Territories were first defined by Bamber and Waterhouse (1971; Fig. 5) and for the Triassic by Norris (1881a, b, h). Dettner et al. (1975) clarified and revised the nomenclature of Permian and Triassic strata in adjacent northeast Alaska.



**Figure 3.** Isopach map of Permian strata.

Formal names were defined for Permian strata of the northern Ogilvie Mountains (Jungle Creek and Tatonduk formations) and used as far east as the Peel River area (Bamber and Waterhouse, 1971). Subsequent investigators extended the use of Jungle Creek Formation into the subsurface of Eagle Plain (Graham, 1973; Pugh, 1983), and the formation was mapped into the Keele Range, northwest of Eagle Plain (Norris, 1981d).

Bamber and Waterhouse (1971) either referred to Permian strata throughout the British and Richardson mountains as “undifferentiated” (British Mountains) or used informal terms (Richardson Mountains). However, these authors did note that the Permian of the British Mountains was equivalent to the Permian “Echooka Member, of the Sadlerochit Formation” (subsequently redefined as a formation of the Sadlerochit Group; Detterman et al., 1975). Subsequent mapping of the Permian in the British



**Figure 4.** Angular unconformity between the Upper Devonian Imperial Formation (1) and Carboniferous or Permian strata (2) of Mattner’s (1990) Coral Unit. Sheep River, Richardson Mountains. ISPG photo 4150-8.

		Northeast Alaska Detterman <i>et al.</i> (1975)	British Mountains (this report)		Northern Richardson Mountains (this report)	Eagle Plain	Northern Ogilvie Mtns Bamber and Waterhouse (1971)	Selwyn Mountains Gordey and Anderson (1993)	Northeast B.C. Southeast Y.T. Kindle (1946) Henderson <i>et al.</i> (1994)
			South	North					
POST-TRIASSIC		KINGAK FM (JURASSIC)	KINGAK FM (JURASSIC)	KINGAK FM (JURASSIC)	BUG CREEK GROUP (JUR)	CRETACEOUS	TRIASSIC OR JURASSIC		GARBUTT FM (CRET)
TRIASSIC	UPPER	RHAETIAN							
		NORIAN	Karen Creek Ss						
		CARNIAN	SHUBLIK FM Clay shale mbr	SHUBLIK FM	SHUBLIK FM				
	MIDDLE	LADINIAN	SHUBLIK FM Limestone and dolomite mbr						LIARD FM
		ANISIAN	SHUBLIK FM Siltstone member					JONES LAKE FORMATION	TOAD FORMATION
		SPATHIAN	SHUBLIK FM Fire Creek Siltstone Member			unnamed ?			
	LOWER	SMITHIAN	IVISHAK FM Ledge Sandstone Member						GRAYLING FORMATION
		DIENERIAN	IVISHAK FM Kavik Member						
		GRIES- BACHIAN							
		CHANGH- SINGIAN							
PERMIAN	DZHULFIAN	SADLEROCHIT GROUP							
	CAPITANIAN	ECHOOKA FORMATION Ikiakpaurak Member	ECHOOKA FORMATION		LONGSTICK FORMATION		TAHKANDIT FORMATION	FANTASQUE FORMATION	
	WORDIAN	ECHOOKA FORMATION							
	ROADIAN	ECHOOKA FORMATION Joe Creek Member			JUNGLE CREEK FORMATION Upper member	JUNGLE CREEK FORMATION Upper member		MOUNT CHRISTIE FORMATION	
	KUNGURIAN				JUNGLE CREEK FORMATION Lower member	JUNGLE CREEK FORMATION Lower member			
	ARTINSKIAN								
	SAKMARIAN								
ASSELIAN									
CARBONIFEROUS	LISBURNE GROUP	LISBURNE GP	LISBURNE GP	LISBURNE GP	ETTRAIN FM	ETTRAIN FM	TSICHU FM	TAYLOR FLAT FM	

Figure 5. Permian and Triassic stratigraphic nomenclature.

Mountains identified the Permian as part of the Sadlerochit Group (Norris, 1981b).

In the northern Richardson Mountains, Bamber and Waterhouse (1971) divided the succession into three informal units, the Carbonate, Shale, and Sandstone units. Norris (1981b) identified four map units: Po, and P1 to P3 in the core of the Cache Creek Uplift and in some areas around the White Uplift. Elsewhere in the Richardson Mountains he mapped the Permian as undifferentiated (map unit Pu: Norris 1981b, e, f). Map unit Po corresponds to Bamber and Waterhouse's Carbonate unit; P1 and P2 correspond approximately to the Shale unit, and P3 appears to be equivalent to the uppermost part of the Shale unit. In the northern

Richardson Mountains, the Carbonate Unit of Bamber and Waterhouse and Norris' map unit Po include mostly Carboniferous beds with some Permian strata at the top of the unit.

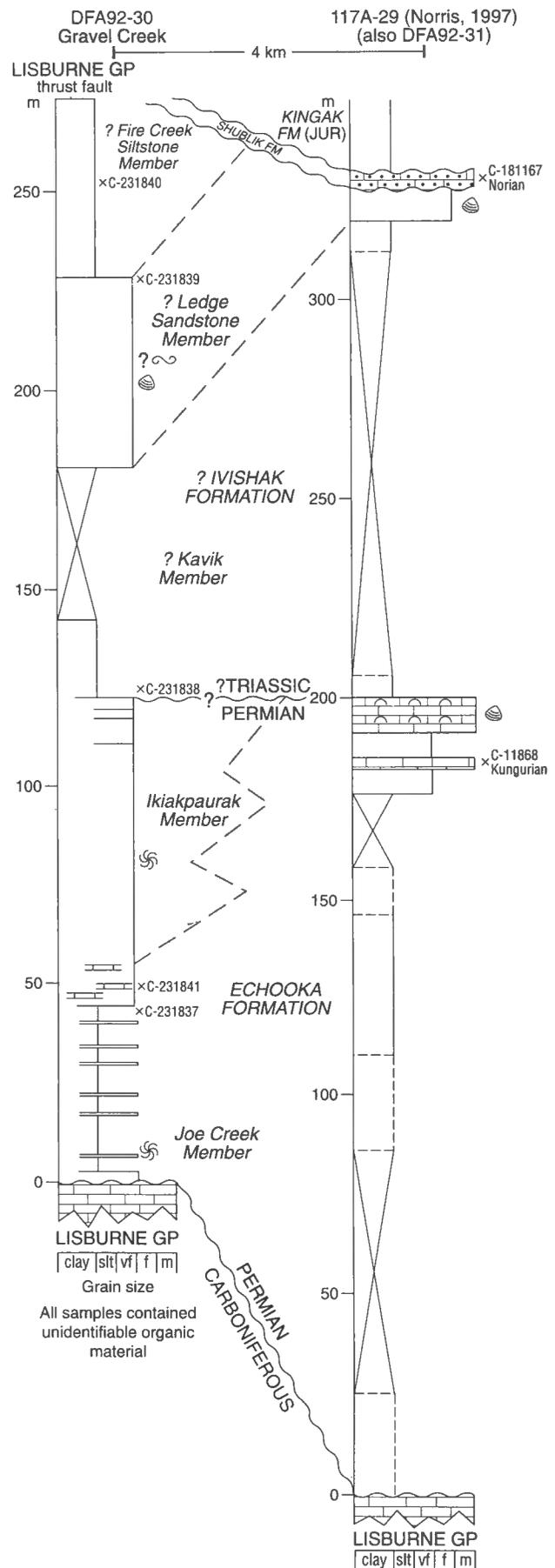
Upper Triassic strata in northern Yukon generally have been named after the Shublik Formation of northeast Alaska (Norris 1981a, b). On the north and south flank of the British Mountains, Norris (op. cit.; 1985) identified the Permian to Triassic Sadlerochit Group, which contains the Lower Triassic Ivishak Formation. Recent work has shown the northern outcrop to be younger than the Ivishak Formation, and age-equivalent to part of the Alaskan Shublik Formation (Dixon et al., 1996).

## Sadlerochit Group (Permian–Triassic)

The Sadlerochit Group in its type area of northeast Alaska consists of the Permian Echooka Formation and the Lower Triassic Ivishak Formation (Fig. 5; Detterman et al., 1975). In adjacent Yukon, Permian fossils confirm the presence of Echooka-equivalent beds (Norris, 1981b; Mamet and Mason, 1970) but no Lower Triassic fossils have yet been identified to confirm the presence of Ivishak-equivalent strata. However, in the Muskeg Creek to Babbage River area of the southern British Mountains, the succession suggests the preservation of Triassic strata in places, hence the designation of these beds as Sadlerochit Group by Norris (1981b) is probably correct. At Norris' (1981b) section A29 (Dixon's section DFA92-30, Fig. 6), poorly exposed beds between dated Kungurian (Lower Permian) and Norian (Upper Triassic) strata favour the presence of Ivishak-equivalent strata. As will become apparent, the overall succession in the southern British Mountains is similar to that of the Sadlerochit Group in northeast Alaska, lending further support to the notion that Lower Triassic strata are present in northwestern Yukon.

Detterman et al. (1975) identified strata of the Echooka Formation of northeast Alaska as far east as the Alaska–Yukon border, in Joe Creek. Norris (1981b) extended this trend of outcrops into the Yukon and mapped it as the undivided, Permian to Triassic, Sadlerochit Group. Elsewhere in the southern British Mountains, Norris (1981b) mapped the Sadlerochit Group in the headwaters of Babbage River, Timber Creek, and Muskeg Creek, where it occurs around the flanks of a large synclinorium cored with Cretaceous and Quaternary deposits.

In the northern British Mountains, in the vicinity of Fish Creek, Norris (1985) mapped an isolated area as Sadlerochit strata, but these beds were subsequently dated as Late Triassic (Dixon et al., 1996). A few kilometres to the south of the Triassic outcrop at Fish Creek, there are extensive areas of the Carboniferous Lisburne Group, overlain locally by a thin succession (a few metres thick) of quartzose sandstone (e.g., section DFA92-18). These sandstone beds are undated and could be erosional remnants of the Triassic sandstone seen at the base of the Fish Creek succession. Alternatively they could be remnants of Permian strata, known to rest abruptly on the Lisburne carbonates in the southern British Mountains. However, the known northward regional truncation of the Permian in the British Mountains and the close



**Figure 6.** Correlation of Permian and ?Triassic sections in the southern British Mountains. Refer to Figure 12 for legend.

proximity to similar and dated Triassic strata tends to favour a Triassic age for these sandstone beds.

### *Echooka Formation (Permian)*

#### *Distribution and stratigraphic relations*

In Alaska the Echooka Formation is divided into the Joe Creek and Ikiakpauruk members (Detterman et al., 1975) with only the former present in the area of Joe Creek, near the Alaska-Yukon border. The Joe Creek Member consists of an interval of calcareous, silty to sandy shale and calcareous siltstone grading upward into a chert-rich interval, in turn overlain by sandy, bioclastic limestone. Ikiakpaurak strata consist of very fine to fine grained sandstone and siltstone with thin interbeds of shale.

The regional relations between these two members in northeast Alaska indicate that the Ikiakpaurak Member overlaps the Joe Creek Member in a northerly direction (Detterman et al., 1975). This type of stratigraphic setting implies that a disconformity exists within the Permian succession, which, from the available paleontological data (Detterman et al., 1975), resulted from late Ufimian or early Kazanian erosion.

Although no sections have been examined in the Yukon part of Joe Creek, it is presumed that only the Joe Creek Member extends into the Yukon, as suggested by the geology a few kilometres west of the border (Detterman et al., 1975).

#### *Lithology and thickness*

In the southern British Mountains, Echooka-equivalent strata are similar to those in Alaska. A lower, shale-rich interval, commonly with a basal sandstone, rests abruptly on Lisburne limestone, and is overlain by an interval of sandstone and limestone. This general succession is comparable to the Joe Creek and Ikiakpaurak members of the Echooka Formation of Alaska, to which it is correlated.

In general the shale-rich interval is poorly exposed, commonly covered by tundra vegetation. Only at section DFA92-30 (headwaters of Gravel Creek) is there reasonably good exposure. Here the interval is about 45 m thick and consists of dark grey, fissile shale with thin interbeds of siltstone and very fine grained sandstone. Fine laminae and the trace fossil *Zoophycus* are present in some of the sandy and silty beds. This interval is probably equivalent to the shale and chert succession of the type section of the Joe Creek

Member. At section DFA92-31 (headwaters of Babbage River, Fig. 6; Norris' section A29, 1981b) the shale succession is about 176 m thick, and at the Muskeg Creek section (section DFA94-6) it is estimated to be between 80 and 130 m thick. At the Babbage River section (DFA92-31) the shale is overlain by about 25 m of interbedded, brachiopod-bearing sandstone and limestone. The Kungurian age cited on Norris' (1981b) map was derived from fossils in this interval (GSC sample locality C-11868). The age and lithology is similar to the upper beds of the Joe Creek Member in Alaska (Detterman et al., 1975).

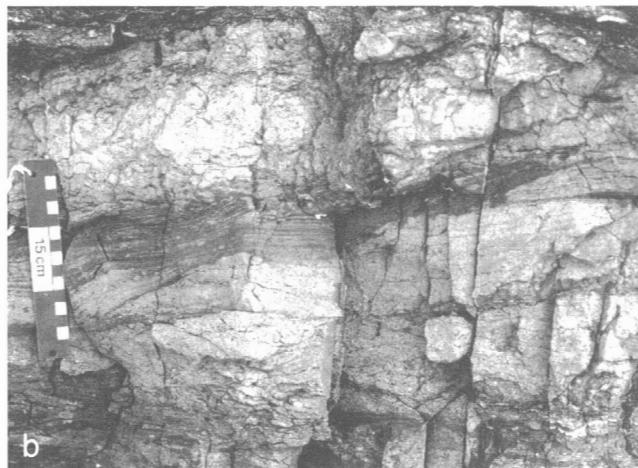
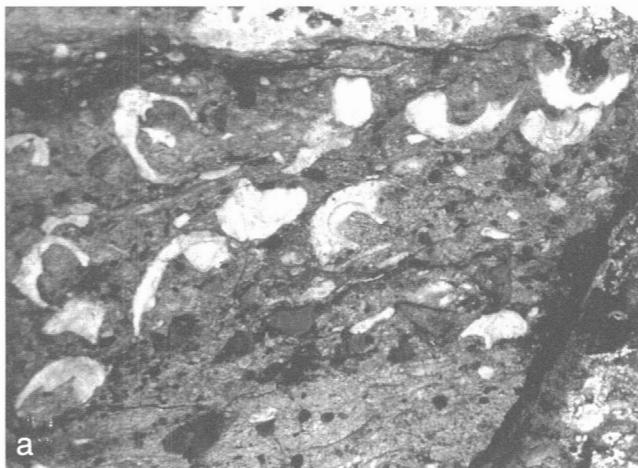
At the Gravel Creek section (DFA92-30) the shale interval is overlain by 9 m of interbedded sandstone, pebbly sandstone, and some limestone beds, in turn succeeded by about 69 m of sandstone. Although no age-diagnostic fossils have been recovered from this section, the lower 9 m of the sandy succession is correlated with the upper part of the type-Joe Creek Member because of their lithological similarity. The remainder of the sandy interval is possibly equivalent to the Ikiakpaurak Member. A similar succession is present at Muskeg Creek (DFA94-6), although no limestone beds were noted in the lower part of the sandy succession. Consequently the sandstone succession at this section may include equivalents of only the Ikiakpaurak Member.

At section DFA92-32 (Cottonwood Creek), the Joe Creek Member is represented by a thick, poorly exposed shale interval (estimated to be between 90 and 130 m thick) overlain by at least 25 m of interbedded bioclastic limestone, calcareous siltstone, conglomeratic sandstone, and fossiliferous, calcareous sandstone (Figs. 7, 8). Above these limy beds the succession is poorly exposed and the stratigraphy uncertain, although Norris (1981b) mapped Norian (Triassic) strata to the east, in apparent stratigraphic continuity.

#### *Sedimentology*

The bulk of the Joe Creek-equivalent succession is poorly exposed shale with thin interbeds of sandstone. Most of the sandstone interbeds are thoroughly bioturbated and many are argillaceous to silty. The lithology, extensive bioturbation, and the presence of endothyrid microfossils (Mamet and Mason, 1970, p. 564), indicate a marine setting.

The very fine to fine grain size and the ubiquitous silica cement in most sandstones of the Echooka Formation tend to mask many sedimentary structures. A few examples of fine, subhorizontal laminae were



**Figure 7.** Examples of some facies types in the Echooka Formation at section DFA92-32. a: conglomeratic, calcareous sandstone – note the large, thick-walled brachiopod shells. ISPG photo 4002-4. b: interbeds of bioturbated and cross-laminated, sandy limestone. ISPG photo 4002-3.

noted but the most common visible sedimentary structure is bioturbation, seen as burrow mottling and some *Zoophycus* burrows.



0 mm 4

**Figure 8.** Sandy bioclastic limestone of the Echooka Formation, section DFA92-32, located between Cottonwood Creek and Babbage River. Fragments of brachiopod, bryozoa, and possibly crinoids (the large crystals). Plane light. ISPG photo 4548-12.

Most of the carbonate beds of the Echooka Formation are silty to sandy bioclastic limestone with broken and whole fossils, especially brachiopods and bryozoa. Examination of thin sections also reveals the presence of calcareous algae, foraminifers, and crinoid ossicles. At the Cottonwood Creek section (DFA92-32), sedimentary structures are well preserved in the limestone and sandy limestone beds. Here, burrow-mottled beds alternate with finely laminated calcarenites near the contact between the lower shale interval and the overlying limestone and sandstone interval (Fig. 7b). Some of the laminated beds appear to contain low-amplitude, medium-scale, hummocky cross strata. This interbedded facies is abruptly overlain by a conglomeratic sandstone in which the larger clasts consist of chert pebbles and thick-walled brachiopod shells (Fig. 7a).

Although there is a lack of well preserved sedimentary structures, enough evidence is available to indicate the Echooka Formation in the British Mountains is of marine origin throughout its known vertical extent. The overall coarsening-upward succession also indicates a general transgressive-regressive cycle of sedimentation. After the initial transgression, which in some places deposited a thin, transgressive sandstone, muds were deposited on a shelf environment, gradually being succeeded by inner shelf and nearshore, higher energy deposits of quartz and lime sand. Internal discontinuities have not been identified, although at the Cottonwood Creek section (DFA92-32) the bioclastic conglomerate does rest erosionally on older beds. However, this erosional event has not been identified in the other sections, consequently it could be local in nature.

The apparently abrupt change from interbedded limestone and sandstone to predominantly sandstone at the contact between the Joe Creek and Ikiakpaurak members could be indicative of a major change in the sedimentary regime. This abrupt facies change could represent a transgression and the beginning of another cycle of sedimentation.

### *Age and correlation*

Fossils from the Echooka Formation in the British Mountains are not very common, except in some of the limestone beds in the upper part of the Joe Creek Member. A Kungurian age (Norris, 1981b, 1997) has been identified for such beds in the Babbage River section (DFA92-31; Norris' 1981b section A29). A few kilometres northwest of the Gravel Creek section (DFA92-30), at section A3 on Norris' map (1981b), Mamet and Mason (1970, p. 564) dated foraminifers from strata equivalent to the lower part of the Joe Creek Member as Permian. In fact they compared the assemblage to similar fossils from the lower part of the Permian of the Ogilvie Mountains (i.e., the Jungle Creek Formation). Such a comparison implies an Asselian or Sakmarian age, based on the subsequent dating of the Jungle Creek Formation (Bamber and Waterhouse, 1971).

These limited pieces of paleontological data indicate an age range of at least Asselian, or Sakmarian, to Kungurian for part of the Echooka Formation of the British Mountains. In Alaska the Joe Creek Member has been dated as early Sakmarian to Kazanian (Wordian) (Detterman et al., 1975). If the limestone-rich interval noted in several sections is co-eval (i.e., Kungurian), then those sections with overlying sandstone beds must contain younger Permian strata, possibly Roadian to Wordian. This would be consistent with the Kazanian (Wordian) age determined for the uppermost beds of the Joe Creek Member and the Ikiakpaurak Member in Alaska (Detterman et al., 1975).

The Echooka Formation is correlative with the Jungle Creek and Longstick formations of the northern Richardson Mountains and the Jungle Creek and Tahkandit formations of the northern Ogilvie Mountains (Fig. 5). The Ivishak Formation appears to have no well established, age-equivalent beds elsewhere in the northern Yukon and adjacent NWT. An isolated occurrence of poorly dated Early or Middle Triassic strata in the northern Richardson Mountains (see later discussion of Triassic stratigraphy), would include

some correlative strata if the Early Triassic age could be confirmed.

### *Possible Echooka strata at Mount Sedgwick*

On the southeast flank of the Mount Sedgwick pluton, Norris (1981b) mapped Carboniferous strata overlain by Norian strata of the Shublik Formation on a ridge between the Trail and Babbage rivers. Although there is a narrow, covered interval between the Carboniferous limestone and an outcrop of dated Triassic strata, Norris' stratigraphy appears to be correct at the northeast end of the outcrop trend (section DFA92-26, Norris' 1981b section A13). About 9 km to the southwest, a thick interval of siliceous sandstone overlies Carboniferous limestone (section DFA92-27). These strata are undated and are atypical of the nearby Shublik Formation along Babbage River (section DFA92-33). They may be either a remnant of the Permian, or a pre-Norian, Triassic succession. Unlike the Permian at Cottonwood Creek (DFA92-32), about 20 km to the southwest, there is no indication of a shale interval between the Carboniferous and the sandstone succession.

These undated strata consist of between 60 and 100 m of poorly exposed, very fine to fine grained sandstone. Because of the fine grain size and the ubiquitous silica cement no primary sedimentary structures, other than bedding, were seen. A few shell impressions, possibly brachiopods, were noted but are not very common. Much of the sandstone occurs as large, near-in situ blocks, and as scattered outcrops. The contact with Carboniferous carbonates is covered but appears to be abrupt and is marked by a change in slope, as well as a lithology change. Overlying strata are masked by tundra vegetation.

Between sections DFA92-26 and 27, exposure is poor but it is obvious that the sandstone interval thins rapidly northeastward. Southwestward from section DFA92-27 exposures are uncommon and stratigraphic relations are not readily discerned.

If the Permian assignment is correct, these outcrops near Mount Sedgwick record the northward truncation of Permian strata. Also, they could record a possible facies change within, or stratigraphic overlap of the shale succession. The latter occurs in the lower part of the Echooka Formation in northeast Alaska. Based on the known northward overlap of the Joe Creek Member (lower Echooka Formation) by the Ikiakpaurak Member (upper Echooka Formation) in

adjacent Alaska, it is possible that a similar stratigraphy may exist between the Cottonwood Creek and Mount Sedgwick outcrops.

### *Ivishak Formation (Lower Triassic)*

Because the Ivishak Formation is so poorly exposed in the southern British Mountains it will be discussed only briefly. In northeast Alaska, Detterman et al. (1975) subdivided the formation into three members, in ascending order: the Kavik Member, Ledge Sandstone Member, and Fire Creek Siltstone Member. These strata are present principally in the Shublik and Sadlerochit mountains, about 120 km west of the Yukon-Alaska border. No Ivishak strata are known from the Joe Creek area near the Alaska-Yukon border, where the Sadlerochit Group has been identified (Norris 1981b, Detterman et al., 1975).

In the British Mountains, possible Ivishak strata may be present in sections at Gravel Creek (DFA92-30) and Babbage River (DFA92-31, Norris' section A29, 1981b, 1997; Fig. 6). At the Babbage River section there is a very poorly exposed succession between Kungurian limestone beds of the Echooka Formation and dated Norian beds of the Shublik Formation (Norris, 1981b, 1997). These undated beds are assumed to be primarily shale in the lower, poorly exposed part. Stratigraphically above the unexposed interval (to the south) and forming part of a low ridge, is a moderately well exposed, thin interval of siliceous, very fine grained sandstone. The total succession is about 128 m thick; the exposed sandstone is only about 8 m thick. The sandstone immediately underlies a thin, sandy limestone bed of the Norian Shublik Formation (GSC fossil locality C-18167) that occurs on the south flank of the ridge. It is still uncertain if the sandstone is part of the Norian or part of the older Triassic, Ivishak Formation. The lithology (presumed and known) and dated subjacent and superjacent beds favour the correlation of this poorly exposed succession with the Kavik and Ledge Sandstone members of the Ivishak Formation.

A similar, but better exposed succession is present at the Gravel Creek section (DFA92-30; Fig. 6) where there are about 151 m of strata above presumed Echooka Formation. Here, the post-Echooka succession consists of about 59 m of shale, overlain by 48 m of very fine grained sandstone, in turn abruptly overlain by about 44 m of shale. The upper contact is a thrust fault, above which are limestone beds of the Lisburne Group. If these beds are equivalent to the Ivishak Formation, the various lithological intervals could correlate to the Kavik, Ledge Sandstone, and

Fire Creek Siltstone members, respectively. Samples for palynological analysis proved to be barren, consequently the stratigraphic affinity of these beds remains unresolved. The succession is located in an area of thrust faults, and the Permian Echooka Formation could be repeated because of an unidentified thrust fault, or because the whole succession is a tight isoclinal syncline against the upper thrust fault.

Until paleontological control is established, the identification of Ivishak strata in the British Mountains is speculative, although the stratigraphic relations tend to favour their presence.

### **Jungle Creek Formation (Permian)**

The Jungle Creek Formation was first defined from the Tatonduk River of west-central Yukon and divided into a Lower and Upper member (Bamber and Waterhouse, 1971; Fig. 9). The Lower member consists of interbedded sandstone, conglomerate, and shale, with minor amounts of thin bedded limestone. The Upper member consists of interbedded limestone and shale. At the type area and throughout the northern Ogilvie Mountains the Jungle Creek Formation is underlain, with apparent conformity, by the Ettrairn Formation, or unnamed equivalents, and overlain conformably by the limestone-dominant, Kungurian to Wordian, Tahkandit Formation (Bamber and Waterhouse, 1971). Elsewhere throughout the northern Yukon, Jungle Creek strata rest unconformably on a variety of lower Paleozoic to Carboniferous units. The upper contact varies from gradational with the overlying Longstick Formation to erosional, with a variety of Triassic to Albian units resting on Jungle Creek strata.

Bamber and Waterhouse (1971) dated the type section of the Jungle Creek Formation as Asselian to Artinskian. However, subsequent work on the dating of the brachiopod faunal zones has indicated that the Dos brachiopod zone in the Lower member is Gzhelian in age (i.e., latest Carboniferous; Waterhouse and Waddington, 1982).

Jungle Creek strata are identified as far east as Peel River, where the lowermost beds are Asselian (Zone Eta; Bamber and Waterhouse, 1971; Norris, 1982b), in contrast to the Carboniferous age for the lower beds at the type section, and Little Wind River area (Norris 1982b). Subsequent workers extended the terminology into the subsurface of Eagle Plain (Graham, 1973; Martin, 1973; Pugh, 1983; Hamblin, 1990), where the Jungle Creek Formation is divisible into a Lower and

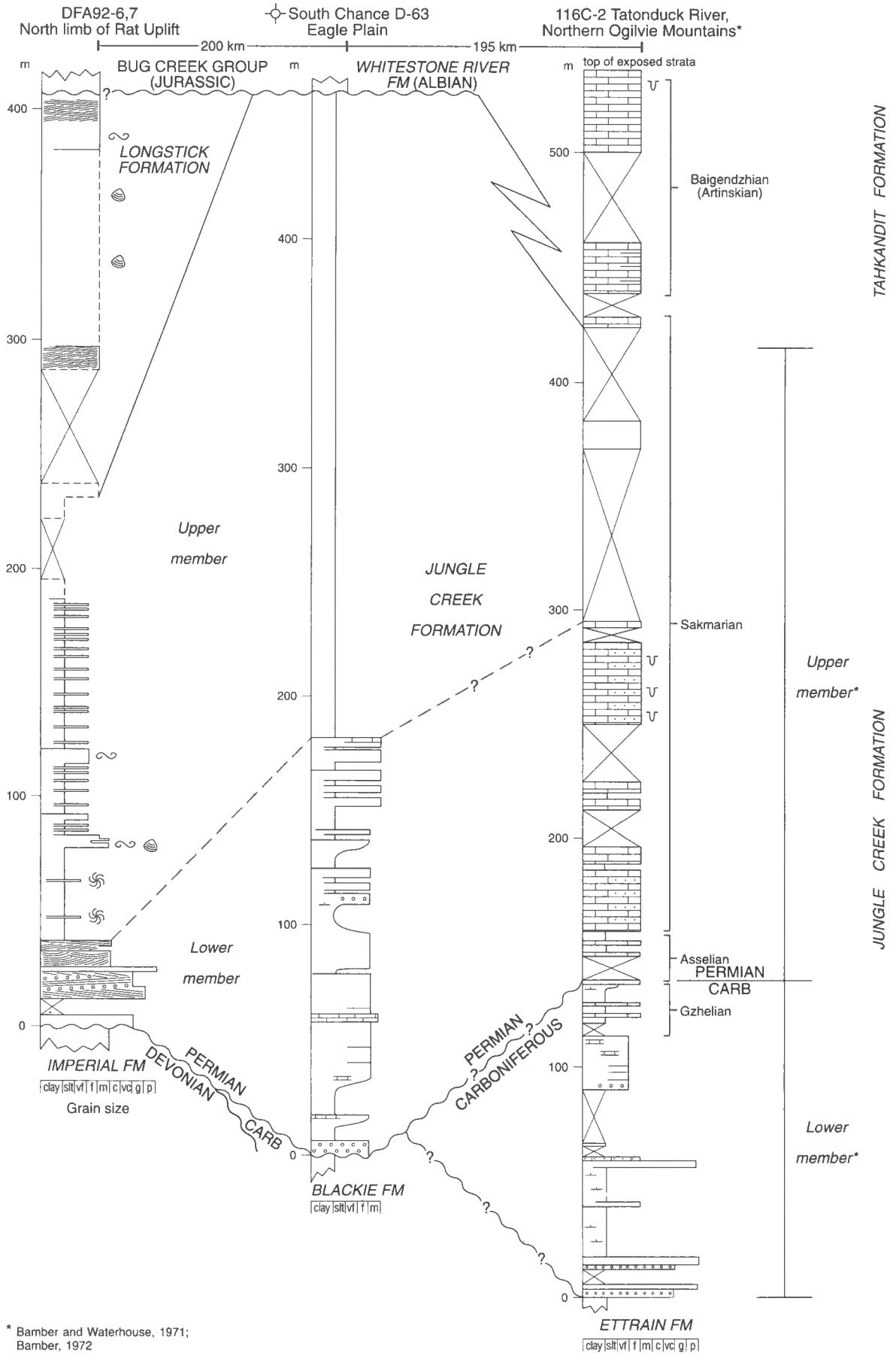


Figure 9. Correlation of Permian strata between the Richardson Mountains, Eagle Plain and the northern Ogilvie Mountains. Refer to Figure 12 for legend.

Upper member (Fig. 9). In Eagle Plain, the Lower member consists of interbedded fine to coarse grained sandstone, some conglomerate, and thin beds of shale and siltstone. A shale-dominated Upper member abruptly overlies the Lower member, and is in turn unconformably overlain by Cretaceous beds. The lithological succession and age-range of the Lower and Upper members at Peel River and Eagle Plain are not consistent with the members of the type section of the Jungle Creek Formation (Bamber and Waterhouse, 1971; Bamber 1972). At the type section, the Lower member is Carboniferous in age (Waterhouse and Waddington, 1982) and dominated by siliciclastics, and the Upper member is limestone-rich and Asselian to Sakmarian in age. It would appear from these data that the Lower member in the Eagle Plain/Peel River areas is age-equivalent to the Upper member of the type section (Fig. 9). Because very little age control is available for the Upper member under Eagle Plain the correlations are more speculative, but it would appear that it is age-equivalent to part of the Upper Member of the Jungle Creek Formation and possibly some of the lower Tahkandit Formation of the Tatonduk River area (Fig. 9).

To the northwest of Eagle Plain, within the Keele Range, Norris (1981d) mapped Jungle Creek strata. However, only a few kilometres to the east of the mapped Jungle Creek Formation, Norris mapped the Permian succession as an unnamed unit on either side of Porcupine River. In the Keele Range and Porcupine River areas, the available data suggests that the Permian succession is similar to that under Eagle Plain: a lower interval of sandstone and conglomerate overlain by a shale-rich succession (Norford, 1964, p. 119; L.S. Lane, pers. comm., 1995), but with an upper interval of interbedded sandstone and shale also preserved (based on airphoto interpretation combined with the mapping of Norris, 1981d).

The Permian of the northern Richardson Mountains is similar to that in Eagle Plain and the Keele Range, consequently it is proposed that the Jungle Creek name be extended to include this area. Bamber and Waterhouse (1971) recognized that the Permian of the Richardson Mountains was partly equivalent to the Jungle Creek Formation, but divided the succession into three informal units. In the core of the Cache Creek Uplift (Fig. 2), Carboniferous and lowermost Permian beds are very similar lithologically and in apparent structural conformity. However, the available paleontological data (Nassichuk and Bamber, 1978; Dixon et al., 1996) indicate a significant erosional gap between the Carboniferous and Permian beds, so some attempt to separate the two intervals is desirable. In such places the boundary between the Carboniferous and Permian beds of the Lower member, Jungle Creek

Formation, is chosen where there is a minor lithological change between dated Carboniferous and Permian beds (see later discussion). At section DFA93-14 (Little Fish River), the lithology changes from a predominantly limestone and sandy limestone succession in the Carboniferous, to calcareous sandstone and sandy limestone in the Permian. To the south of this locality, at section DFA93-16 (Almstrom Creek), the lithological change is even less pronounced; both the Carboniferous and Permian beds consists of fine to coarse grained, calcareous sandstone. However, there is some fossil control to indicate the general interval within which the boundary falls. The base of a grass-covered interval lying between Permian limestone and coral-bearing Carboniferous sandstones is chosen to mark the Carboniferous-Permian boundary.

In the northern Richardson Mountains, the Permian succession is very similar to that seen elsewhere in parts of the northern Yukon: a variably thick basal interval of mixed lithology unconformably overlying older beds, abruptly overlain by a shale-dominated interval, in turn overlain by a sandstone-rich succession. The first two intervals are identified as the Lower and Upper members of the Jungle Creek Formation and the sandstone interval is the newly named Longstick Formation. However, the limited age control and regional considerations indicate that the member divisions in the Jungle Creek Formation of the Richardson Mountains are not age-equivalent to the members at the type section, but more akin to those under Eagle Plain and the Peel River area (see previous discussion; Fig. 9).

Along part of the northwest flank of Rat Uplift, just to the south of section DFA92-6, Norris (1981e) mapped Jurassic resting directly on the Devonian. However, subsequent re-examination of this area (section DFA93-8) revealed that the Permian is present, although locally the structure is complex, with near-vertical beds and faults.

### *Lower member*

#### *Distribution*

Throughout the northern Richardson Mountains the lithological facies within the Lower member vary from place to place, consisting of one or more of the following: fine to coarse grained sandstone, conglomerate, breccio-conglomerate, mudstone, siltstone, shale, sandy bioclastic limestone, and calcareous bioclastic sandstone. An abrupt facies change to shale marks the contact between the Lower and Upper members.

In most areas the Lower member is well exposed throughout the known distribution of the Jungle Creek Formation. Around White Uplift it appears that the Lower member is not well represented because of fault contacts between the Upper member and pre-Permian beds. In the subsurface of Mackenzie Delta, beds of the Lower member have been drilled at Aklavik A-37 and F-38, Napoiak F-31, Beaverhouse Creek H-13, Ulu A-35, Unak L-28, and Kugpik L-24 and O-13 (Fig. 10). Only at Aklavik A-37 and F-38, Napoiak F-31, Beaverhouse Creek H-13, Unak L-28, and Kugpik O-13 does the drilled succession extend below the Lower member. However, only at Beaverhouse Creek H-13, Kugpik O-13, and Unak L-28 (Fig. 10) is there a complete Lower member; at the other wells the Lower member is incomplete as a result of pre-Jurassic erosion.

In most places the Lower member rests with marked angular unconformity on older beds. From Jurassic Butte to the eastern end of McDougall Pass, the Lower member overlies shale and chert of the Ordovician-Silurian Road River Formation (Figs. 11, 12). Much of this area is within the Scho Uplift. Immediately north and south of McDougall Pass, the Lower member of the Jungle Creek Formation rests on the Upper Devonian Imperial Formation (Figs. 4, 13). This latter area is within the Rat Uplift. Only 5 km separates the northeasternmost exposure of Permian strata in Rat Uplift, where the Lower member rests on the Upper Devonian, from the westernmost exposure of Permian strata in Scho Uplift, where the Lower member sits on Ordovician-Silurian rocks (Norris, 1981e). This rapid change in the stratigraphy underlying the pre-Permian unconformity may indicate a major Late Devonian structural boundary (i.e., an Ellesmerian feature). In the core of the Cache Creek Uplift, on the eastern margin of the White Mountains, around and under parts of Mackenzie Delta, the Lower member rests in structural conformity on Carboniferous beds (Fig. 13) but the lack of uppermost Carboniferous beds in the subsurface indicates that the contact is a disconformity (Dixon et al., 1996).

### Thickness

Thicknesses of the Lower member are highly variable (Figs. 10, 12, 13). In the subsurface, the maximum known complete thickness is 224 m in Unak L-28. At Ulu A-35 the incomplete succession is 277.4 m thick. At Jurassic Butte, a pre-Jurassic unconformity truncates down to the Lower member and the succession varies between 120 and 160 m in thickness. A few kilometres southwest of Jurassic Butte, 217 m of



**Figure 11.** Contact between chert and siliceous shale of the Road River Formation (1) (Ordovician-Silurian) and breccio-conglomerate of the Lower member, Jungle Creek Formation (2), at Jurassic Butte, Aklavik Range. ISPG photo 3813-12.

an incomplete section of the Lower member was measured (section DFA93-17). On the south flank of Scho Uplift the lower member varies between 50 and 70 m, thickening southwestward toward the Horn Lake area where about 180 m were measured.

Pre-Jurassic erosion on the southeast flank of Rat Uplift, in the vicinity of Mount Millen, also truncates down to the Lower member, and between 40 and 70 m are preserved. On the northwest flank of Rat Uplift, the thickness rapidly increases from about 40 to 50 m in the vicinity of sections DFA92-6 and 7 to between 220 and 250 m in the Sheep Creek area (Bamber, 1972; Mattner, 1990). These latter thicknesses appear to be the maximum for the outcropping Lower member and include about 25 m of the lowermost beds that Mattner (op. cit.) called the Coral Unit, which may be Carboniferous in age.

Thicknesses of the Lower member decrease northward into the Cache Uplift area, where it is estimated that only 20 to 30 m are present.

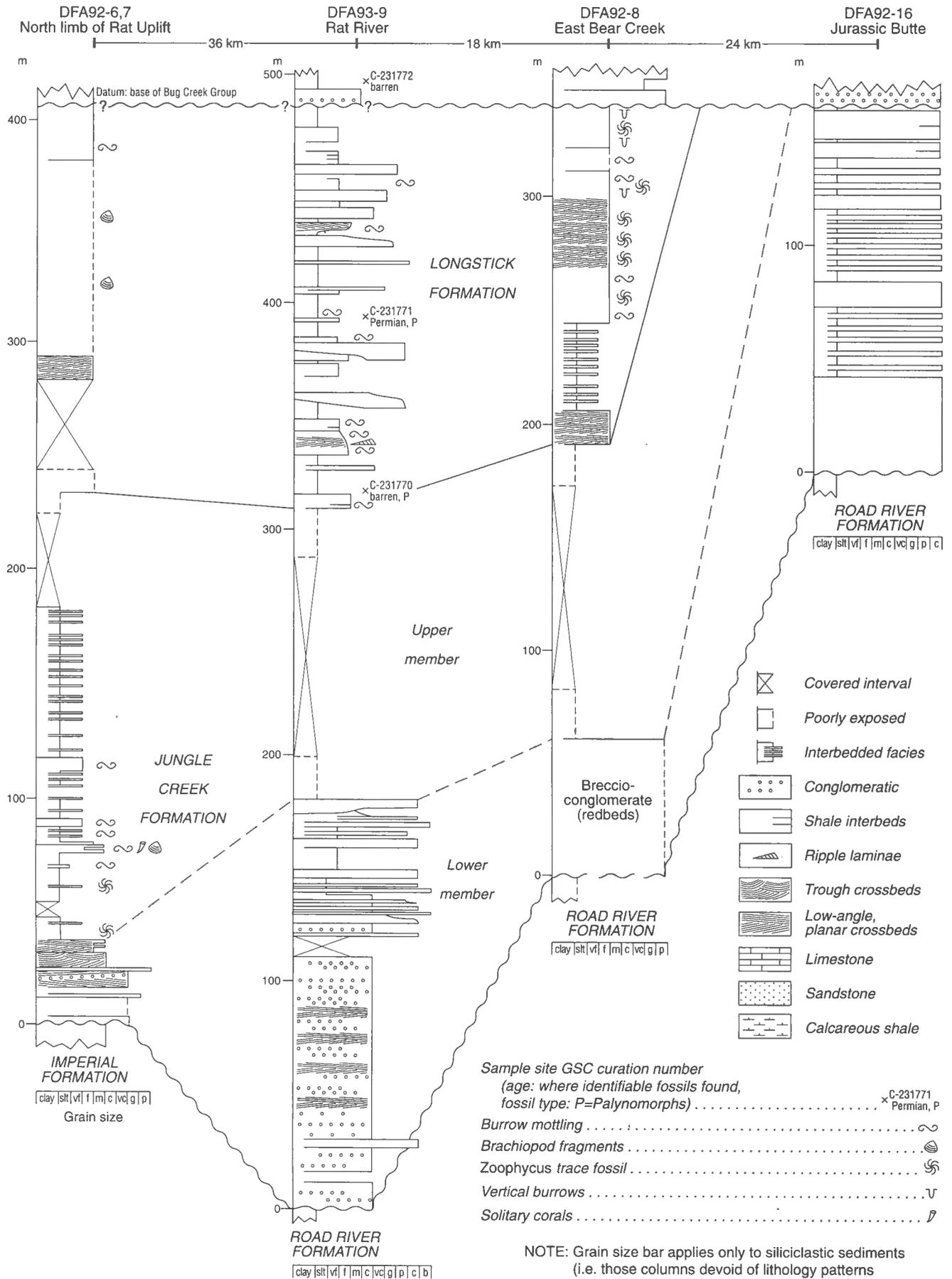


Figure 12. Stratigraphic cross section of Permian strata between Rat Uplift and Jurassic Butte.

## *Facies*

Three facies assemblages are recognized within the Lower member, and each assemblage has a distinct distribution in the northern Richardson Mountains. Assemblage 1 consists of red to brown breccio-conglomerate, conglomerate, sandstone, and mudstone; assemblage 2 of grey to brownish grey sandstone, conglomerate, and shale; and assemblage 3 of sandy limestone, calcareous sandstone, and shale.

Mattner (1990, fig. 3.8) mapped and described a local facies assemblage from the vicinity of Sheep Creek, on the south side of McDougall Pass, which he called the "Coral Unit". This unit lies between the Devonian Imperial Formation and the typical sandy beds of the Lower member of the Jungle Creek Formation. It consists of a basal 5 m of interbedded sandstone and shale capped by a thin bed (0.8 m) of conglomeratic, coarse grained sandstone. The latter is abruptly overlain by 18.2 m of shale in which there is a thin interval containing limestone beds. The limestones contain bothrophyllid corals. The age of this unit is uncertain and could be either Carboniferous or Permian. Mattner (op. cit.) interpreted this unit to be shallow-water marine or lagoonal in origin. Although Mattner (op. cit.) was unable to find an exposed upper contact he believed the rapid facies change from shale to sandstone indicated an abrupt, possibly disconformable contact. Re-examination of the Sheep Creek locality in 1996 revealed that typical Jungle Creek basal beds rest abruptly and probably erosionally on the Coral Unit.

Based on the stratigraphic position of the Coral Unit, its absence in nearby exposures, the contrast in facies between it and the more typical facies of the Lower member of the Jungle Creek Formation that overlie it, the abrupt, probably erosional, contact with typical Jungle Creek basal beds, the presence of a significant thickness of shale and a coral-bearing limestone unit, it seems likely that the Coral Unit was deposited during an earlier depositional cycle than that of the Lower member of the Jungle Creek Formation. If the stratigraphic-sedimentological relationships are as interpreted above, then a Carboniferous, rather than a Permian age may be more likely. Furthermore, if the Coral Unit is Carboniferous, this would be the most southerly exposure of Carboniferous rocks in the northern Richardson Mountains.

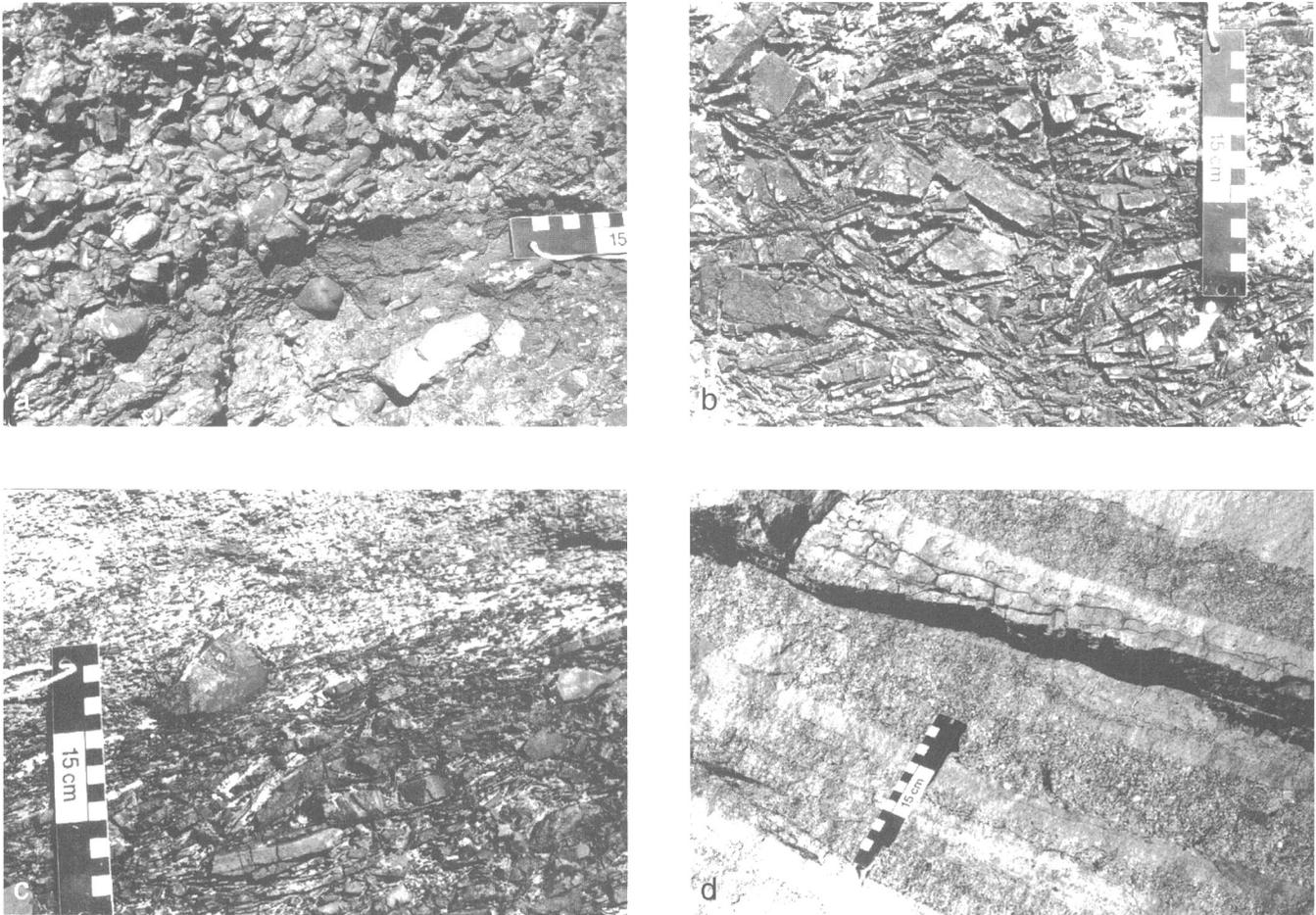
Using the interpreted stratigraphic relationships discussed above, the following depositional interpretation is suggested for the Coral Unit. The vertical lithological succession and stratigraphic relationship with under- and overlying strata suggest that the Coral Unit represents a transgressive-

regressive depositional cycle. Using the transgressive-regressive scenario, the following interpretation would apply: the basal transgressive sandstone is capped by a wave-reworked lag deposit (the conglomeratic sandstone). The abrupt surface separating the sandy beds from the overlying shale is a marine flooding surface. Overlying the basal transgressive beds are predominantly regressive, low-energy, marine shales interbedded with some coral-bearing limestones. These in turn are erosionally overlain by transgressive beds of the Lower member of the Jungle Creek Formation.

***Facies assemblage 1.*** Facies assemblage 1 extends from the Aklavik wells in the subsurface into the nearby outcrops of the Aklavik Range, and southwestward to the Horn Lake area of McDougall Pass. This assemblage is dominated by red to reddish brown breccio-conglomerate, conglomerate, fine to coarse grained sandstone, and mudstone (Fig. 14a-c). The facies assemblage is readily recognized because of its colour and the presence of breccio-conglomerate in many areas. The term breccio-conglomerate is used to denote a lithology that consists of predominantly angular to subangular, poorly sorted, generally tabular clasts but which also contains a significant number of tabular clasts with rounded edges, and in some places subspherical clasts.

Within this facies assemblage there is a distinct lateral facies change southwestward from Jurassic Butte. At Jurassic Butte, and in the nearby Aklavik wells, the succession consists of only two interbedded facies: breccio-conglomerate and mudstone units (Fig. 15). Sandstone and conglomerate content increases southwest of Jurassic Butte. At the sections in East Bear Creek (DFA91-13, 93-8 to 13, 93-1; Fig. 1) these sandstone and conglomerate beds tend to occur in the uppermost part of the Lower member, above a lower interval dominated by breccio-conglomerate. Farther to the southwest, in the vicinity of Horn Lake (section DFA93-9), conglomerate and sandstone beds become predominant and breccio-conglomerate beds are uncommon.

The breccio-conglomerate units consist of angular to subrounded, generally tabular clasts of black, siliceous shale and laminated chert embedded in a clay to sand matrix (Fig. 14a-c). Locally some of the breccio-conglomerate units may contain spherical clasts, especially near the base of the Lower member. Clast size ranges from a few millimetres to over 20 cm. Isolated lenses of sandy mudstone or silty sandstone within the breccio-conglomerate units are present, but not very common. Generally the fabric is chaotic, although some imbrication, and subhorizontal and near-vertical alignment of clasts are present in a few beds (Fig. 14c). Only in a few instances was normal or



**Figure 14.** Examples of facies within the Lower member, Jungle Creek Formation. a: Conglomerate at Jurassic Butte, Aklavik Range, section DFA92-14. ISPG photo 4007-2. b: Breccio-conglomerate with an apparently random fabric. Section DFA92-11. ISPG photo 4002-17. c: Breccio-conglomerate with subhorizontally aligned and inclined clasts abruptly overlain by a granulestone to small-pebble breccio-conglomerate. Section DFA92-10. ISPG photo 4002-1. d: Erosionally based, thin beds of granulestone grading up into laminated coarse grained sandstone. Section DFA92-7. ISPG photo 4002-11.

inverse clast-grading noted. Breccio-conglomerates occur in units a few centimetres to over 90 m thick. In the thicker units it is suspected there are multiple beds, evident from slight variations in clast size within some thick units. However, bedding surfaces are extremely difficult to identify because of the generally uniform character of the breccio-conglomerate.

The thickest and best developed beds of breccio-conglomerate are present in the vicinity of Jurassic Butte, where they constitute more than 60 per cent of the exposed succession of the Lower member. The origin of the chert and siliceous shale clasts is believed to be the subjacent, lower Paleozoic, Road River Formation. At Jurassic Butte, the Lower member unconformably overlies black, bedded chert of the Road River Formation (Fig. 11).

The Lower member at Jurassic Butte and vicinity contains a red, silty to sandy mudstone, a facies not

seen elsewhere. This facies is interbedded with the breccio-conglomerate beds, and occurs locally as small lenses within breccio-conglomerate units. Because of its weakly cemented character it is less resistant to weathering than the breccio-conglomerate (Fig. 15). The mudstone beds have no apparent macrofabric and are massive in appearance. Thin lenses or beds of breccio-conglomerate commonly are present within the mudstone units. Mudstone units range in thickness from a few centimetres to about 10 m. In general they are considerably thinner than the breccio-conglomerate units. A few mudstone units contain calcareous nodules, ranging in size from a few millimetres to about 10 cm in diameter. These are grey and are not very common. Some mudstone beds also have grey to very light grey, bleached intervals, commonly occurring at the top of the beds.

Southwestward from Jurassic Butte, in the East Bear Creek and Bear Creek valleys, the Lower member



**Figure 15.** *Interbedded mudstone and breccio-conglomerate beds at Jurassic Butte. Note the angular discordance between two bedsets (arrow). Section DFA92-14. ISPG photo 4002-8.*

becomes thinner. In these valleys, the lower beds are predominantly breccio-conglomerates with a few thin interbeds of conglomerate and sandstone. In many places the upper beds consist of crossbedded, medium to coarse grained sandstone to pebbly sandstone, granulestone, and small-pebble conglomerate. Individual beds are usually only a few centimetres to about 1 m thick and tend to occupy wide, shallow scours. In the sandy beds, subhorizontal stratification to very low-angle, planar crossbeds may be present. Conglomerate beds tend to lack visible sedimentary structures, although locally some clast imbrication or crude, very low-angle crossbedding can be discerned. Because of the thinness of the sandy to conglomeratic beds and the presence of shallow erosional scours, rapid and complex lateral facies changes can be found within the scale of a single, small outcrop.

At the southwesternmost extent of facies assemblage 1, south of Horn Lake in McDougall Pass, the Lower member lacks breccio-conglomerate units and consists of interbedded fine to coarse grained sandstone, pebbly sandstone, granulestone, and conglomerate. Only a few thin interbedded mudstone units are present. Although red coloration is still evident, shades of maroon and reddish brown are equally prominent. Beds are 20 cm to 1 m thick and commonly occupy shallow erosional scours. Some sandstone units contain very low-angle crossbeds. Many conglomerate beds fine upward, from cobbles at the base to small pebbles at the top. In some instances they grade up into granulestone or coarse grained sandstone. The conglomerates tend to be massive in appearance although some discoidal clasts may be imbricated or subhorizontally aligned.

Facies assemblage 1 is similar to facies present in alluvial fans and coastal fans, such as described by Blair and McPherson (1994) and Howard (1985), and range from debris-flow deposits to a variety of bar deposits formed in braided streams. In the Jurassic Butte area the predominance of breccio-conglomerates and mudstones indicate deposition was dominated by mass-wasting processes, such as debris- and mud-flows. At one of the Jurassic Butte sections (DFA92-14) an internal discordance between two sets of dipping redbeds is visible (Fig. 15), indicating a shift in the locus of deposition. The presence of bands of calcareous nodules within some mudstone units in an otherwise siliciclastic succession, plus some bleached mudstone intervals, are interpreted to have resulted from incipient paleosol formation, and probably formed during periods of subaerial exposure.

Southwest of Jurassic Butte, in the East Bear Creek and Bear Creek areas, the lowest deposits of the Lower member are dominated by breccio-conglomerates, interpreted to have been deposited by debris-flows. In the upper beds, thin units of crossbedded sandstone and conglomerate are more common and are interpreted as high-energy, current-deposited sediments. The relative thinness of the scour-based units, coarse grained character, and rapid lateral and vertical facies changes, strongly favour deposition as meso-scale, migrating bars deposited in shallow, braided streams on the fan-complex. A relatively short distance to the southwest, at the eastern end of McDougall Pass, most of the Lower member consists of similar sandstone and conglomerate deposits, also interpreted to be of braided stream origin. Very few breccio-conglomerate beds of debris-flow origin are present in the McDougall Pass section. The presence of some thin, silty mudstone beds is interpreted as indicating that some floodplain or overbank deposits were preserved.

Facies assemblage 1 extends for a distance of about 80 km, from the Aklavik wells under Mackenzie Delta to the east end of McDougall Pass. It occupies a belt about 5 to 10 km wide. The distribution and relatively thin overall succession of the Lower member containing strata of facies assemblage 1 suggest that the deposit was the result of amalgamation of several fans. As will become apparent later, these redbeds merge laterally (i.e., to the west and northwest) into marine strata, hence their designation as fan-deltas, or coastal fans, may be more appropriate.

**Facies assemblage 2.** Facies assemblage 2 consists of greyish brown to grey, fine to very coarse grained sandstone, granulestone, pebbly sandstone, conglomerate, and shale. Shale is a minor component, present

in only a few locations. This facies assemblage is best preserved around the Rat Uplift and on the northwest flank of Scho Uplift.

In the vicinity of Mount Millen (sections DFA93-6 and 7), at the southernmost exposures of the Lower member, facies assemblage 2 is dominated by conglomerate and granulestone. Here, individual beds are very difficult to distinguish and sedimentary structures are poorly preserved. Clasts range up to small boulder grade and tend to be spherical, although some discoidal clasts are present. A few interbeds, or large lenses of sandstone are present, some of which contain trough crossbeds.

A few kilometres to the north of Mount Millen, facies assemblage 2 consists of a mixture of sandy to conglomeratic lithotypes, and beds range from a few centimetres to about 50 cm in thickness, such as at sections DFA92-6 and 7 (Fig. 14d). Generally each bed has a basal, planar, erosional surface overlain by structureless or subhorizontally laminated to very low-angle, crosslaminated granulestone or sandstone. Trough crossbeds are present in a few places. Beds of granulestone or pebbly sandstone commonly grade upward into sandstone (Fig. 14d). Lenses of granulestone or conglomerate are preserved within some sandy intervals.

At section DFA92-6, on the northwest flank of Rat Uplift, facies assemblage 2 contains thin beds of bioclastic limestone and calcareous sandstone, in which brachiopod debris is a common component. These calcareous beds occur at the top of the Lower member. At section DFA96-2 (see Fig. 18), a short distance west of Sheep Creek, the upper 20–40 m of the Lower member are very distinct from the lower beds of the member. There is an abrupt contact between trough crossbedded, fine grained to granular sandstones of the lower beds and hummocky cross-stratified, very fine to fine grained sandstone of the upper beds. This change is also accompanied by a colour contrast, from predominantly grey in the lower beds to a yellowish brown in the upper beds. Above the hummocky cross-stratified beds there are three, thin, coarsening-upward successions, above which is the Upper member.

On the north flank of Scho Uplift, facies assemblage 2 is dominated by very fine to fine grained sandstone in 30 to 50 cm thick beds (e.g., section DFA96-5). Fine, subhorizontal to very low-angle laminae and the trace fossil *Zoophycus* are the prevalent sedimentary structures. Burrow-mottled beds and beds containing brachiopod debris also are present.

At Brat Creek, a tributary of Rat River, and located a few kilometres east of McDougall Pass (section DFA94-1; Fig. 1), Jeletzky (1967) identified a succession of interbedded sandstone, conglomerate, and carbonaceous shale as Triassic. However, these beds are more akin to the Lower member of the Jungle Creek Formation in the Richardson Mountains than they are to any known Triassic strata in the northern Yukon and northern District of Mackenzie. Although the palynomorphs recovered from this locality (op. cit.) are long ranging (i.e., Permian to Triassic), the facies and the flora are consistent with a Permian age. If correctly identified as Permian, these Brat Creek beds would be typical of facies assemblage 2 of the Lower member, Jungle Creek Formation.

Facies assemblage 2 reflects a south-to-north transition from nonmarine, braided river and debris-flow deposits in the Mount Millen area to high-energy, nearshore deposits a few kilometres to the north. The succession at Brat Creek, now considered to be Permian, is interpreted as representing braided river and floodplain deposition. The vertical facies changes seen at sections DFA92-6 and 7, and DFA96-2 are interpreted as representing a change from possible coastal braidplain deposits to high-energy, marine sediments. At section DFA96-2 the abrupt contact between trough crossbedded and hummocky cross-stratified beds is interpreted as a surface of transgression. At the same section, the contact between the Upper member and the uppermost coarsening-upward succession of the Lower member is interpreted as a maximum flooding surface, the beds between this and the underlying transgressive surface deposited during a marine transgression.

**Facies assemblage 3.** Facies assemblage 3 consists of interbedded sandy limestone, calcareous sandstone, sandstone, and shale. This facies assemblage is present in the core of the Cache Creek Uplift (section DFA93-14; Figs. 1 and 11) and in parts of the subsurface, under southwest Mackenzie Delta (Dixon et al., 1996). In these areas this facies assemblage constitutes the whole of the Lower member. A limestone unit caps the Lower member in the Cache Creek Uplift and at Unak L-28 (Figs. 8 and 10). In the known outcrops, this limestone contains *Palaeoaplysina*, a possible hydrozoan (Davies, 1971). Davies (1971) identified *Palaeoaplysina* mounds from near locality DFA93-14, whereas to the south, at DFA93-16, the limestone unit is more tabular, and individual mounds were not noted.

Section DFA93-14 is the only known outcrop containing facies assemblage 3 (Fig. 16). Here, the Lower member of the Jungle Creek Formation consists



**Figure 16.** Section DFA93-14, Little Fish River, northern Richardson Mountains. Carboniferous (2) to Permian (3) beds are faulted against Devonian limestone (1) on the west. The Carboniferous-Permian boundary (dashed line) is based on available paleontological and field data (Nassichuk and Bamber, 1978; and field data of Dixon). Note the prominent, *Palaeoaplysina*-bearing limestone (the arrows) at the top of the Lower member, Jungle Creek Formation (this part of the succession is repeated as a result of a tight fold and possible fault). ISPG photo 4150-2.

of interbedded sandstone and limestone. Trough crossbeds and hummocky cross-stratification (HCS) are present in the sandy beds. Many of the sandy beds contain bioclasts, most commonly present in the basal parts. Bed thicknesses range from about 15 cm to 1 m, but most are 30 to 40 cm. The bioclastic limestone beds are similar in thickness, and clast types include brachiopod debris and foraminifers. In the subsurface, glauconite is a common component of the sandstone beds.

The presence of trough crossbeds, hummocky cross-strata, and bioclasts of marine organisms indicates deposition in a high-energy, nearshore environment. Capping these high-energy beds is a *Palaeoaplysina*-bearing, micritic limestone (Fig. 17) which is interpreted as indicating a less turbulent, siliciclastic-free depositional regime in a subtidal environment. Davies (1971) interpreted the vertical succession of carbonate facies within the limestone bed as shallowing upward, although he recognized that the overall basal Permian succession was one of transgression and deepening.

### **Upper Member**

#### **Lithology**

The Upper member varies from poorly to well exposed and consists predominantly of shale with interbeds of

siltstone, sandstone, and locally some limestone (Figs. 10, 12, 13, 18). Limestone beds tend to occur near the top of the member, especially in the transition facies between the Upper member and the overlying Longstick Formation (Fig. 19). Sandstone beds commonly occur as part of coarsening-upward intervals within the Upper member (Figs. 10, 12, 13). Such intervals commonly grade upward from bioturbated silty shale into thoroughly bioturbated argillaceous, very fine grained sandstone, in turn capped by less argillaceous, but still bioturbated, very fine to fine grained sandstone. The trace fossil *Zoophycus* is the most common visible feature in these bioturbated sandy beds. In some coarsening-upward intervals the capping sandstone may contain finely laminated beds; however, they are not very common. Brachiopod and bryozoan debris is present in some sandstone beds, and in some locations these fossils are present in thin bioclastic beds.

In the Cache Creek Uplift the Upper member has the following general vertical succession: a lower interval of shale with thin interbeds of siltstone and sandstone, commonly capped by a thin, coarsening-upward cycle; a middle interval consisting predominantly of shale; and an upper interval of shale containing several coarsening-upward cycles, each of which are capped by bioturbated sandstone beds. In the upper interval, limestone beds may be present locally. Mattner (1990) considered the limestone-bearing part of the upper interval to be mappable in



**Figure 17.** *Palaeoaplysina* in thin section (plane light). Partially recrystallized micritic matrix with some bioclasts. Section DFA93-16. ISPG photo 4548-7.

the McDougall Pass area, and informally named it the “*Zoophycus* Carbonate-Shale unit” (his map unit P3). Beds below the *Zoophycus* Carbonate-Shale Unit were identified as the “*Cladochonus* Shale unit” by Mattner (op. cit., his map unit P2). These two units of Mattner’s are equivalent to the Upper member of the Jungle Creek Formation. Brachiopod shells and the coral *Cladochonus* are present in some of the limestone beds, and the former are present in some sandy beds. The most prevalent sedimentary structure is the trace fossil *Zoophycus*. Mattner (1990) described in some detail the various forms of *Zoophycus* he identified from Permian strata of the McDougall Pass area.

Near the top of the Upper member in the Cache Creek Uplift is a light-grey weathering calcareous unit (Fig. 20; unit P2 of Norris, 1981b) that can be mapped throughout the core of the uplift. On the west side of

the uplift this unit is a sandy limestone. Thin section examination reveals this limestone to be composed almost entirely of calcite prisms (Fig. 21), with some silt-sized to very fine sand-sized quartz grains. On the east side, the same unit is a calcareous sandstone, consisting of very fine to fine grains of quartz in a matrix of calcite prisms. Some of the prisms occur as agglomerations. At locality DFA92-12 (Little Fish River), brachiopods occur at the top of the limestone unit. Also, in the more sandy variety of this facies, *Zoophycus* traces are abundant. This unique facies has been identified as the product of the almost complete breakdown of bivalve shells of the genus *Kolymia* (Bychkov and Gorodinsky, 1991, p. 21).

### Thickness

The thickness of the Upper member is variable, although in general there is an increase from south to north, from the basin margin to the basin centre. Thicknesses may be modified by post-Permian erosion, such as in the subsurface occurrences. In the vicinity of East Bear Creek the Upper member is estimated to be about 170 to 200 m thick, which is similar to the thickness at section DFA92-6, on the southwest flank of Rat Uplift. At the east end of McDougall Pass, the Upper member is between 130 and 170 m thick (section DFA93-9). The thickness rapidly increases northward, to about 330 to 350 m at Bamber’s (1972) section 116P-11, near Sheep Creek (section 11 on Norris’ 1981e map), 14 km northeast of section DFA92-6. Within the core of the Cache Creek Uplift, more than 1300 m of strata have been measured (section DFA93-16), with no apparent fault repeat. Here Jurassic strata rest directly on the Upper member, although at one location within the Cache Creek Uplift Triassic strata rest on the Permian (see later discussion). The thickest complete section of the Upper member occurs in the subsurface, at Ulu A-35, where there are 550 m of strata. However, there is a possibility of repeated section in this well as a result of faulting. In the Unak B-11 well there may be a thicker Upper member but the stratigraphy is uncertain and fault repeat is also a possibility (Fig. 10).

### Age and correlation

Microfossils and macrofossils have been recovered from the Lower member, but very little paleontological data is available for the Upper member. In the latter there are few macrofossils and the palynomorphs and foraminifers tend to be either long-ranging or the degree of alteration of the palynomorphs makes identification difficult.



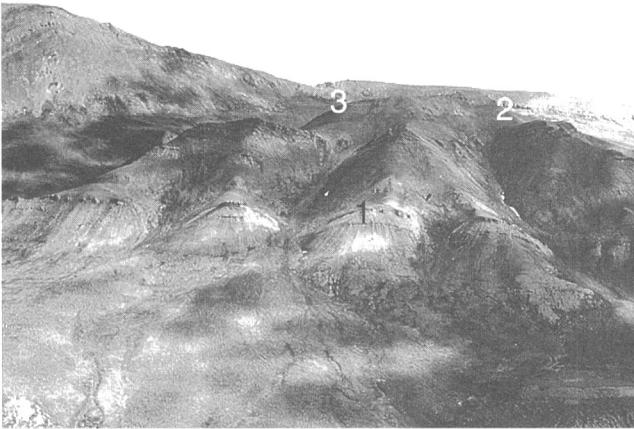
**Figure 18.** Typical outcrop character of Permian strata on the north flank of Rat Uplift, just west of Sheep Creek. 1: Devonian. 2: Lower member of the Jungle Creek Formation; 2a - trough crossbedded, fine to coarse grained, granular sandstone; 2b - hummocky cross-stratified, very fine grained sandstone in the lower part and shale-to-sandstone coarsening-upward cycles in the upper part. 3: Upper member of the Jungle Creek Formation. 4: Longstick Formation. Unit 2 was examined along the ridge where the numbers are located (section DFA96-2). ISPG photo 4150-9.

Foraminifers from the *Palaeoaplysina*-bearing limestone at the top of the Lower member from section DFA93-16 may be Sakmarian, but they are not definitive (Pinard and Rui, pers. comm., 1993). Davies (1971) cites a possible Asselian age, but a middle to late Sakmarian or early Artinskian age for the equivalent carbonate unit located near section DFA93-14 is more likely. Nassichuk (1995) identified the early Artinskian ammonoid *Metalegoceras crenatum* Nassichuk, Furnish and Glenister, collected from talus and apparently within the upper beds of the Lower member on the southwest flank of Richardson Mountains. The early Artinskian ammonoid *Neoshumardites triceps* Rhuzhencev was collected from similar strata, also on the southwest flank of the northern Richardson Mountains (Nassichuk, 1995). Nassichuk (op. cit., p. 220) points out the differing ages identified from the ammonoid and brachiopod fauna for the Lower member, with the brachiopod fauna indicating older ages.

In the Upper member, a Baigendzhenian (late Artinskian) ammonoid fauna has been collected from the lower beds (Nassichuk et al., 1965; Nassichuk, 1995). Conodonts from the *Kolyma*-bearing limestone in the Upper member indicate a Leonardian age



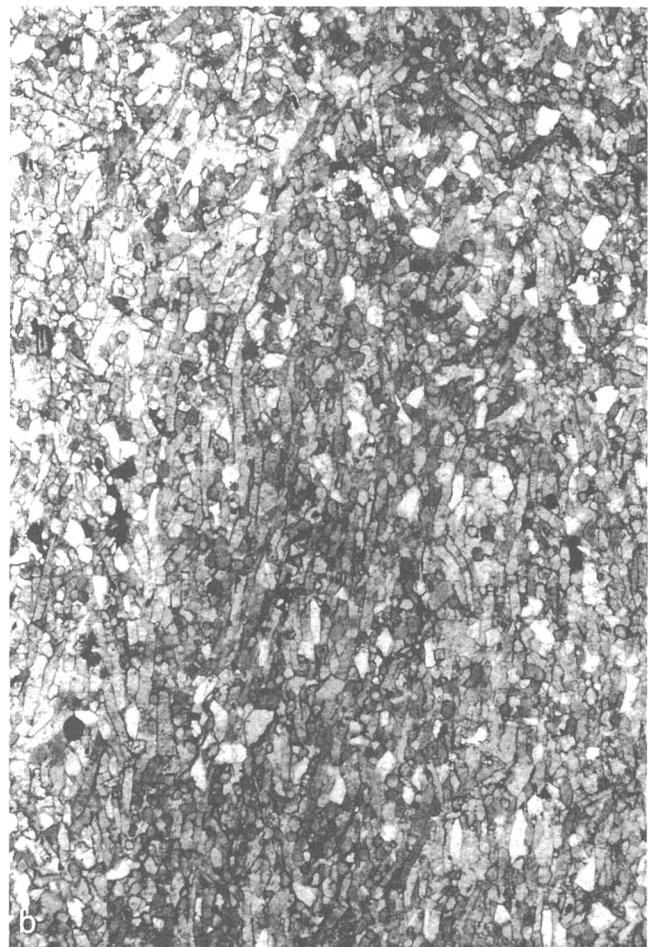
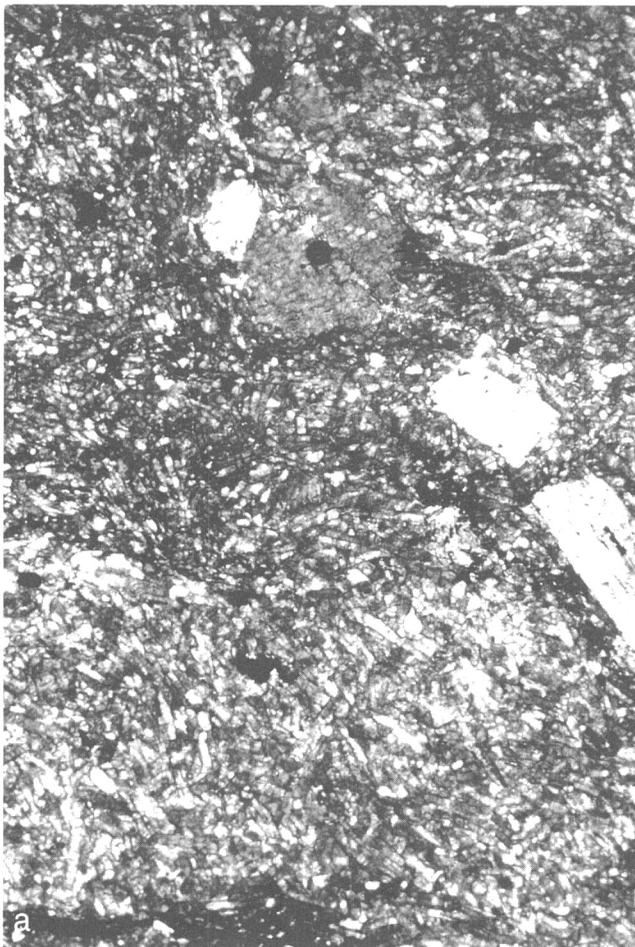
**Figure 19.** Transition strata between the Upper member, Jungle Creek Formation and Longstick Formation. Symmetry Mountain, McDougall Pass area. ISPG photo 4150-11.



**Figure 20.** Permian to Jurassic succession at section DFA93-12, eastern slope of the upper reaches of Little Fish River. 1: Limestone bed within the Jungle Creek Formation. 2: Lower Triassic strata. 3: Presumed Bug Creek Group (Jurassic). ISPG photo 4150-7.

(Artinskian; M. Orchard, pers. comm., 1995). At Bamber's (1972) section 116P-11, brachiopods of the *Lissochonetes* Zone are present in limestone beds in the lowermost beds of the overlying Longstick Formation. This brachiopod zone is dated as Ufimian (Kungurian; Bamber and Waterhouse, 1971, table 3).

From this limited dataset, and regional considerations (see Bamber and Waterhouse 1971), the age range of the Jungle Creek Formation in the northern Richardson Mountains seems to be at least Sakmarian to Artinskian. Asselian fossils have not been identified with certainty from the Richardson Mountains succession, although Asselian fossils have been identified from the Jungle Creek Formation of the Peel River and northern Ogilvie Mountains areas (Bamber and Waterhouse, 1971). The youngest age may be Kungurian, based on the presence of Kungurian fossils in the lowermost beds of the overlying Longstick Formation (Bamber, 1972, section 116P-11).



**Figure 21.** Limestone composed of calcite prisms derived from the near-complete disaggregation of *Kolymia* bivalve shells; Upper member, Jungle Creek Formation. a: Sample C-231798 from section DFA93-13. Approximately 40x magnification in plane light. ISPG photo 4553-5. b: Sample C-231836 from section DFA93-16. Approximately 40x magnification in plane light. ISPG photo 4553-17.

Correlative strata occur in part of the Echooka Formation, principally the Joe Creek Member (Fig. 5). Further afield, correlative strata are present in part of the Mount Christie Formation of the Selwyn Mountains (Gordey and Anderson, 1993) and the Kindle Formation of southeasternmost Yukon (Fig. 5; Henderson et al., 1994). Correlations into the Arctic Islands have been reviewed recently by Beauchamp (fig. 2, 1995).

### *Longstick Formation (new name)*

#### *Definition*

Permian strata lying above the shale-dominant succession of the Upper member of the Jungle Creek Formation, but below Mesozoic beds, are herein designated the Longstick Formation. The formation is dominated by sandstone, with subordinate amounts of interbedded shale and limestone. The name is derived from a short tributary of Rat River, which originates on the dip slope of the type section, at DFA92-8 (Fig. 1) in the East Bear Creek valley, a few kilometres west of Mount Lang. Longstick River joins Rat River just before the latter enters the delta plain of Mackenzie River.

The type section is located in a prominent gully on the southern slopes of East Bear Creek (Fig. 22; Bear Creek is already in use as a formational name, hence

the need for another term), at latitude 67° 51' 48"N, longitude 135° 47' 12"W (UTM 7527400N, 466800E, map sheet 116M/13, 1:50 000 scale). Beds dip 8 to 10° to the southeast and the formation occurs in the middle to upper slopes of the gully, with the Jurassic Bug Creek Group forming the uppermost sandstone outcrops. Bug Creek strata disconformably overlie the Longstick Formation at the type section. This section is virtually the same as section 106M-7 in Bamber and Waterhouse (1971), although in the latter case, measurements appear to have been made on the western spur of the gully rather than in the gully.

At the type section (Fig. 12), the base of the formation is covered but it is assumed that the first outcrop of sandstone above the recessive weathering Upper Member of the Jungle Creek Formation is close to the base (Fig. 22). An outcrop containing the lower contact is present 1 km to the south, at section DFA96-1, where a transitional contact with the underlying Jungle Creek Formation is seen. Above the first sandstone outcrop at the type section the succession is almost entirely sandstone, with a few interbeds of argillaceous sandstone or siltstone in the first 53 m. The sandstones are very fine to fine grained and characteristically contains abundant *Zoophycus* trace fossils. Thoroughly bioturbated beds are the most common lithotype, although some beds contain low-angle crosslaminae. *Skolithus*-like trace fossils also are present in a significant number of beds. The contact with the Jurassic Bug Creek Group is erosional



**Figure 22.** Type area of the Longstick Formation on the southern slopes of East Bear Creek. Section DFA92-8. 1: Lower Paleozoic limestone and shale. 2: Lower member, Jungle Creek Formation. 3: Upper member, Jungle Creek Formation. 4: Longstick Formation. 5: Bug Creek Group. ISPG photo 4002-14.

and the first Jurassic bed is a conglomerate. Immediately overlying the basal Jurassic conglomerate, strata tend to be either conglomeratic, or coarse grained sandstone to granulestone. Also there is a distinct colour change, from dull brown in the Permian rocks to orange-red in the Jurassic strata. The Permian–Jurassic contact occurs about 200 m below the top of the ridge. This location contrasts with that on Norris' (1981f) map, where the Permian–Jurassic contact appears to be near the top of the ridge. A total of about 150 m of the Longstick Formation occurs in the type section. A more detailed description of the type section can be found in Appendix 1.

The Longstick Formation is equivalent to Bamber and Waterhouse's (1971) Sandstone Unit of the northern Richardson Mountains, and Mattner's (1990) *Zoophycus* Sandstone unit (map unit P4). Norris (1981e) incorporated Longstick strata into his map unit Pu, undifferentiated Permian.

### *Distribution*

The Longstick Formation is present throughout the northern Richardson Mountains, especially around the flanks of Scho, Rat, and White uplifts, and in parts of the subsurface of Mackenzie Delta. In the core of Cache Creek Uplift, Longstick strata are absent, primarily because of pre-Jurassic erosion. However, a possible change to a shalier facies may account for their absence in some areas.

Under Mackenzie Delta, the Longstick Formation is present in Beaverhouse Creek H-13, Ulu A-28, and Unak B-11 (Fig. 10). Elsewhere in the subsurface it has been eroded toward the basin margin, south and southeast of the three wells, and toward the Tununuk High in the north. In the known three subsurface occurrences, the Jurassic Bug Creek Group overlies the Longstick Formation.

Although there is no published confirmation of Longstick-like facies in the area from Salmon Cache Canyon on Porcupine River westward into the Keele Range, interpretation of aerial photographs in this area strongly favour its presence. However, details of the facies and thicknesses are lacking.

The contact between the Jungle Creek and Longstick formations varies from gradational to abrupt. In most of the outcrops where the contact has been seen it is gradational (Fig. 19). In the subsurface, the log character at Beaverhouse Creek 13 and Ulu A-28 suggest an abrupt contact (Fig. 10), whereas at Unak B-11 a gradational contact is apparent.

### *Lithology*

Throughout its known area of occurrence the Longstick Formation is dominated by very fine to fine grained, generally bioturbated sandstone. Most of the sandstone comprises quartz and chert grains and many beds contain glauconite, especially in the subsurface. Bioturbation ranges from moderate, where distinct burrow-types such as the ubiquitous *Zoophycus* and *Skolithus*-like burrows are readily identified, to thoroughly burrow mottled, where individual burrow-types are not readily distinguished. Only toward the basin margins are crossbedded sandstones preserved. Stratification consists mostly of sub-horizontal to low-angle crosslaminae. In some sections the stratified units occur in 15 to 50 cm thick beds with scoured basal contacts. Overlying each bed may be a thin coquina of brachiopod shell debris, which is in turn overlain by low-angle crosslaminated sandstone.

At only one section, DFA93-9B, at the east end of McDougall Pass, were facies coarser than the norm encountered. Here, small-pebble conglomerate, granulestone, and coarse to very coarse grained sandstone facies are interbedded with finer grained sandstone, argillaceous sandstone, and sandy shale. The coarser facies commonly occur in thin (few tens of cm to about 1 m), scour-based beds, usually in multistoried units. Stratification in the coarser facies generally is not visible, although trough crossbeds are present locally.

Around the east flank of the White Uplift, the Longstick Formation contains more interbedded shale intervals than to the south and southeast. Sandstone units generally are thoroughly bioturbated, although a few beds of stratified sandstone may be preserved. Stratification types include low-angle planar cross-laminae and hummocky cross-stratification. In this area, the shale-to-sandstone intervals form coarsening-upward cycles.

In the vicinity of Sheep Creek and Symmetry Mountain, on the north flank of Rat Uplift, and at Bamber's (1972) section 116P-11, on the west flank of Scho Uplift, limestone beds are present in the transitional strata between the Jungle Creek and Longstick formations, and in the lowermost beds of the latter (Figs. 10, 15). These are 10 to 50 cm thick beds of bioclastic limestone, commonly containing brachiopod and bivalve fragments. At Symmetry Mountain (section DFA93-4), the transitional beds consist of interbedded limestone, sandstone, and shale arranged in mesoscale (few metres thick), coarsening-upward cycles, all of which combine to form a large-scale, coarsening-upward succession.

## *Thickness*

As previously stated, the type area contains about 150 m of the Longstick Formation. A similar thickness was measured on the southwest and east flank of Rat Uplift (sections DFA92-6 and 93-9A). Bamber (1972) records about 400 m at section 116P-11 (section 11 on Norris' 1981e map), about 14 km northeast of DFA92-6, and just over 700 m at section 116P-6 (section 6 on Norris' 1981e map), about 5 km east of the White Uplift. The rapid northward thickening reflects basinward, stratigraphic thickening. Southward thinning is due to both depositional thinning and truncation at the pre-Jurassic unconformity. In the subsurface, Unak B-11 contains 316 m, Ulu A-35 360 m and Beaverhouse Creek H-13 341 m of Longstick strata.

## *Age and correlation*

Paleontological control in the Longstick Formation is very poor, because of a lack of micro- and macrofossils. At Bamber's (1972; also, Bamber and Waterhouse, 1971) section 116P-11, near Sheep Creek in the Rat Uplift, brachiopods of the *Lissochonetes* Zone were identified and dated as Ufimian (?Kungurian) (Bamber and Waterhouse, 1971). These fossils were recovered from limestone in the lowermost beds of the Longstick Formation. Bamber and Waterhouse (1971) have reported fossils from the *Crancrinelloides* Zone within the Longstick Formation (section 116P-6, east of the White Mountains, Fig. 13), which they date as Kazanian (Wordian). Attempts to identify palynomorphs from shales within the Longstick Formation adjacent to White Uplift were unsuccessful because of high levels of thermal alteration. Based on the limited data, the age span of the Longstick Formation is at least Kungurian to Kazanian.

Correlative strata are present in the upper beds of the Echooka Formation of the British Mountains and adjacent Alaska (Detterman et al., 1975), and in the Tahkandit Formation and Step Conglomerate of the northern Ogilvie Mountains and adjacent east-central Alaska (Bamber and Waterhouse, 1971; Brabb, 1969; Fig. 5). In the Selwyn Mountains, the upper part of the Mount Christie Formation contains equivalent beds (Gordey and Anderson, 1993), and in south-easternmost Yukon, the Fantasque Formation is age-equivalent (Henderson et al., 1994).

## *Lower/Middle Triassic*

Well dated Lower or Middle Triassic strata within the study area are uncommon. The Lower Triassic Ivishak

Formation (see description of the Sadlerochit Group) is believed to extend into the British Mountains, based on stratigraphic relations but without any paleontological support for the age designation. The only other known occurrence of possible Lower Triassic strata occurs in an isolated outcrop in the core of Cache Creek Uplift, at section DFA93-12 (Little Fish River). Here, a grey shale unit, located between rust-coloured, bioturbated siltstone to argillaceous, very fine grained sandstone and a cliff-forming, light grey, very fine to fine grained sandstone, contains palynomorphs with an age range of Early to Middle Triassic (J. Utting, pers. comm., 1994; sample C-231785). This Triassic shale lies between Permian (Jungle Creek Formation) below and presumed Jurassic (Bug Creek Group) strata above. The thickness of the Triassic shale is estimated to be between 20 and 30 m.

## *Middle/Upper Triassic*

At Salter Hill, on the east flank of the central Richardson Mountains, conodonts recovered from a sample of poorly exposed Triassic strata have a known age range of Ladinian to Carnian (M.J. Orchard, pers. comm., 1994; sample C-231726). This age range spans the Middle-Upper Triassic boundary, consequently the specific age of these rocks remains uncertain. The facies in these isolated exposures are dominated by thin beds of sandy bioclastic limestone (Fig. 23). Outcrops are only a few metres thick and it is estimated that there may be only about 5 to 10 m of Triassic strata preserved at Salter Hill, where they cap the tops of low-relief, rolling hills.

Norris (1981e) mapped an isolated and undated occurrence of Triassic strata on the west flank of the Richardson Mountains, just to the south of where the Dempster Highway crosses the contact between Devonian and Cretaceous strata. This outcrop is described as consisting of marine sandstone and limestone. It is the nearest Triassic outcrop to that at Salter Hill and its general lithological character is similar, leading to the speculation that it may be correlative with the Triassic of Salter Hill.

## *Upper Triassic-Shublik Formation*

### *Stratigraphic nomenclature*

Scattered throughout the British and Barn mountains are isolated outcrops of Upper Triassic strata, the bulk of which has been dated as Norian, and identified as the Shublik Formation (Norris, 1981a, b). An outcrop of Triassic strata near Fish Creek in the northern British Mountains, originally identified as part of the



**Figure 23.** Bioclastic limestone from the Triassic at Salter Hill. Section DFA92-2. Plane light. ISPG photo 4548-1.

Permian to Lower Triassic Sadlerochit Group (Norris, 1985), has recently been identified as a Carnian to Norian succession (Dixon et al., 1996). The age span of these Fish Creek strata falls within the Shublik Formation of the type area.

Shublik strata were originally defined from northeast Alaska (Detterman et al., 1975), where the formation is an Anisian to Norian (Middle to Upper Triassic) unit containing three members. In ascending order they are: the Anisian to Ladinian Siltstone member, the Carnian Limestone and dolostone member, and the Norian Clay shale member. The available age determinations for the Shublik Formation in the British and Barn mountains indicate that only equivalents of the Carnian to Norian part of the Shublik Formation are present. Dixon et al. (1996) pointed out that the rock types of the Shublik Formation in northern Yukon are very different from age-equivalent strata in northeast Alaska and questioned the validity of using the Shublik as a name for the Yukon strata. However, because the nomenclature has become embedded in the literature no changes were proposed, nor are they in this report.

### *Distribution and thickness*

As previously indicated, Upper Triassic Shublik strata are limited to the British and Barn mountains, unless the Triassic at Salter Hill is Carnian rather than Ladinian. The most extensive exposure occurs around the rim of Loney Syncline (Norris, 1981b), in the British Mountains. Here, principally Norian strata are reasonably well exposed in several stream-cut sections. At Loney Syncline the thickness of Shublik strata varies between 17 and 62 m (Fig. 24), the latter being the maximum measured at an incomplete section on the east side of Malcolm River (DFA88-10). The Shublik Formation at Loney Syncline unconformably overlies Paleozoic strata: Carboniferous limestone of the Lisburne Group in the southwest and west, and red, green, and grey phyllite and chert of the lower Paleozoic Neruokpuk Formation around the remainder of the syncline (Norris, 1981b). Disconformably overlying the Shublik Formation are shale and siltstone of the Lower Jurassic Kingak Formation.

About 15 km west-northwest of Loney Syncline, along the northern valley side of Fish Creek, are Carnian to Norian beds of the Shublik Formation (Dixon et al., 1996). This area contains about 220 m of Shublik strata, unconformably overlying the Carboniferous Lisburne Group and overthrust by Carboniferous Kayak shale.

Another area of well exposed Shublik strata is in the vicinity of the middle to upper reaches of Babbage River (Norris, 1981a). At a small gorge along Babbage River, there are about 61 m of well exposed Shublik Formation (Figs. 24 and 25, section DFA92-33; Norris' section A20, 1981a). A few kilometres upstream, in a section on the east bank of Babbage River (Norris' section A21, 1981a; Dixon's section DFA94-7), the Shublik has a similar thickness (49 m was measured, the remainder estimated). West and east of the Babbage River outcrops, strata mapped as Shublik Formation (Norris, 1981a) are generally poorly exposed, only a few metres thick, and tend to cap some of the low hills.

Isolated exposures of Norian strata only a few metres thick are present in the northwestern Barn Mountains (Norris, 1981a) and a single exposure of unknown thickness is present along the southern edge of the Barn Mountains, about 12 km east of Sam Lake (section DFA92-36).

### *Facies*

Facies within the Upper Triassic vary dramatically with location. In the vicinity of Fish Creek, the Carnian

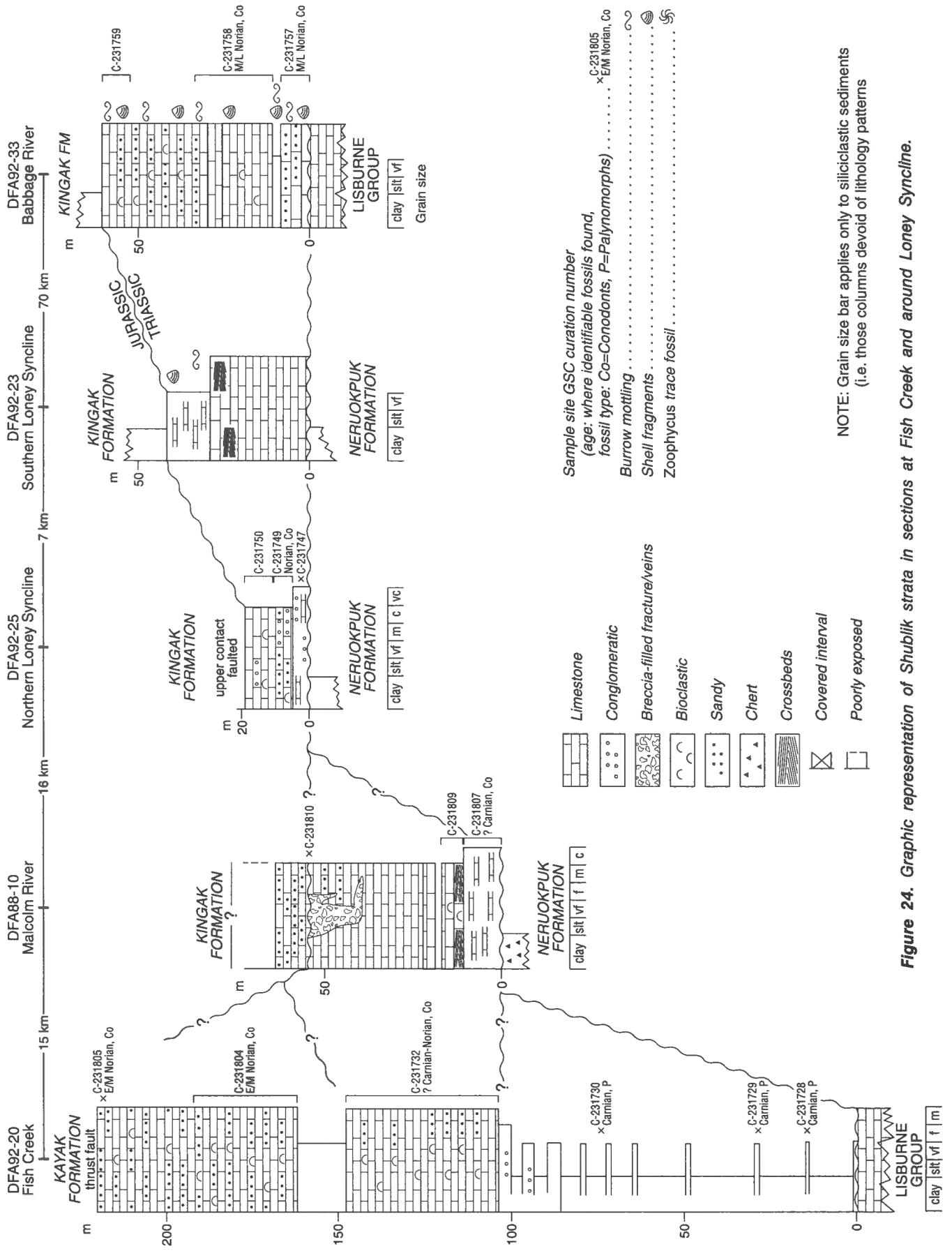


Figure 24. Graphic representation of Shublik strata in sections at Fish Creek and around Loney Syncline.

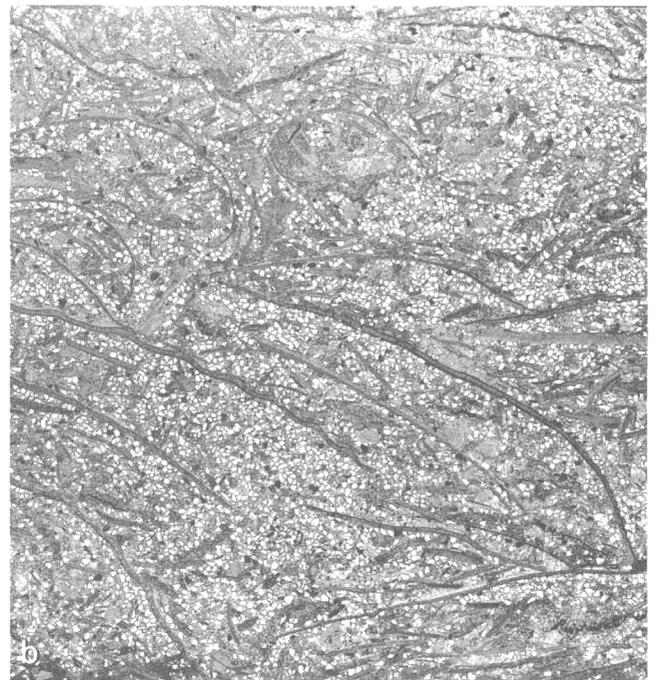


**Figure 25.** Shublik Formation at Babbage River, section DFA92-33. ISPG photo 4002-6.

consists of a very thin to moderately thick (few metres) basal sandstone, overlain by a shale succession with thin interbeds of fine to coarse grained sandstone, in turn gradationally overlain by sandstone (Fig. 24). The sandstone is apparently abruptly overlain by a limestone-dominant succession split into a lower and upper carbonate interval by a median sandstone unit (Fig. 24).

Beds from the lower carbonate interval consist of silty bioclastic limestone. Thin-walled bivalve shells and peloidal clasts “float” in a matrix of fine to medium crystalline calcite. Samples from the upper carbonate interval consist of a mixture of very fine grained, silty, calcite-cemented sandstone, bioclastic, very fine to fine grained sandstone, and sandy, bioclastic limestone.

In Loney Syncline, Shublik strata are a mixture of bioclastic limestone (Fig. 26a), sandy to pebbly bioclastic limestone, sandy to calcareous siltstone, calcareous, very fine grained sandstone, and locally, a thin basal conglomerate that fills in small depressions on the unconformity surface. At section DFA88-10, on the east bank of Malcolm River, there are thick, vertical to subhorizontal veins of limestone breccia (Fig. 27). The limestone beds contains bioclasts of bivalve shells, bryozoa and crinoidal debris in a medium to coarsely crystalline matrix. Extensive recrystallization is evident in many of the calcareous beds. Low-amplitude, hummocky cross-stratification is present in some of the limestone and sandstone beds. In other beds, only vague indications of laminae are present. Siltstone and very fine grained sandstone beds commonly are thoroughly bioturbated, and in some of these beds, shell impressions and debris of *Monotis* spp. are a common component (Fig. 26b).



**Figure 26.** Facies types within the Shublik Formation. a: Bioclastic limestone – clasts of bryozoa are abundant. Plane light. Section DFA92-25. ISPG photo 4548-5. b: Bioclastic siltstone. Thin bivalve shells in a carbonate-cemented siltstone. Plane light. Section DFA94-7. ISPG photo 4548-10.



**Figure 27.** Calcite and limestone breccia infilling vertical to subvertical fissures in the Shublik Formation. These breccias may have resulted from subaerial exposure at an intra-Norian unconformity. Section DFA88-10, Malcolm River. Markings on measuring staff are 10 cm apart. ISPG photo 4549-1.

In the sections along Babbage River, the dominant lithology is argillaceous to calcareous, coarse grained siltstone to very fine grained sandstone, and silty to sandy bioclastic limestone. The beds tend to be thoroughly bioturbated and contain few primary sedimentary structures. Brachiopod and bivalve shell debris or impressions are common in these beds.

Some of the isolated outcrops of strata mapped as Shublik Formation north and south of the Babbage River (Norris, 1981a) differ from the Shublik facies seen on the Babbage River sections. Outcrops generally consist of a few metres of siliceous, very fine grained sandstone, in contrast to the bioturbated siltstone, calcareous sandstone, and limestone of the Shublik Formation in the Babbage River sections. Few sedimentary structures are visible in these strata and only scattered occurrences of shell impressions were noted. The Norian age of these isolated outcrops remains uncertain – a Permian age is possible – and their correlation to the Shublik Formation also is tenuous.

The isolated Norian Shublik beds east of Sam Lake (section DFA92-36) contain three facies types. In vertical succession they are: dark rusty brown siltstone; light rusty brown, very fine grained sandstone with abundant impressions of *Monotis*, and a very light-grey weathering, siliceous, very fine grained, highly fractured sandstone that contains fine, sub-

horizontal laminae. The poor quality of the outcrop does not allow thicknesses to be accurately measured.

The very poorly exposed Triassic Shublik strata on the northwest flank of Barn Mountains contain very thin successions (a few metres) of siliceous, very fine to fine grained sandstone.

### *Age and correlation*

Norris (1981a, b) and Mountjoy (1967) indicated that many outcrops of Shublik strata contain Norian fossils. Only the strata at Fish Creek were reported to contain slightly older, Carnian, beds (Dixon et al., 1996). Many of the first age determinations were based on occurrences of *Monotis* spp. and *Halobia* spp., whereas conodont (M.J. Orchard, pers. comm., 1994) and palynomorph (E.H. Davies, pers. comm., 1994) identifications have been used for the present report.

Most sections of the Shublik Formation of Loney Syncline and on Babbage River are Middle or Late Norian in age (M.J. Orchard, pers. comm., 1994), with the exception of possible Carnian beds in the Malcolm River section (DFA88-10; sample C-231735 from the lowest beds; M.J. Orchard, pers. comm., 1995). The older age from the Malcolm River section could be interpreted in two ways: either the Carnian fauna was recycled into younger beds, or there is an older unit in the section at Malcolm River not present in the eastern sections of Loney Syncline. The latter scenario is feasible because the Malcolm River section is substantially thicker than the other Triassic sections measured around the eastern end of Loney Syncline. The implications of this will be discussed later.

The Shublik Formation at Fish Creek ranges in age from Carnian in its lower beds to Early Norian in the upper (Dixon et al., 1996). Palynomorphs from shale in the lowest beds indicate the Carnian age. The lower of the two limestone intervals may span the Carnian and Norian – a composite sample from this interval yielded Carnian and Lower Norian conodont elements. Better collections will be needed to resolve this problem. Conodonts from the upper limestone suggest an Early Norian age (Dixon et al., 1996).

### *Regional correlations of Triassic strata*

Triassic strata are not very widespread throughout the Yukon or mainland NWT. The nearest occurrences to those of the study area are unnamed successions in the northern Ogilvie Mountains (Norris, 1982a), and Tombstone Range and Rackla River area (Green, 1972;

Templeman-Kluit, 1970). Norris (op. cit.) indicated a Ladinian age for one of the Ogilvie Mountain occurrences, making it age-equivalent to part of the Shublik Formation. The Triassic of the Tombstone Range and Rackla River area is poorly dated but appears to span the Lower to Upper Triassic, making it correlative with both the Ivishak and Shublik formations.

Elsewhere in Canada's northern mainland, Triassic strata occur in only a few places: the Jones Lake Formation in the Selwyn Mountains (Fig. 5; Gordey and Anderson, 1993) and the Grayling, Toad and Liard formations of southeasternmost Yukon (Fig. 5). These southern areas of Triassic strata contain age-equivalents with both the Ivishak and Shublik formations.

## Depositional history

### Permian

Very little evidence is available to indicate that the Permian of the British and northern Richardson mountains contains widespread, internal discontinuities. Consequently, in a general sense, the Echooka, Jungle Creek, and Longstick formations record an overall, large-scale, transgressive-regressive (TR) cycle of sedimentation for the Permian period, a similar interpretation to that presented by Richards et al. (1997). This is in contrast to the Permian of western and Arctic Canada (Henderson et al., 1993, 1994; Beauchamp, 1995), where several internal unconformities have been recognized, dividing the Permian succession into a number of TR cycles. In the northern Ogilvie Mountains and adjacent Alaska an unconformity is present between the Step Conglomerate and older strata (Brabb, 1969).

The Lower member of the Jungle Creek Formation and basal sandy beds of the Joe Creek Member, Echooka Formation, record the transgressive phase of the TR cycle. Transgression began in the Asselian in the northern Ogilvie Mountains and Peel River area, possibly not reaching the northern Richardson Mountains until the Sakmarian. In most places, the top of these basal sandy beds is marked by an abrupt change to silty and shaly beds, reflecting a more basinward position and lower levels of depositional energy. The shale-dominant succession of the Joe Creek Member (Echooka Formation) and Upper member of the Jungle Creek Formation, represent the more basinward deposits of the regressive phase of sedimentation, which lasted from Sakmarian to Artinskian time. However, the presence of mesoscale

coarsening-upward cycles within the shaly succession indicates that there are lower order TR cycles present, although whether these are local or regional in extent is still an open question. Finally, the Longstick Formation and Ikiakpaurak Member of the Echooka Formation represent the final regressive phase, being deposited as inner shelf to shoreline sands that prograded basinward. This final regressive phase lasted from the Kungurian to at least the Kazanian.

The transgressive deposits are the most varied of the Permian facies (Fig. 28; i.e., the Lower member of the Jungle Creek Formation, and the basal beds of the Joe Creek Member, Echooka Formation). In the Aklavik Range and extending into the eastern end of McDougall Pass, the Lower member of the Jungle Creek Formation contains redbeds interpreted as having been deposited on coastal alluvial fans or small fan-deltas at the basin margin (Fig. 28). The abundance of debris-flow deposits and possible paleosols in these beds suggest a generally dry climate with periods of heavy rainfall, resulting in intense flooding and rapid runoff. Southwest of the redbeds, strata of the Lower member become grey and show evidence of more fluvial deposition, along with some mass-wasting deposits. Here, the basin margin beds were probably deposited as fan-delta beds, with a mix of braided stream and debris-flow deposition.

There is a rapid change northward and north-westward into nearshore deposits (Fig. 28), with only a few places known where redbeds and nearshore strata are interbedded (e.g., a short distance southwest of Jurassic Butte, section DFA92-17). Farther north, the shoreline to nearshore siliciclastic deposits are replaced laterally by shallow-water, inner shelf, calcareous sandstones and sandy limestone beds. The presence of hummocky cross-stratification in some of these beds indicates deposition below normal wave-base (i.e., shallow subtidal). This mixed facies is also typical of some of the more northerly subsurface occurrences.

In many of the more basinward locations, the lowermost transgressive beds are capped by a limestone. This limestone commonly contains *Palaeoaplysina*, plus corals, brachiopods, and foraminifers. The limestone is interpreted as representing a major flooding event, with the maximum flooding surface commonly occurring a short vertical distance above the limestone bed, usually at the top of a succession of interbedded shale, siltstone, and thin sandstone interbeds (Figs. 8, 10). In basin margin positions, the transgressive beds are abruptly overlain by shale, without an intervening limestone. Here, the shale-on-sandstone contact is considered to be the maximum flooding surface.

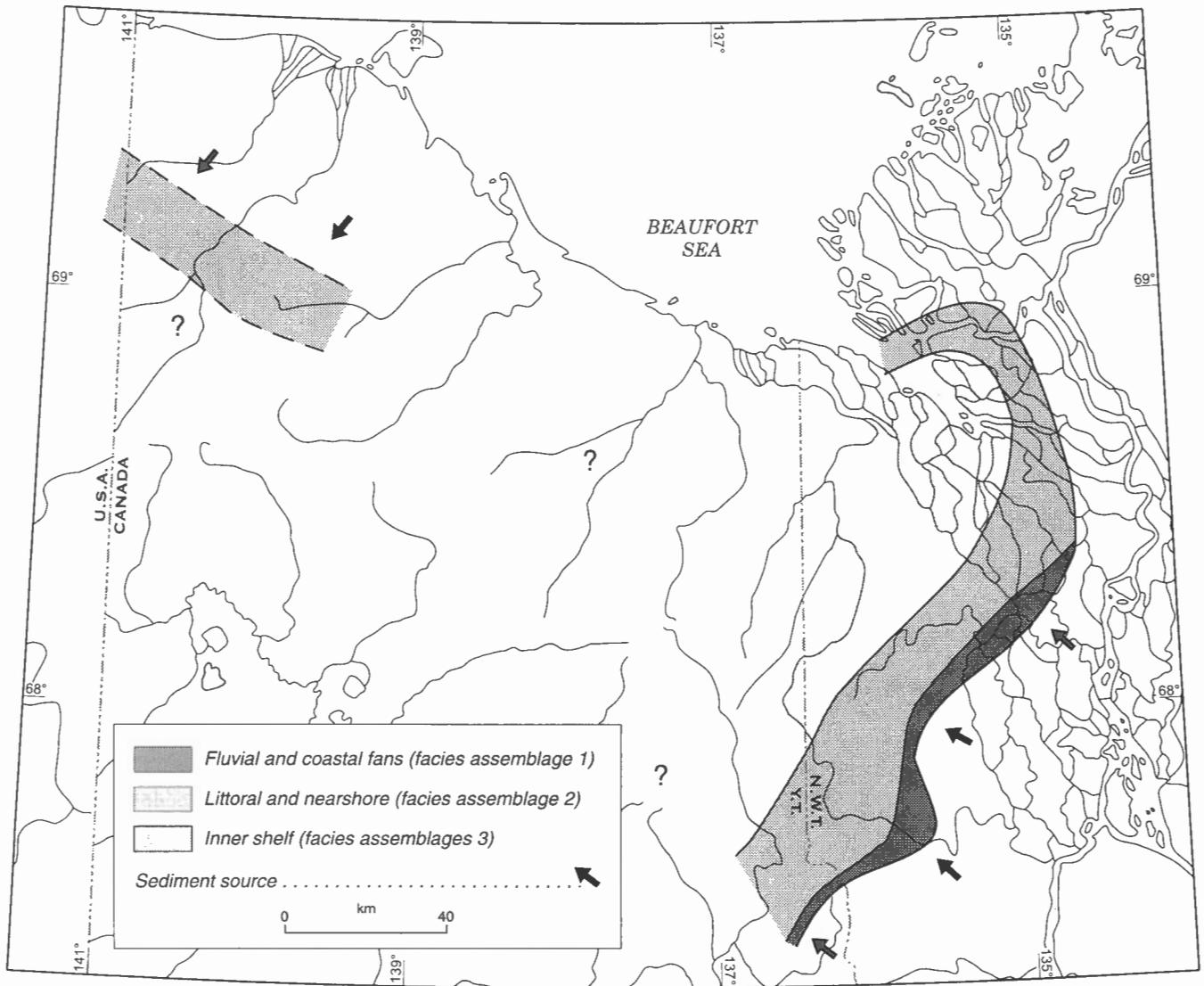


Figure 28. Distribution of Asselian-Sakmarian depositional facies.

Thicknesses of the basal beds are quite variable, even between closely spaced sites. This suggests that the basal unconformity has some low-relief topography.

In the Richardson Mountains and adjacent subsurface, immediately overlying the basal beds, the lower 50 to 200 m of the Upper member, Jungle Creek Formation generally contains one to three coarsening-upward cycles (Figs. 8, 10). In the Kupik O-13 and L-24, and Tullugak K-31 wells, this interval is very sandy (Fig. 10) and appears to indicate proximity to a northern shoreline. At section 116P-10 (Fig. 13: Bamber, 1972) the possibly correlative interval consists of interbedded sandstone and limestone. The sandy beds in the basal part of the Upper member are interpreted as indicating minor phases of regression.

The bulk of the Upper member (Jungle Creek Formation) consists of low-energy shelf deposits (shale

onto which a few regressive sandstone wedges prograded. Although the sandy coarsening-upward units within the Upper member are locally prominent, their correlation between sections is not possible with presently available stratigraphic controls; consequently their regional significance is not known.

In most areas, the change from the shale-dominant shelf deposits of the Upper member, to sandstone-dominant, nearshore to shoreline deposits of the Longstick Formation is gradational. However, in the Kandik area of eastern Alaska, the age-equivalent Step Conglomerate rests unconformably on older beds (Bräbb, 1969). In northeastern Alaska, the correlative Ikiakpaurak Member of the Echooka Formation overlaps the Joe Creek Member northward, indicating the presence of an unconformity. The available paleontological data and regional considerations (Detterman et al., 1975) indicate that the unconformity developed during the Roadian. Beauchamp (1995) has shown that there is a Roadian unconformity within the

Sverdrup Basin succession. This event appears to be approximately co-eval between these widely spaced areas. In the Richardson and British mountains this event is difficult to recognize with the presently available data. Only at Beaverhouse Creek H-13 and Ulu A-35 (Fig. 10) is there any indication for an abrupt, possibly erosional, base to the Longstick Formation. If such an unconformity is present in the Longstick Formation it is probably located within the lower beds, rather than at the base of the formation. For example, in sections 116P-9 and 11 (Fig. 13; Bamber, 1972), the lowermost strata of the Longstick Formation contain significant amounts of interbedded limestone abruptly overlain by sandstone. This abrupt change in facies could reflect the erosional event seen elsewhere in the Arctic areas. The age of these limestone beds (Kungurian) is consistent with such an hypothesis.

The overall Permian history outlined above for the Richardson Mountains succession is similar to that recorded in the Echooka Formation of the British Mountains, except in the latter area the succession is much thinner. Also, the transgressive beds in the Echooka Formation are less prominent and in places are represented only by a very thin bed of sandstone. In adjacent Alaska, the northward overlap of Joe Creek beds by Ikiakpuarak strata is well documented, but in the British Mountains there are no biostratigraphic data to confirm the presence of a similar stratigraphic geometry. However, the Permian and presumed Permian strata in the vicinity of Mount Sedgwick and Babbage River could be interpreted to infer similar relations. If this stratigraphy is correct then the northern source terrain identified from the Permian stratigraphy of northern Alaska can be continued into northwest Yukon.

### *Triassic*

Because of the highly scattered distribution, thin successions, and differing ages of the Triassic outcrops in the study area, interpreting a cogent depositional history is difficult. In general, the Triassic sediments indicate a period of marine sedimentation on an inner shelf setting. The apparent northward overlap of Lower Triassic by Carnian to Norian strata in the British Mountains also suggests the presence of a northerly land area. However, the eastward overlap of Carnian and Lower Norian strata by Middle/Upper Norian beds indicates a shift in the orientation of the possible land area during the Carnian and Norian to a more easterly direction. The possible Ladinian or Carnian deposits at Salter Hill also seem to indicate a nearshore environment, presumably close to an eastern shoreline.

The differing ages and overlapping relations are strong indicators of the presence of significant discontinuities in the Triassic succession (Figs. 4, 19). The most obvious discontinuity is between the Lower Triassic Ivishak Formation and the Upper Triassic Shublik Formation. Within the Carnian to Lower Norian succession at Fish Creek, the abrupt switch from siliciclastic to carbonate sediments could indicate a discontinuity in sedimentation. Also, the reappearance of a thick sandstone unit within the carbonates likewise may indicate another discontinuity. The eastward overlap of Carnian/Lower Norian by Middle/Upper Norian strata at Loney Syncline indicates the presence of a Middle Norian unconformity. At the Malcolm River locality (DFA88-10), the possible Carnian succession contains breccia-filled vertical to subhorizontal joints and pipes overlain by a poorly exposed interval of sandy limestone with no breccia. These breccia-filled pipes could have resulted from the development of a subaerial unconformity between ?Carnian and Middle/Upper Norian beds.

In summary, the available data indicate that the Triassic succession of the British and Richardson mountains contains at least two reasonably well identified unconformities, one between Lower and Upper Triassic strata, and the other below Middle/Upper Norian beds. Two others may be present, but the evidence is more tenuous. The first one is within the upper Carnian or between Carnian and Norian beds, and the second within Lower Norian strata.

### **THE PERMIAN "ANCESTRAL AKLAVIK ARCH"**

Bamber and Waterhouse (1971) identified the Ancestral Aklavik Arch as a major Permian tectonic element of the northern Yukon. Their interpretation has been reiterated by subsequent workers (Henderson et al., 1993; Richards et al., 1997). The original identification of the arch was based mainly on rapid thinning of Permian strata between sections 117A-5 and 106M-7, and thickening again southwest of the 106M-7 section (Bamber and Waterhouse, 1971, fig. 10). The distribution of Asselian and Sakmarian coarse grained clastics in the vicinity of Porcupine River and the 106M-7 section (op. cit., fig. 15) also was used to interpret the presence of an arch. At the time of the interpretation there was a lack of knowledge about the Permian under Eagle Plain (indicated by Bamber and Waterhouse to be an area of eroded Permian; op. cit., fig. 15). Subsequent to Bamber and Waterhouse's work, two new pieces of information became available. Firstly, Permian strata have been identified under Eagle Plain (Martin, 1973; Graham,

1973; Pugh, 1983), and there, the Asselian-Sakmarian facies are predominantly conglomerate and sandstone (see South Chance D-63 on Fig. 9 for an example of the rock types in the Lower member of the Jungle Creek Formation under Eagle Plain). Secondly, the critical section at 106M-7 has been re-examined by the author (section DFA92-8, Fig. 12) and the Permian is thicker than Bamber and Waterhouse illustrated. The section contains a typical Permian succession consisting of a basal coarse grained siliciclastic interval overlain by a shale succession (these two intervals are the Lower and Upper members of the Jungle Creek Formation respectively), in turn overlain by sandstone of the Longstick Formation. It would appear that only the sandstone succession of the Longstick Formation was recorded in section 106M-7 (described more completely in Bamber, 1972), and that the underlying Permian Jungle Creek Formation was not recognized. Although section 106M-7 is now known to contain a thicker and more complete Permian succession, strata still thin towards this location, but in a less pronounced way than previously thought.

The new data indicate a much reduced thinning trend toward the site of the presumed Ancestral Aklavik Arch and a more widespread distribution of Asselian-Sakmarian coarse grained clastics. These data can be interpreted to suggest that the arch may not have been the prominent Permian feature Bamber and Waterhouse (1971) presented. Alternatively, it is possible to interpret the new data to show that the arch may not have existed during the Permian. The distribution of Asselian-Sakmarian siliciclastic facies (Fig. 28) could be interpreted as indicating that the thinning trend documented by Bamber and Waterhouse over the Ancestral Aklavik Arch is no more than thinning towards the basin margin. The Asselian-Sakmarian coarse grained facies would be interpreted as nonmarine to marginal-marine deposits adjacent to the basin margin, rather than flanking an arch (Fig. 28).

## ECONOMIC GEOLOGY

The hydrocarbon and mineral potential of Permian and Triassic strata in the northern Yukon and adjacent Northwest Territories is not considered to be high. No economically important mineral showings have been seen by the author, or reported elsewhere.

The few Rock-Eval analyses available from GSC files for subsurface Permian strata do not indicate much source rock potential for hydrocarbons. However, if there are areas with unidentified potential source rock in Mackenzie Delta, the thermal maturity of Permian rocks is not particularly high. A TAI of

2+ has been reported for shales in the Longstick Formation of the Beaverhouse Creek H-13 well (J. Utting, pers. comm.). This indicates that the rocks are within the oil window of thermal alteration. In outcrops of the nearby northern Richardson Mountains, the thermal alteration of Permian strata is similar to that of the subsurface. However, thermal alteration increases rapidly to the south, and in the vicinity of the White and Rat uplifts TAI values of 4 or more have been noted from outcrop samples (J. Utting, pers. comm.).

Potential reservoir rocks are present in the Lower member of the Jungle Creek Formation and in the Longstick Formation. Truncation of the latter limits the area of preservation in the subsurface and extensive silica cementation appears to be common in these beds, consequently porosity values are low. Strata of the Lower member (Jungle Creek Formation) are more extensively preserved in the subsurface and the presence of calcareous beds and calcite cement in sandstones could favour the development of secondary porosity. However, porous beds seem to be lacking in the wells that have penetrated this interval. Although the Upper member of the Jungle Creek Formation is normally shale-rich, in the Kugpik area this member contains sandstone units that could be potential reservoirs if porous sandstones are present.

No Triassic strata are known from the subsurface and the regional geology suggests that they are unlikely to be present under Mackenzie Delta. The extension of Triassic strata into the subsurface north of the British Mountains is also considered to be unlikely, as a result of the northward truncation trend seen in outcrop. Also, the TAI of Triassic strata in the British Mountains is very high (4 or more). If present in the offshore they would be buried under a very thick Jurassic to Tertiary succession (Dixon et al., 1992). Porous beds within the known Triassic are not very common.

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# APPENDIX 1

## Field description of the type section of the Longstick Formation

### Section DFA92-8

Headwaters of East Bear Creek, Richardson Mountains, Northwest Territories. This section is in close proximity to section 7 on D.K. Norris' (1981f) geological map (GSC map 1520A).

Lat. 67°51'48"N, Long. 135°47'12" – this is the location of our campsite and the co-ordinates were obtained using a helicopter-mounted Global Positioning System. The actual measured section is located about 0.5 km to the west, in a prominent gully.

NTS map: 116M/13

UTM: 7527400N 466800E

Strata: Jungle Creek and Longstick formations (Permian); Bug Creek Group (Jurassic)

Unit	Thickness (m)	Ht. above base (m)	Description
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### JUNGLE CREEK FORMATION (PERMIAN)

Lower member

1 15 incomplete

**Redbeds:** poorly exposed, talus covered.

Red breccia and mudstone with some green beds. Angular to subangular, tabular to blocky clasts of black chert; varies from clast to matrix supported. Clast size ranges from granule to cobble grade but most are 1–3 cm. Breccias are crudely bedded with no apparent internal fabric. Matrix-supported breccias tend to be green. Base not exposed but there are underlying lower Paleozoic black shales and chert in nearby outcrops. Top not exposed.

Upper member

2 Not measured

**Covered:** vegetated. Some local talus and small exposures of shale.

Estimate about 190 m of Jungle Creek Formation.

Measurements begin at first sandstone exposure in the gully. The traverse was done primarily on the west (right) side of the gully, until near the top of the section. Although the actual contact between Jungle Creek and Longstick strata is covered at the type section, about 1 km to the south, on a west-facing slope, the contact is exposed (section (DFA96-1). At this latter section a gradational change from the shale-dominant Jungle Creek Formation to sandstone-dominant Longstick Formation is evident.

### LONGSTICK FORMATION (PERMIAN)

3	7.2	7.2	<b>Sandstone:</b> fine grained, siliceous. Poor quality exposure. Low-angle cross-stratification. Small, oxidized mudstone clasts at the base of some beds: few mm to 4 cm in diameter, well rounded, flat. Slight pinkish hue commonly giving banded appearance. Bedding difficult to see.
4	0.5	7.7	<b>Sandstone:</b> thin bedded. Very fine to fine grained. Slightly recessive. Shaly partings between beds. Poorly exposed.
5	17.0	24.7	<b>Sandstone:</b> cf. unit 3.
6	28.5	53.2	<b>Recessive:</b> scattered outcrops of thin bedded, argillaceous, very fine grained sandstone and thin shaly/silty beds. Gradual upward increase in sandstone content. Thoroughly bioturbated sandstone. Trace of crosslaminae. Talus contains an abundance of <i>Zoophycus</i> trace fossil.
7	6.7	59.9	<b>Sandstone:</b> Irregularly bedded. Dirty brown colour. Very fine grained. Argillaceous. Thoroughly bioturbated. Abundant <i>Zoophycus</i> . Upper part of interval mostly talus covered.

8	16.0	75.9	<b>Sandstone:</b> gradational change from unit 7 into the sandstone-dominant interval of unit 8. Beds tend to be thicker and less irregularly bedded than in unit 7. Thoroughly bioturbated. Abundant <i>Zoophycus</i> in talus and some long, thin vertical burrows. A few beds contain crosslaminae. There is a prominent 1 m thick laminated bed about 8.5 m above base of unit.
9	39.0	114.9	<b>Sandstone:</b> massive appearance; "clean", fine grained. Slight reddish hue and oxidation banding. About 32 m above base there are in situ <i>Zoophycus</i> within "clean" sandstone. At about 37 m above base of unit there are abundant long, narrow vertical burrows that predominate in the uppermost 2 m. Generally poor quality outcrop. Difficult to see sedimentary structures in most of interval. Some beds of fine, low-angle crosslaminae. In at least one interval, approximately within the middle of unit 9, there are 20–30 cm thick beds, each bed consisting of a basal scour overlain by 2–5 cm of granules and scattered pebbles (chert, sandstone, quartzite), in turn overlain by finely crosslaminated sandstone.
10	1.5	116.4	<b>Bioturbated sandstone:</b> grey. Argillaceous. Abundant vertical burrows and <i>Zoophycus</i> . Base not exposed.
11	3.0	119.4	<b>Burrowed sandstone:</b> "cleaner" than unit 10. Dominated by vertical burrows with some <i>Zoophycus</i> . Abrupt, uneven base. Grey weathering.
12	10.5	129.9	<b>Talus:</b> with a few outcrops of burrowed, very fine to fine grained sandstone containing long, narrow, vertical burrows and some <i>Zoophycus</i> .
13	16.5	146.4	<b>Sandstone:</b> very fine to fine grained. Indistinct bedding. Abundant long, narrow, vertical burrows in all beds but more abundant in beds with low abundance of <i>Zoophycus</i> . Intervals with a low abundance of <i>Zoophycus</i> alternate with intervals richer in <i>Zoophycus</i> .
14	0.8	147.2	<b>Sandstone:</b> very fine grained. Fine subhorizontal and low-angle crosslaminae. Capped by <i>Zoophycus</i> -bearing bioturbated bed.
15	2.2	149.4	<b>Sandstone:</b> very fine to fine grained. Vertical burrows and <i>Zoophycus</i> . Some remnant laminae.

### BUG CREEK GROUP (JURASSIC)

Abrupt, erosional, unconformity surface.

16	6.0	155.4	<b>Conglomerate:</b> dark reddish brown weathering. Crudely bedded. Pebbles of chert, red mudstone, sandstone and vein quartz. Clasts up to large pebble/small cobble grade; mostly pebble sized.
17	27.0	182.4	<b>Talus:</b> distinct, orange-brown weathering sandstone with some beds of grey granulestone/small-pebble conglomerate.
18	4.5	186.9	<b>Granulestone-conglomerate:</b> Small pebbles. Pebbles mostly chert with some oxidized mud clasts. Matrix of fine to granular sand. Subhorizontal bedding with at least one 50 cm thick planar cross-stratified bed. Slight reddish hue.
20	Not measured		Talus slope.

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End of measurements

Bug Creek strata are reasonably well exposed at the top of the ridge and consist mostly of sandstone. The base of of the Bug Creek Group is at least 200 m below the crest of the ridge—this contrasts with Norris' (1981f) map (GSC map 1520A) where the contact is placed at the top of the ridge.