Devonian–Carboniferous paleogeography and orogenesis, northern Yukon and adjacent Arctic Alaska[1]

Larry S. Lane

Abstract: Surface and subsurface data from northern Yukon document a northward facies transition from shelf carbonates to basinal graptolitic shales and cherts from Late Cambrian to Early Devonian time. Parts of this north-facing continental margin were deformed during separate orogenic events of Early Devonian and Early Carboniferous ages. The first event, the Romanzof Orogeny, is identified in exposures across northwestern Yukon, in adjacent northeastern Alaska, and locally in the subsurface of the Alaska North Slope. It resulted in tight folds, north-directed thrust faults, and intrusion by Late Devonian posttectonic granitic plutons. Notwithstanding the thrust-fault orientations, southward diminution of deformation intensity combined with facies variations suggest that tectonic transport was generally southward. Evidence for an Early Carboniferous event is preserved in the northern Richardson Mountains and locally in the subsurface of the Mackenzie Delta region. It consists of detached open folds and minor thrust faults. Geological and geophysical data from northern Yukon document the location and orientation of the Early Carboniferous deformation front, and define a regional tectonic transport direction toward the south or southeast. This event is a distal foreland element of the Ellesmerian Orogeny (sensu stricto) of the Canadian Arctic Islands and is distinct from the Romanzof event in age, intensity, and extent. Endicott and Lisburne group strata, deposited on a southwest-facing subsiding shelf, overstep rocks deformed by the Romanzof event even as Ellesmerian deformation encroached from the north.

Résumé : Des données de surface et de subsurface du nord du Yukon documentent, entre le Cambrien tardif et le Dévonien précoce, une transition de faciès, en direction nord, de carbonates de plate-forme à des schistes graptolitiques de bassins et des cherts. Des parties de cette bordure continentale faisant face au nord ont été déformées durant des événements orogéniques distincts du Dévonien précoce et du Carbonifère précoce. Le premier événement, l’orogène de Romanzof, est identifié dans des affleurements à travers la partie nord-ouest du Yukon, dans le nord-est de l’Alaska avoisinant et localement dans la subsurface du versant nord de l’Alaska. Cet orogène a produit des plis serrés, des failles de chevauchement vers le nord et l’intrusion de plutons granitiques post-tectoniques au Dévonien tardif. Malgré l’orientation des failles de chevauchement, la diminution vers le sud de l’intensité de déformation et des variations de faciès suggèrent que le transport tectonique ait été généralement vers le sud. Des preuves pour un événement au Carbonifère précoce sont préservées dans le nord des monts Richardson et localement dans la subsurface de la région du delta du Mackenzie. Ces preuves comprennent des plis ouverts détachés et des failles de chevauchement mineures. Des données géologiques et géophysiques du nord du Yukon documentent l’emplacement et l’orientation du front de déformation au Carbonifère précoce et elles définissent une direction régionale de transport tectonique vers le sud ou le sud-est. Cet événement est un élément distal d’avant-pays de l’orogène ellesmérien (proprement dit) des îles de l’Arctique canadien et il est distinct de l’événement Romanzof en âge, en intensité et en étendue. Les strates des groupes d’Endicott et de Lisburne, déposées sur une plate-forme en effondrement orientée vers le sud-ouest, transgressaient les roches déformées par l’événement Romanzof alors même que la déformation ellesmérienne empiétait en venant du nord.

[Traduit par la Rédaction]

Introduction

The early Paleozoic paleogeography of northern Yukon and adjacent Arctic Alaska (Fig. 1) is well established in terms of its large-scale regional framework. However, a detailed understanding of the region’s complex pre-Carboniferous structural evolution is lacking, and thus its potential significance for constraining the tectonic evolution of the Arctic region has been largely overlooked (Moore et al. 1994, pp. 112–114; Lane 1997). Although pre-Carboniferous rocks are widespread in the subsurface of the Alaska North Slope (Carter and Laufeld 1975; Dumoulin et al. 2000) and exposed in numerous thrust slices within the Brooks Range, they are most continuously exposed in the northeastern Brooks Range of Alaska and the British, Barn and Richardson mountains of northern Yukon Territory (Lenz 1972; Reiser et al. 1980; Norris 1984; Moore et al. 1994; Lane et al. 1995). In the British Mountains, pre-Carboniferous structures strike approximately east–west. Tight folds are predominantly

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L.S. Lane. Geological Survey of Canada, Calgary, AB T2L 2A7, Canada. (e-mail: llane@nrcan.gc.ca).

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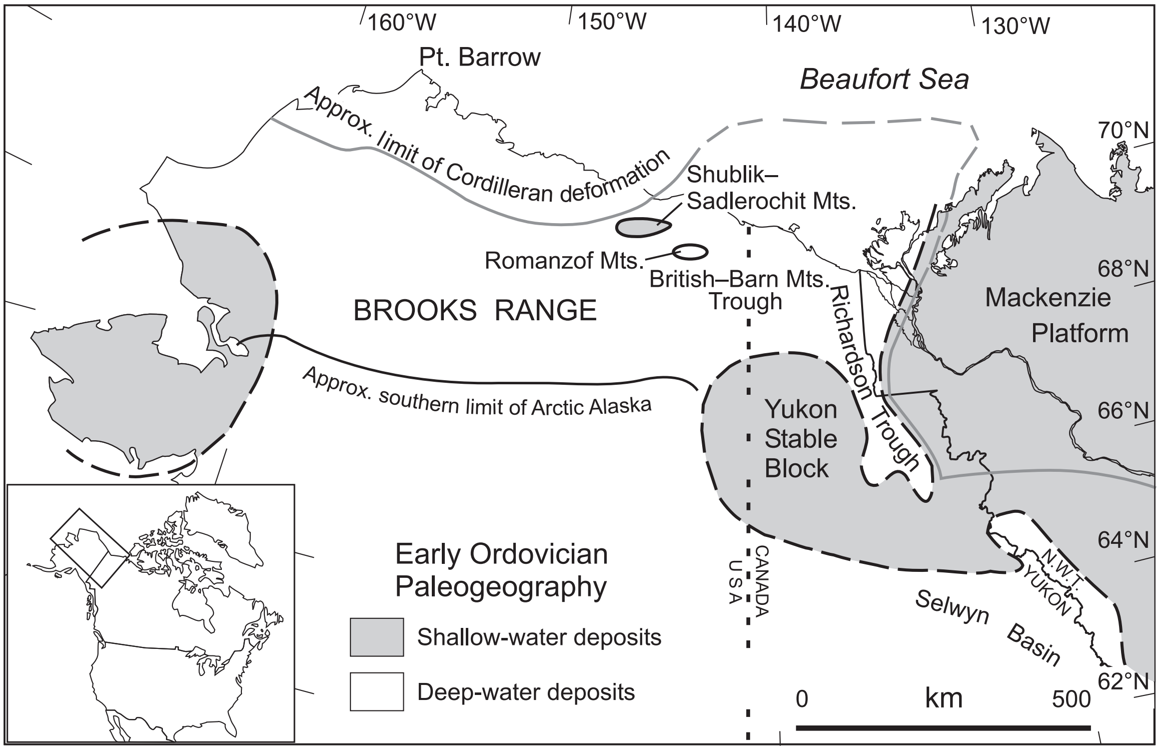
Fig. 1. Arctic Alaska and northern Yukon with generalized distribution of Early Ordovician facies and major tectonic elements of Paleozoic age; local areas of shallow-water carbonate deposition in the central Brooks Range are omitted for clarity. Substantial Mesozoic–Tertiary northward shortening in the Brooks Range and early Tertiary eastward shortening in Yukon Stable Block (not restored) have resulted in modifications to the original positions of the facies boundaries (compiled from Dumoulin and Harris 1994; Cecile and Norford 1993).



upright but thrust faults are dominantly north-directed, a fact which has contributed to previous interpretations that Paleozoic structures formed by closure of an ocean basin adjacent to a south-facing convergent continental margin (present coordinates) across Arctic Alaska (Moore et al. 1994, p. 113; Plafker and Berg 1994, p. 1006). In contrast to some Alaskan researchers, Bell (1973) considered Paleozoic convergent deformation in northern Yukon to have a southward tectonic transport, primarily based on exposures in the northern Richardson Mountains (Richardson Trough, Fig. 1).

Although both sets of structures have traditionally been attributed to Ellesmerian orogenesis, best developed in the Canadian Arctic islands, their local expression has contributed to these differing opinions about the regional tectonic setting. This paper examines the basis for that difference of opinion—two distinct events of different ages are recorded across the region. Reprocessed petroleum industry seismic data, together with previously published and new geological data, help to constrain the regional distribution and kinematics of Early Devonian and Early Carboniferous deformation events in Alaska, northern Yukon, and adjacent Northwest Territories. This paper synthesizes these data and discusses some implications for the plate tectonic evolution of northwestern North America.

In the Arctic region, pre-Carboniferous tectonic evolution and paleogeography are very poorly understood, resulting in uncertainties in regional correlations. A fuller understanding of local and regional tectonic evolution is an essential step in making interregional correlations and validating models of Arctic tectonic evolution. Improved syntheses and new regional correlations have important impacts on exploration strategies in the resource sector, and can lead to improved models of basin evolution and the delineation of new play concepts.

Paleogeographic setting

Aspects of the Paleozoic paleogeography of northern Yukon are summarized in several reviews (Fritz et al. 1991; Lane 1991; Cecile and Norford 1993). The existence of an early Paleozoic north-facing transition from carbonate shelf to shale–chert basin is well established (Fig. 1). Lenz (1972) showed that the Richardson Trough opened northward and was continuous with the British–Barn Mountains Trough of northern Yukon (Fig. 1). Churkin (1975) suggested that the British–Barn Mountains Trough continued in the subsurface of Arctic Alaska westward at least as far as Point Barrow (Fig. 1), and constituted part of a widespread basinal facies. He further considered that the Richardson Trough was a failed rift related to the evolution of a Paleozoic paleo-Arctic (Franklinian) ocean. His analysis was essentially a plate tectonic reformulation of an earlier synthesis (Martin 1959, p. 2435).

More recent work in Arctic Alaska documented widespread Ordovician deep-water facies (Reiser et al. 1980; Carter and Tailleur 1984; Moore and Churkin 1984; Harris et al. 1995) (Fig. 1). However, in the central Brooks Range, evidence indicates a shallowing upward trend through the

Ordovician (Dumoulin and Harris 1994; Harris et al. 1995). Also, recent work in the British Mountains has confirmed the widespread distribution of basin facies Ordovician and Silurian strata and extended the age of known continental slope and basin facies at least as far back as Early Cambrian time (Kelley et al. 1994; Hofmann et al. 1994; Lane et al. 1995), and probably as early as Late Proterozoic (Windermere) time (D.K. Norris 1985; Lane 1991).

The distribution of shelf carbonate rocks, and the transition to shale facies is constrained by regional mapping in northern Yukon and adjacent Alaska (Brosgé and Reiser 1969; Brabb 1970; Brosgé et al. 1976; Norris 1981*a*, 1981*b*, 1981*c*, 1981*d*, 1981*e*). The Yukon Stable Block of northern Yukon (Fig. 1) was a prominent stable shelf area during Late Cambrian to Early Devonian time (Cecile and Norford 1993; Morrow 1999). The north-facing early Paleozoic carbonate–shale facies transition on the northern margin of Yukon Stable Block is preserved in the subsurface and is visible in seismic reflection profiles from northeastern Eagle Plain (Lane 1996). In particular, the distribution and facies variations of Early Devonian rocks in northwestern Canada have been extensively studied, based on surface and subsurface data (Pugh 1983; A.W. Norris 1985; Morrow 1999). The north-facing carbonate to shale transition marking the northern margin of Yukon Stable Block is located near 67° north (present coordinates) for much of the Early Devonian, but it expands northward in Emsian (late Early Devonian) time (Fig. 2). By Givetian (late Middle Devonian) time, regional transgression resulted in widespread drowning of carbonate platforms and deposition of black organic shale of the Canol Formation (Morrow 1999).

Paleozoic orogenesis

Evidence for Devonian tectonism is widespread across northern Yukon and eastern Arctic Alaska (Martin 1959; Gabrielse 1967; Norris and Dyke 1987; Moore et al. 1994). However, because of intense overprinting by Mesozoic–Cenozoic structures, the extent and character of Devonian events largely have been obscured in Alaska. In northern Yukon, Mesozoic–Cenozoic deformation intensity is relatively low and affects mainly shallow structural levels (Lane and Dietrich 1995; Lane 1996, 1998). In this region, Paleozoic structures are more easily distinguished. The following sections document temporally and spatially distinct Devonian and Carboniferous deformation events in northern Yukon.

Romanzof Orogeny (Early Devonian)

Structures characterizing the Romanzof Orogeny are found in the British Mountains of northwestern Yukon, in the contiguous Romanzof Mountains of adjacent Alaska (Fig. 1), and in the nearby Barn Mountains to the east (Fig. 3). As exposed in a Tertiary structural culmination in the British Mountains, Devonian thrust faults and tight to isoclinal folds have duplicated and thickened latest Proterozoic to Early Devonian rocks (Fig. 3). Structural trends are eastward to southeastward. In argillaceous units, the direction of tectonic transport is ambiguous because of the predominance of upright folds. However, in more competent sandstone-dominated units, tectonic transport is predominantly northeastward (Lane and Cecile 1989; Lane et al. 1995). Farther east in the Barn Mountains (Fig. 3), Devonian structural trends swing southward, and the thrust faults are predominantly directed eastward (Cecile and Lane 1991). This intense deformation was followed by widespread intrusion of granitic plutons.

The age of the Romanzof Orogeny is defined by critical data from northwestern Yukon and the adjacent Alaska North Slope. Involved in the deformation is a basinal chert and argillite succession that is equivalent to the calcareous shales of the Early Ordovician to Early Devonian Road River Group in the Richardson Trough (Lenz 1972; Cecile and Norford 1993). The basinal succession includes rocks as young as Early Devonian, based on Pragian and Emsian graptolite faunas in the Driftwood Hills, a Paleozoic inlier south of the Barn Mountains (locality 2, Fig. 2). In contrast, in adjacent northeastern Alaska, a synrift clastic succession (unit Ds, Reiser et al. 1980) containing an early Middle Devonian marine brachiopod fauna lies with spectacular angular unconformity above intensely folded pre-Devonian strata (Popov et al. 1994; Moore et al. 1994). Thus, the Romanzof Orogeny is tightly constrained to be late Early Devonian to earliest Middle Devonian in age. A suite of granitic plutons in northern Yukon intrude the deformed strata (Fig. 3), truncate structures, and impart metamorphic aureoles on the deformed rocks. These plutons have yielded Late Devonian U–Pb ages (Mortensen and Bell 1991; Lane et al. 1993) that provide a less precise constraint that supports the faunal data. The granites and deformed older strata are unconformably overlain by Tournaisian and Visean (earliest Carboniferous) Endicott Group strata (Fig. 4).

The time–space progression of the Romanzof Orogeny is defined in part by the distribution of Early to Middle Devonian clastic rocks and by the areal extent of angular unconformities. A distinctive succession of silty dark grey shale and turbiditic sandstone, locally with chert pebble conglomerate and limestone, in part of Early Devonian age, is widespread along the northeastern slopes of the British Mountains in the area of the Firth and Malcolm rivers. Extensive exposures of these shales are interbedded with abundant siltstones and subsidiary sandstones (Fig. 5). Where the sandstones are locally the dominant rock type, they are bedded a few centimetres to 3 m thick, locally with load casts and flute casts at the bases, and ripple crosslaminations at the tops. They are typically fine to medium grained with a quartz–feldspar–chert composition, locally containing detrital white mica grains, argillite chips, and coaly fragments. The siltstones and shales also contain coalified plant fragments and white mica, as well as common tracks and trails on bedding surfaces. Some of these have been identified as *Scalarituba* and *Phycosiphon*, which are indicative of a deep-water setting below wave base (J-P. Zonneveld, personal communication, 2006). The depositional setting of this unit is interpreted as a succession of turbidites in a distal slope environment. These characteristics are consistent over 75 km along strike from the Alaska border area (Lane et al. 1995) to east of Firth River (Lane and Cecile 1989). Although the basal contact of this unit is conformable in most places, locally it is demonstrably unconformable, placing the Devonian rocks on Ordovician and Cambrian cherts and slates. Nonetheless, detailed mapping documents that these beds are involved in the tight Devonian folding and thrust faulting, whereas the overlying

Fig. 2. Distribution of Early Devonian facies (figs. 11, 12 in A.W. Norris 1985) with additional localities identified. The shelf to basin facies transition migrated northward (arrows) from Pragian (early Early Devonian) to Emsian (late Early Devonian) time. Localities 1 and 3 bracket major turbiditic facies not present farther south. Positions are not restored for Tertiary deformation.

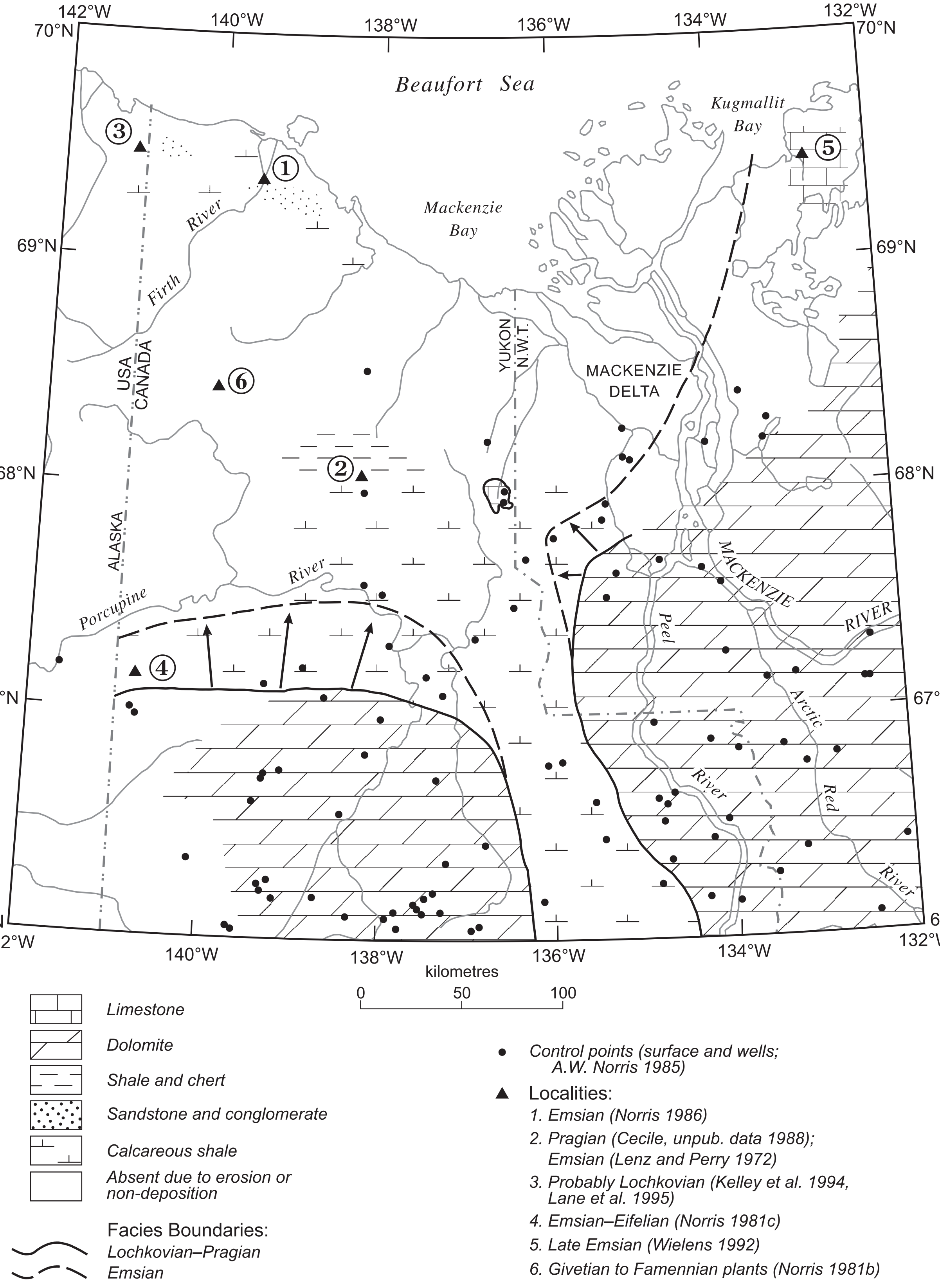


Fig. 3. Simplified geologic map of northwestern Canada showing structural elements mentioned in the text. Romanzof Mountains extend westward from the British Mountains into Alaska. Ellesmerian deformation front excludes the isolated Iroquois folds, probable Ellesmerian structures located some 200 km to the southeast. Locations of Figs. 6–8 are indicated. U–Pb age uncertainties are 2σ (Mortensen and Bell 1991; Lane et al. 1993; Lane and Mortensen, unpublished data, 2005).

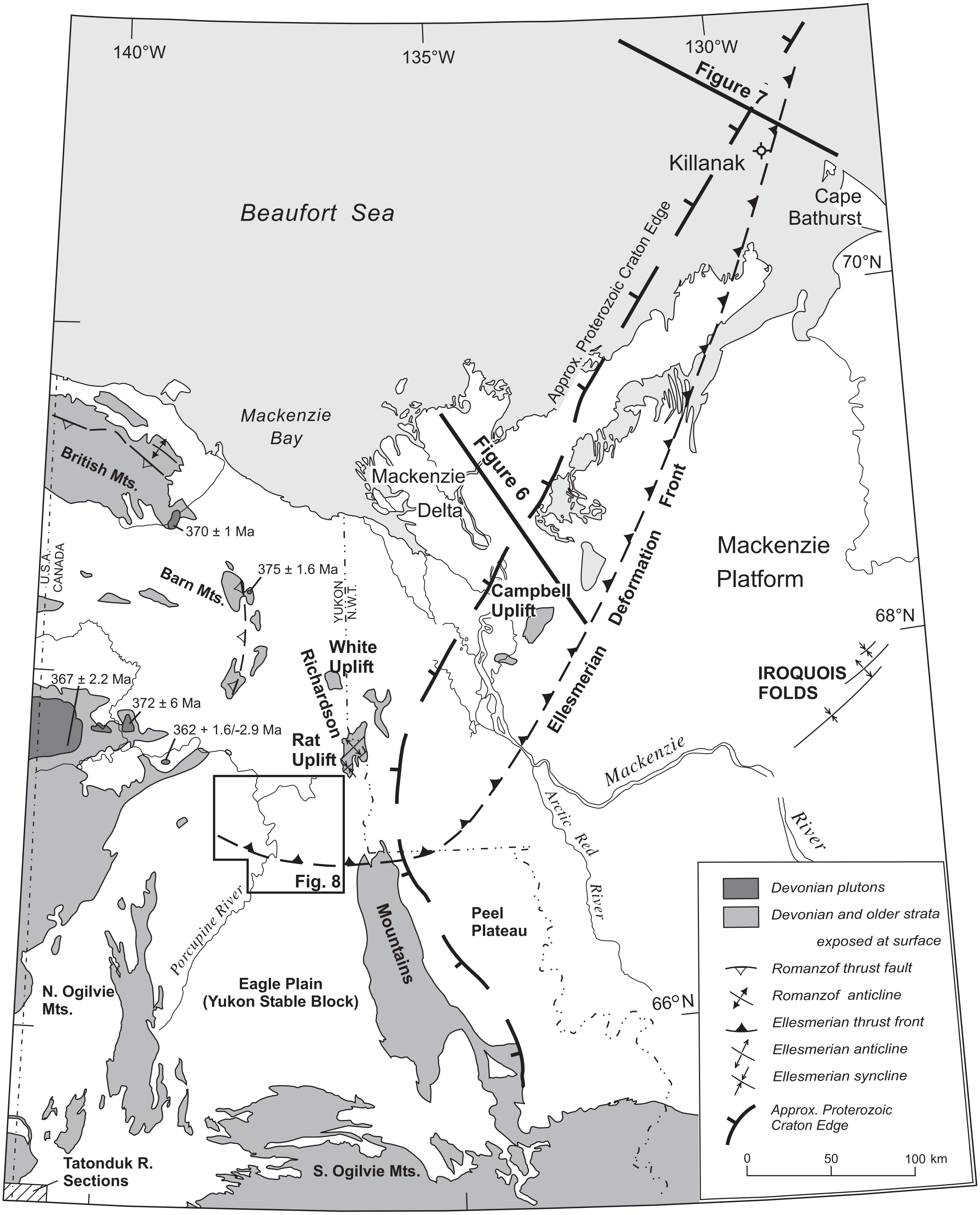


Fig. 4. Subhorizontal conglomerate of the earliest Carboniferous Kekiktuk Formation, capping the ridge, unconformably overlies subvertical Proterozoic and Cambrian quartzite of the Neruokpuk Formation, British Mountains, Yukon.

Early Mississippian and younger successions are not (Lane and Cecile 1989; Lane et al. 1995).

The Devonian turbiditic strata are lithologically distinct from the Early Ordovician to Early Devonian chert and argillite succession, referred to the Road River Group, exposed throughout the region. The Road River argillites are siliceous, locally carbonaceous, and graptolite bearing but devoid of trace fossils. Visible detrital muscovite, though present, is less common and finer grained. The argillites are associated with highly siliceous cherty beds and common bedded chert. Coarse clastic rocks are not present in this succession.

Two fossil localities in the northwestern Yukon and adjacent Alaska indicate that this silty shale and turbiditic sandstone unit is Early Devonian in age. The first is a conodont locality, 4 km west of the Yukon–Alaska border (locality 3, Fig. 2), giving a Pridolian (latest Silurian) to earliest Pragian (Early Devonian) age (Kelley et al. 1994; Lane et al. 1995). This locality is treated here as essentially earliest Devonian because aspects of the fauna suggest that it dates from “possibly middle through late Lochkovian” (A.G. Harris, unpublished report, 1990). This site lies near the base of a section of dark grey shale and siltstone with minor sandstone that is mapped continuously for more than 20 km along strike and lies conformably on graptolite-bearing Silurian shale (Lane et al. 1995). A second locality containing an Emsian (late Early Devonian) conodont fauna has been reported (Norris 1986) in black carbonaceous shale with subsidiary limestone (locality 1, Fig. 2). This locality is faulted and so it cannot be directly related to the turbiditic succession that is well exposed nearby. However, it does confirm that the area was still undergoing marine sedimentation at that time. In contrast, Middle to Late Devonian plant fossils farther south (locality 6, Fig. 2) indicate that at least parts of the region were subaerial by Late Devonian time (A.W. Norris 1985). Because the turbidite-bearing unit overlies dated strata of Late Silurian and Early Devonian age but is involved in the intense deformation predating Middle Devonian strata in adjacent Alaska, it must therefore be Early Devonian in age.

This distinctive Early Devonian succession of shale, siltstone and turbiditic sandstone records the progradation of a coarse clastic facies into the northernmost parts of the Yukon in Early Devonian time. These coarse clastics are not known in age-equivalent Early Devonian strata farther south in the Driftwood Hills. Accordingly, this succession is most reasonably interpreted as being associated with a sedimentary source area encroaching from the north, marking an early stage of the Romanzof event in this area.

Beyond the area of exposed structures, evidence for the proximity of the Romanzof event is subtle at best. The northward expansion of shallow shelf deposition in Emsian time (Fig. 2) may signal crustal thickening or tectonic wedging related to Early Devonian encroachment of the Romanzof orogen; however, it is more reasonably regarded as part of a widespread eustatic event (Morrow 1999). By the Middle Devonian, a resumption of regional subsidence led to widespread drowning of both the Yukon Stable Block and adja-

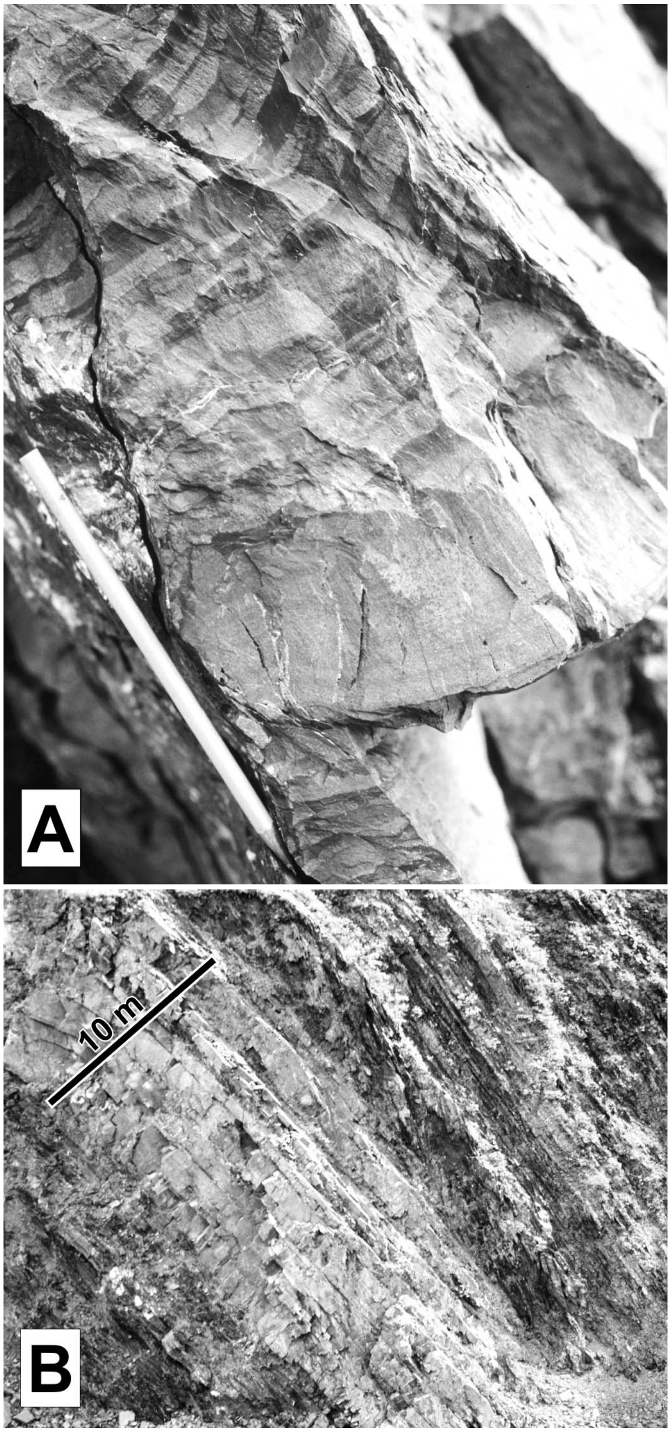


Fig. 5. (A) Graded bedding in sand–silt beds of the Devonian sand–shale turbidite succession, British Mountains, Yukon–Alaska border area. Sand beds locally have scoured and loaded bases. Pencil is ~17 cm long. (B) Outcrop view of thick-bedded sandstone of the Devonian turbidite succession, Firth River, Yukon. Sandstone unit is 10 m thick.

cent Mackenzie Platform, and the deposition of basinal shale of the Canol Formation in Givetian time (Morrow 1999, p. 70). This was followed by the arrival of the Imperial Formation, Ellesmerian foredeep clastics (Pugh 1983; A.W. Norris 1985).

In the northern Richardson Mountains (White Uplift, Fig. 3), inliers of lower Paleozoic strata do not preserve evidence of an Early or Middle Devonian deformation. There, a local carbonate buildup (White Mountains) shows evidence for mid-Silurian and Late Silurian (sub-Devonian) disconformities. But, angular truncations indicative of major deformation are absent (Morrow 1989). On the southwest margin of Yukon Stable Block (Tatonduk River area, Fig. 3), Cambrian to Carboniferous strata comprise a paraconformable succession with no evidence of Devonian deformation (Allison 1987; Clough and Blodgett 1987; Gehrels et al. 1999). In summary, widely separated localities in the Richardson Mountains adjacent to the north and east margins of Yukon Stable Block, on the block itself and on its southwest margin, locally show evidence of depositional hiatuses but no evidence of angular discordances indicative of significant Early or Middle Devonian deformation.

Older compilations (Norris 1984) propose the existence of an hypothetical extrapolation of the early Tertiary Kaltag fault of western Alaska toward the northeast through northern Yukon. Such an extension is definitively precluded on stratigraphic, structural, and geophysical grounds (Bamber and Waterhouse 1971; Richards et al. 1997; Lane 1992, 1998). Accordingly, the structural history of Yukon Stable Block is a key area to provide evidence relevant to the tectonic evolution of the adjacent Yukon and Alaska North Slope (Fig. 3).

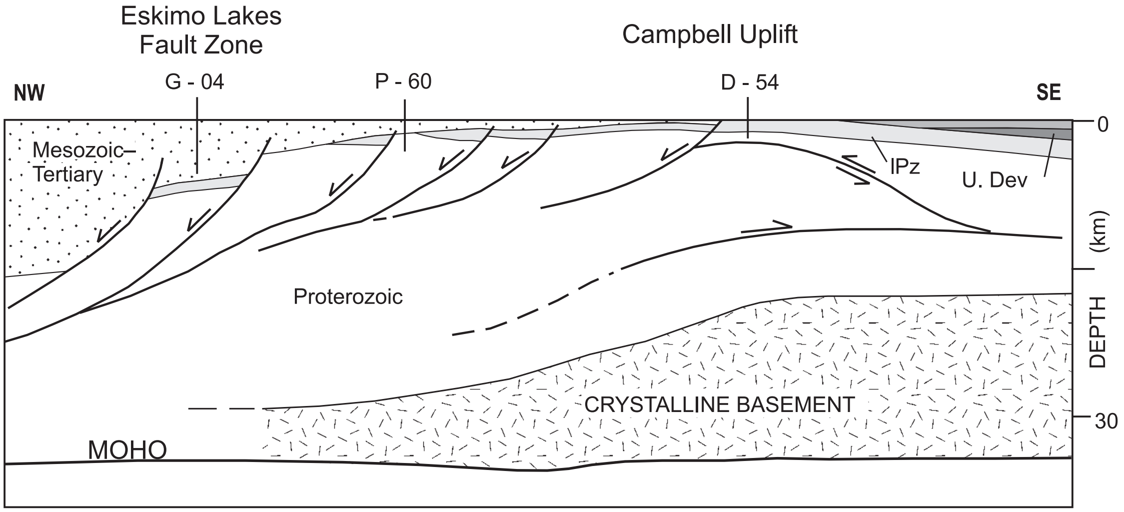
Ellesmerian Orogeny (Early Carboniferous)

The Ellesmerian Orogeny (sensu stricto) is defined as a regional deformation event affecting rocks throughout the Canadian Arctic Islands and adjacent northern Greenland. This event involves and therefore postdates Famennian (latest Devonian) strata that are in turn posttectonically overlain by late Visean (late Early Carboniferous) rocks of the Emma Fiord Formation (Trettin et al. 1991; Harrison 1995).

The Ellesmerian Orogeny produced an important and widespread clastic wedge, which is identified as the Imperial and Tuttle formations in the Beaufort–Mackenzie region (Pugh 1983; Braman and Hills 1992). Only the northern basinal facies of the Imperial Formation represents the clastic wedge, consisting of deep-water shale interbedded with turbiditic sandstone of Late Devonian age, derived from the north. Its present distribution extends from the continental margin north of Tuktoyaktuk Peninsula southwestward to Eagle Plain. In the Tatonduk River area of adjacent east-central Alaska, the Nation River Formation comprises equivalent strata. Conformably overlying the Imperial strata is the Tuttle Formation of Late Devonian and earliest Carboniferous age. It consists of a conglomerate, sandstone, and shale succession of more limited extent encompassing Peel Plateau to Eagle Plain (Fig. 3). Both units reach their maximum recorded thickness in the vicinity of the central Richardson Mountains, and thin to a depositional zero-edge beneath southern Eagle Plain where coeval strata form the lower part of the basinal Ford Lake shale (Pugh 1983).

In the Mackenzie Delta area (Figs. 3, 6), seismically identified northeast-trending thrust faults deform lower Paleozoic platformal rocks (Cook et al. 1987). Those structures were interpreted to define an Ellesmerian triangle zone at the

Fig. 6. Southern half of deep crustal seismic line FGP86-1, with interpretation simplified from Cook et al. (1987). Proterozoic crustal ramp and Devonian thrust faults are shown: lPz, lower Paleozoic platformal carbonates; U. Dev, Upper Devonian Imperial Formation. Using petroleum industry seismic data, Coflin et al. (1990) showed that the Imperial Formation is syntectonic in this area. Line location is shown in Fig. 3.



deformation front in the Mackenzie Delta area and are the result of orogenic shortening with southeastward vergence. Overlying strata of the Imperial Formation were interpreted to have been deposited syntectonically, defining the local timing of deformation (Coflin et al. 1990). In a seismic profile north of Cape Bathurst, 300 km northeast of the Mackenzie Delta (Figs. 3, 7), three small thrust faults are also interpreted as Ellesmerian structures (Dietrich et al. 1989). Southeast of Mackenzie Delta, a few isolated northeast-striking folds (Iroquois folds, Fig. 3) are pre-Cretaceous in age (Cook and Aitken 1975), and were interpreted (by Norris and Dyke 1987) as being likely Ellesmerian structures lying beyond the front of regional deformation.

In the northern Richardson Mountains (Rat Uplift, Fig. 3), rocks of the Imperial Formation are exposed beneath unconformably overlying Permian rocks (Norris 1981*f*). In the Rat Uplift, the structure of the Devonian rocks consists of a pair of upright northeast-trending folds that predate deposition of the Permian strata (Bell 1973). No preferred vergence is suggested by these upright structures. Nearby, similar Permian strata lie with angular unconformity on Silurian and older rocks (Norris 1981*f*), indicating that significant Ellesmerian-age deformation has removed Late Devonian strata between the two sites (Dixon 1998, p. 20). At other localities in the northern Richardson Mountains (Bamber and Waterhouse 1971, p. 83) and in well penetrations beneath the Mackenzie Delta (Dixon et al. 1996), Late Carboniferous carbonates, and at one locality latest Early Carboniferous and younger strata, occur disconformably below the Permian. Therefore, Ellesmerian folds must be of Early Carboniferous age in this area. The exposed southern limit of these Ellesmerian-age structures is approximately 50 km south of the Rat Uplift (Norris and Dyke 1987).

Petroleum industry seismic reflection data from northeastern Eagle Plain (Fig. 8) illustrate several open upright anticlines and synclines that are truncated by the overlying sub-Mesozoic unconformity (Fig. 9). Petroleum exploration well intersections that are tied to the seismic lines (Fig. 8) demonstrate that the folded rocks consist of Imperial Formation, possibly including sandstone and conglomerate of the overlying Tuttle Formation. Although the folded rocks are overlain in the seismic section by Mesozoic strata, exposed structures in the adjacent Richardson Mountains demonstrate that these subsurface structures are Early Carboniferous in age.

The Ellesmerian structures beneath Eagle Plain are mapped across a grid of seismic lines, where the east–west axial surface traces mimic the local trend of the early Paleozoic carbonate–shale facies transition (Fig. 8). That this frontal zone lies just south of the carbonate–shale facies transition and mimics its arc-shaped trend illustrates the influence of the facies transition on the mechanics of deformation in this area (Lane 1996). The southernmost structures are imaged clearly (Fig. 9), unambiguously defining the southern limit of the Early Carboniferous deformation in this area and the tectonic transport direction as being southward. Also, the folds are detached within the Imperial Formation, as illustrated by the lack of deformation in the underlying lower Paleozoic carbonate rocks.

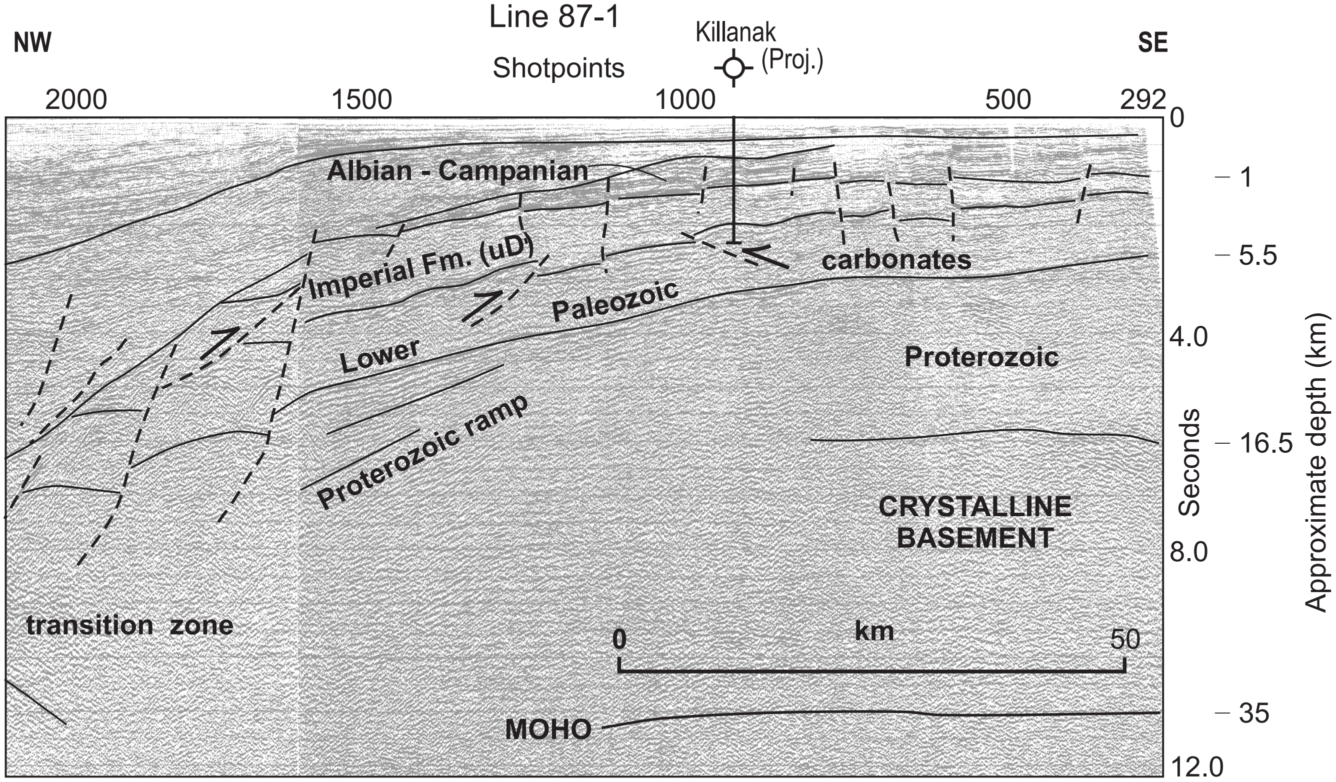
In adjacent Arctic Alaska, there is no evidence that Late Devonian or Early Carboniferous shortening affected rocks now found beneath the Alaska North Slope. A widespread, prominent “sub-Mississippian” unconformity, present in exposures and subsurface of the Alaska North Slope and adjacent Brooks Range, marks the progressive northward drowning of a previously deformed tectonic highland (Romanzof orogen). The Late Devonian to Carboniferous tectonic setting there is interpreted as that of continental rifting followed by post-rift subsidence which transgressed northward through early Carboniferous time (Moore et al. 1994; Dumoulin et al. 1997; Mull et al. 1997; Young 2004).

Summary of tectonic events

Romanzof Orogeny

The Romanzof event, consisting of tight upright folding

Fig. 7. Eastern half of deep crustal seismic line FGP87-1, with interpretation after Dietrich et al. (1989). Proterozoic craton margin and thrust faults involving Upper Devonian (uD, Imperial Formation) are shown. Line location is shown in Fig. 3.



and thrust faulting, predates deposition of early Middle Devonian marine strata in northeastern Alaska and the intrusion of Late Devonian postorogenic granites in northern Yukon. Evidence for this event is preserved in exposed basin-facies strata, including Early Devonian strata, in the Romanzof and British Mountains, and adjacent areas of northern Yukon as far eastward as the Barn Mountains (Fig. 10), as well as in the subsurface of the Alaska North Slope. If it occurred within the Brooks Range, it was thoroughly masked by Mesozoic and Cenozoic deformation and metamorphism.

The Early Devonian paleogeography of northern Yukon constrains the tectonic transport direction of the Romanzof Orogeny. In northern Yukon, northernmost exposures of Early Devonian strata include turbiditic sandstones not present in coeval shale–chert basinal exposures farther south (locality 2, Fig. 2). The locally unconformable base of the turbiditic succession suggests the initiation of low-relief structures that were bevelled by submarine erosion, onto which the Devonian silty shales and turbiditic sandstones were deposited. These features are best interpreted as evidence that the Romanzof Orogeny encroached on this region from north to south, beginning in Early Devonian time. Where Romanzof structures are well exposed in northernmost Yukon, most folds are upright, but north-directed thrust faults are common locally (Lane and Cecile 1989; Lane et al. 1995). However, the lack of deformation on adjacent Yukon Stable Block suggests that the north-directed structures may be back thrusts possibly related to encroachment and tectonic wedging of Romanzof structures into continental margin rocks north of the platform.

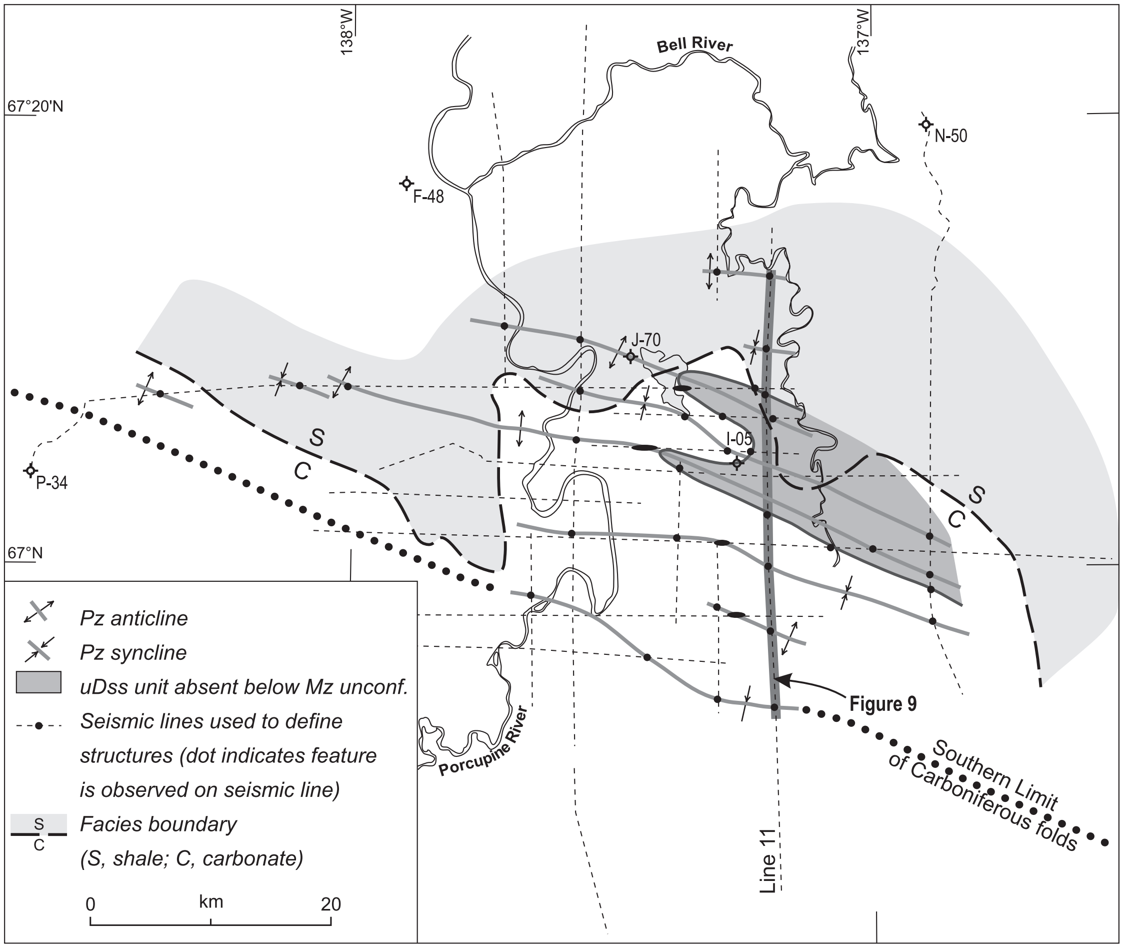
Although more data are required before an adequate regional understanding of the Romanzof Orogeny can be achieved, the geological record on the Yukon and Alaska North Slope preserves evidence of intense Early Devonian deformation and Devonian pluton emplacement which is not present on the adjacent Yukon Stable Block or elsewhere in the Beaufort–Mackenzie region. Also, in Arctic Alaska, the Romanzof Orogeny was followed by a regional rifting event that produced felsic magmatism, and a south-facing, subsiding, passive continental margin by Late Devonian time (e.g., Moore et al. 1994; Young 2004).

Ellesmerian Orogeny

In northern Yukon, this event produced open to closed detached folds and thrust faults. Its age is bracketed by the Late Devonian age of the Imperial Formation involved in the folding (Braman and Hills 1992; A.W. Norris 1985) and by the latest Early Carboniferous age of the oldest dated beds overlying the deformed succession (Bamber and Waterhouse 1971; Norris 1981*f*; Dixon et al. 1996). Evidence for low-intensity contractional faults and folds involving the Imperial Formation, and locally carbonate platformal rocks, is widespread over more than 500 km from Cape Bathurst in the northeast to the Richardson Mountains in the southwest (Fig. 3).

South- to southeastward-directed tectonic transport is demonstrated by the Ellesmerian deformation front, which is mapped in the surface and subsurface across the northern Richardson Mountains, and can be approximated in the subsurface of the Mackenzie Delta region. Also, the Imperial Formation is widely interpreted as a clastic wedge succession derived from the northwest, indicative of a proximal

Fig. 8. Trends of Devonian structures at the northern margin of Yukon Stable Block (northeastern Eagle Plain). Mz, Mesozoic; Pz, Paleozoic; unconf., unconformity; uDss, Upper Devonian sandstone–shale succession. See Fig. 3 for location. Shaded part of seismic line 11 is shown in Fig. 9.



tectonic highland source area during Late Devonian time (Pugh 1983; Braman and Hills 1992). Yet, these rocks were subsequently deformed in the Early Carboniferous. This temporal progression is additional documentation that deformation progressed approximately from north or northwest to south or southeast.

Ellesmerian structures are absent on Yukon Stable Block to the south, and they have not been identified in Early Carboniferous rocks to the west on the Yukon and Alaska North Slope (Fig. 10). Within parts of the Brooks Range, Middle Devonian through Early Carboniferous strata record continuous marine deposition (Moore et al. 1994, pp. 113–114). Moreover, the available data from Arctic Alaska defines a tectonic setting dominated by extensional tectonism followed by passive thermal subsidence through Late Devonian and Early Carboniferous time (Young 2004).

Early Carboniferous structures extend for more than 500 km in the subsurface across the northern Yukon – Mackenzie Delta region, indicating that they were produced by a tectonic event of regional importance. This event is interpreted most simply as the southwestward extremity of the Late Devonian and Early Carboniferous Ellesmerian Orogeny (sensu stricto) of the Canadian Arctic Islands (Trettin et al. 1991; Harrison 1995), which is interpreted here as being the result of the broadly southward-directed collision of a continental landmass against northwestern North America (Trettin et al. 1991). Although no firm evidence is available to demonstrate that structures were once continuous from the Arctic Islands to the northern mainland, the age and tectonic transport direction of the two events are essentially the same (Figs. 10, 11).

Discussion

Although the deformation identified here as the Romanzof Orogeny has been regarded as an element of the Ellesmerian Orogeny in the past, it is distinctly older, more intense, and associated with an important postorogenic magmatic component. The delineation in northern Yukon of two distinct deformation pulses of Early Devonian and Early Carboniferous ages, and the partial definition of the areal limits of these events, help to constrain models of the tectonic evolution of northern Laurentia and the Arctic region for mid-Paleozoic time. It also suggests avenues for future work.

Within Yukon, the transition between Romanzof and Ellesmerian structures lies east of the Barn Mountains (Fig 10). No evidence of Romanzof structures has been found to the east and no demonstrably Ellesmerian structures have

Fig. 9. Part of Chevron Canada Resources Ltd. seismic reflection line 11 (see Fig. 8 for location). lPzc, lower Paleozoic carbonate shelf facies, transitional northward to an off-shelf shale facies; uDsh, Upper Devonian Imperial Formation, shale-dominant succession; DCss, interbedded sandstone–shale succession (Imperial and (or) Tuttle formations); J-uK, Jurassic to Upper Cretaceous Mesozoic clastic succession, unconformably overlying the deformed Paleozoic strata. lKu, lower Cretaceous unconformity; mKu, mid-Cretaceous unconformity; Prot., Proterozoic. Folds, outlined by high-amplitude reflections of the uDss unit, are mapped across a grid of seismic lines. Low-amplitude reflections in the underlying uDsh unit do not resolve the structure owing to interference by multiples. Folds are detached on a basal décollement above the carbonates. These subsurface Ellesmerian folds represent an untested petroleum play.

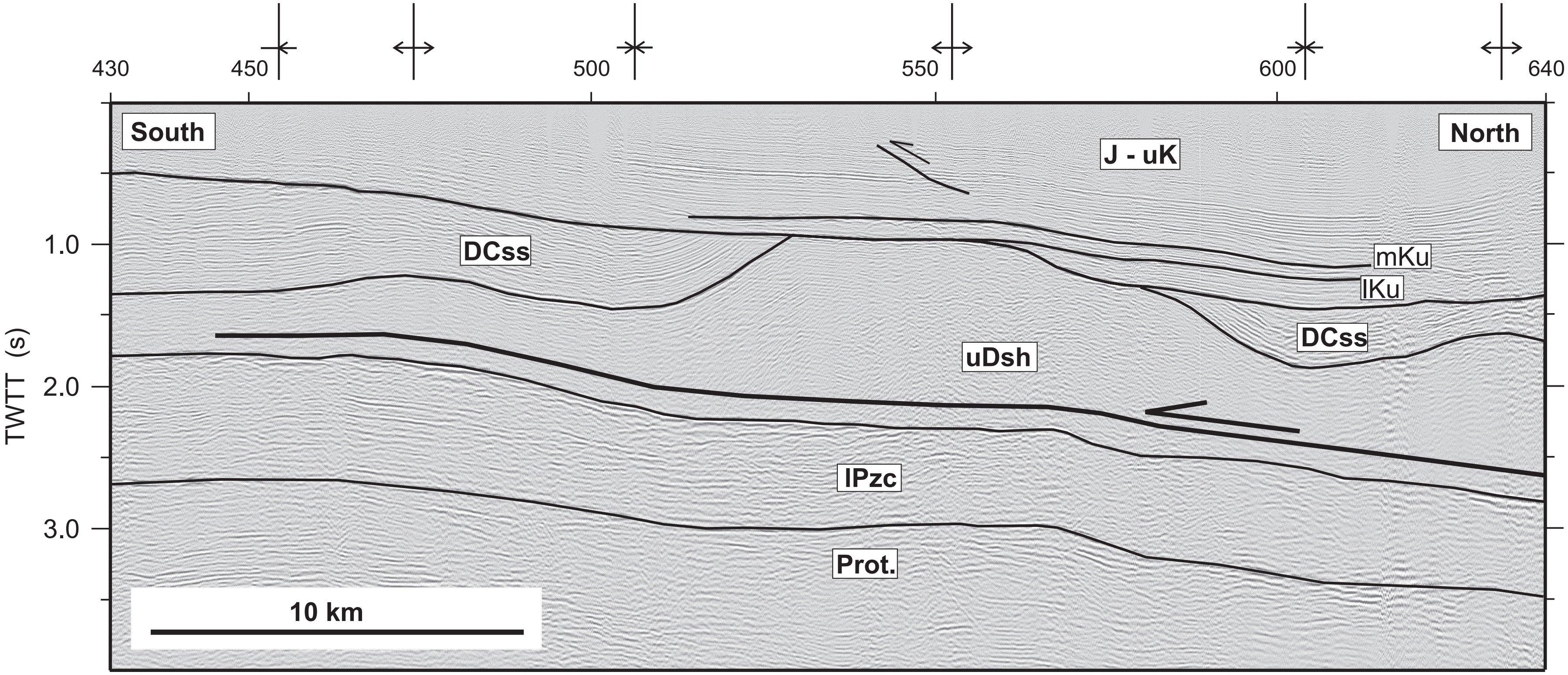
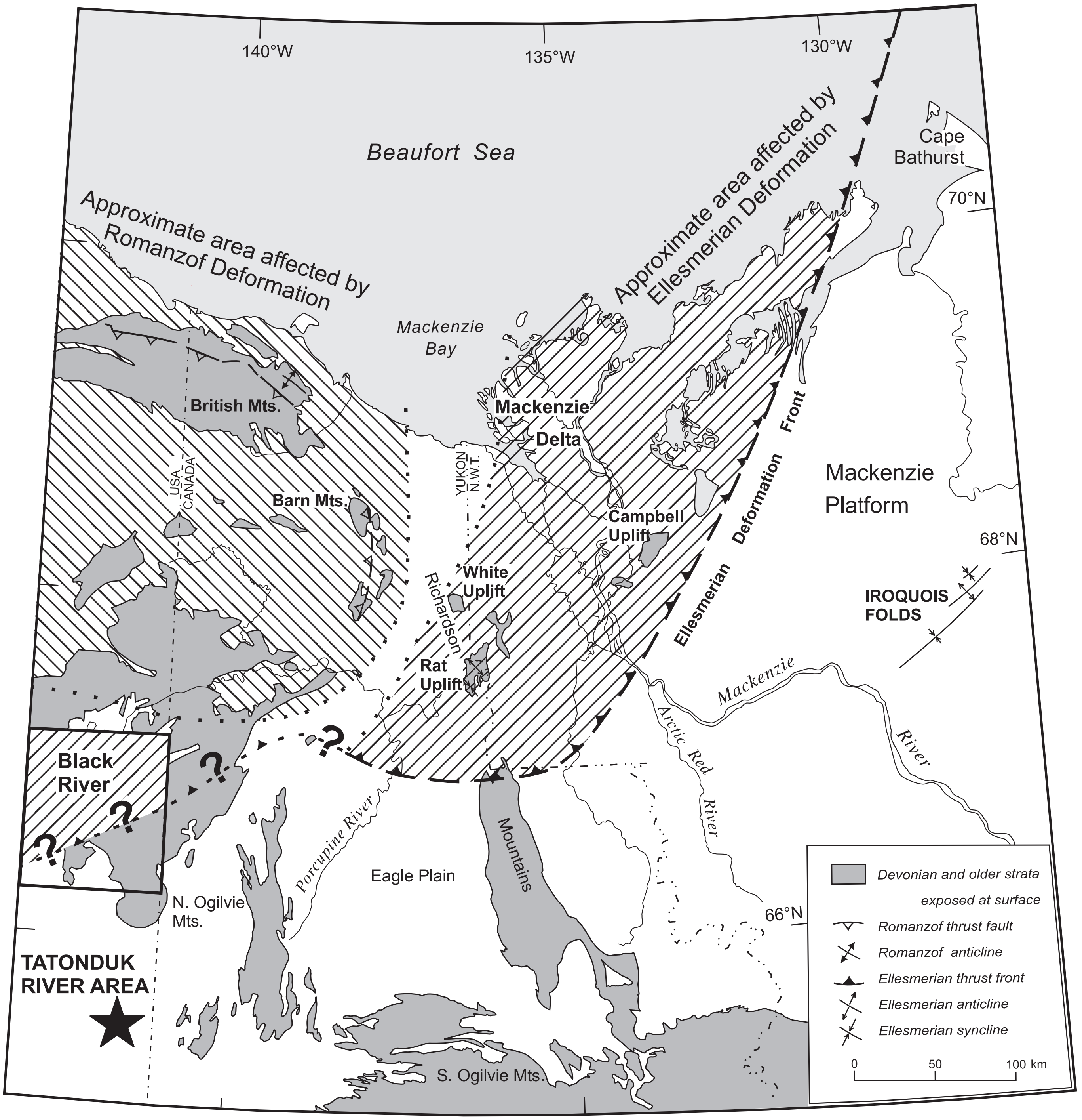
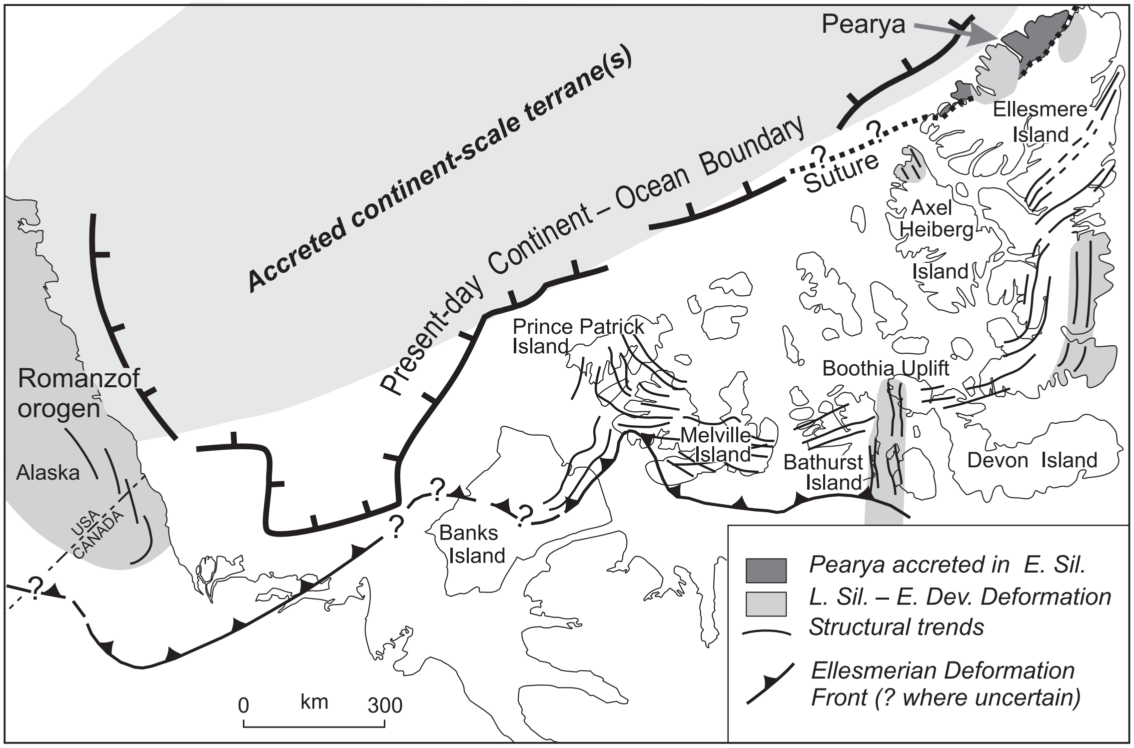


Fig. 10. Regional map showing areas affected by Romanzof (Early Devonian) and Ellesmerian (Early Carboniferous) deformation. Except for Ellesmerian deformation front, limits are undefined. Black River map area of eastern Alaska contains a mapped unconformity bounded by dated Middle Devonian rocks below and Upper Mississippian rocks above (Brabb 1970). Ellesmerian deformation front must lie between Black River and the Tatonduk River area (black star) where no evidence of Devonian deformation is preserved (Allison 1987; Gehrels et al. 1999).



been found to the west. At present, it is unclear whether this is because of lack of exposure or preservation of suitably aged successions, to some key element of Devonian tectonics, to overprinting by Cretaceous extension and Tertiary convergence, or to a lack of adequate study (or some combination thereof). In any case, the regional-scale continuity of southwestward-deepening Carboniferous facies belts requires that the Romanzof- and Ellesmerian-deformed areas were juxtaposed by Early Carboniferous time (Bamber and Waterhouse 1971; Richards et al. 1997).

Fig. 11. Distribution of Ellesmerian structural trends in Arctic North America (Trettin et al. 1991), not restored for Mesozoic and Tertiary deformation. Deformation front is taken from Harrison (1995) Melville Island area and Miall (1976) for Banks Island. Between Banks and Prince Patrick islands, the distribution of Ellesmerian structures is unknown. The structural trends of the Romanzof event are notably similar to those of the potentially correlative Silurian – Early Devonian transpression event in the Arctic Islands. E., Early; L., Late; Dev., Devonian; Sil, Silurian.



Previous studies of early Paleozoic facies variations across northern Alaska, Yukon, and the Canadian Arctic Islands document the existence of a widespread deep ocean basin, the Franklinian Basin, bordering the ancient continent (e.g., Martin 1959; Lenz 1972; Churkin 1975; Cecile and Norford 1993). Seismic data from northeastern Eagle Plain and recent mapping in northern Yukon help to document a north-facing shelf to basin transition across northern Yukon, supporting these earlier interpretations.

Regionally, the Franklinian Basin margin became convergent in the early Paleozoic and a succession of collisions with allochthonous terrane(s) occurred, beginning at about 440 Ma (Early Silurian) with the oblique accretion of Pearya, an exotic terrane with Caledonian characteristics (including Grenville-age basement and an Early Ordovician tectonomagmatic event, Trettin 1998). This was followed in Late Silurian – Early Devonian time by sinistral transpression and granitic intrusion across northern Ellesmere and Axel Heiberg islands and Boothia Uplift; and finally by the Ellesmerian event of latest Devonian and Early Carboniferous age, which extended from northern Greenland to the Yukon (Fig. 11). The Romanzof Orogeny implies a fourth tectonic–magmatic event along the Yukon–Alaska segment of the Franklinian margin in the Early Devonian. Although exposed thrust faults of the Romanzof orogen are northward directed, both the lack of Early to Middle Devonian deformation south of the orogen and the apparent southward progradation of an Early Devonian turbiditic clastic succession support a southward, not northward, tectonic transport direction. This interpretation suggests a correlation between the Romanzof event and the Late Silurian – Early Devonian sinistral transpression event that affected primarily Axel Heiberg and northern Ellesmere islands 2000 km to the north (Fig. 11). Logically, all four tectonic events can be ascribed to the progressive encroachment and collision of a single continent-scale terrane from Silurian through Early Carboniferous time, with individual tectonic events determined by plate geometries and (or) temporal changes in plate kinematics over this time interval (Fig. 11).

The nature of such an allochthonous terrane is partly characterized by the Caledonian character of its fragment, Pearya, which accreted to northwestern Ellesmere Island (Trettin 1998). Additional clues derive from the occurrence of a significant cluster of 430 Ma age detrital zircon grains from the Late Devonian Nation River Formation of east-central Alaska and the correlative Imperial Formation of adjacent northern Yukon, which were interpreted as having a possible Caledonian or Siberian source terrane (Gehrels et al. 1999). Similarly, northward-derived Triassic strata from the Canadian Arctic Islands contain detrital zircons characterized by 445–490 Ma and 500–600 Ma grains, sourced from the landmass that occupied the present-day Arctic Ocean basin in post-Devonian, pre-Cretaceous time (Miller et al. 2006). Also, global plate-tectonic reconstructions for Silurian–Devonian time show the Siberian craton to be approximately in the right place to be involved in such a continent-scale collision (Scotese 2001). Finally, the important Siberian (as well as Laurentian) faunal affinity of many Alaskan fossil collections, primarily of early Paleozoic age, indicates that Alaska was in faunal communication with Siberian as well as Laurentian populations, whereas northern Laurentia itself contains no Siberian faunas (Dumoulin et al. 2000). Taken altogether, these data suggest that the accreted terrane forming the hinterland of these Paleozoic deformations was adjacent to or connected with a part of the Siberian craton, although probably not the craton itself. Further, it also suggests that much of Arctic Alaska may have been accreted to northwestern Laurentia during Romanzof tectonism (Dumoulin et al. 2000).

The Ellesmerian deformed belt is strongly controlled by Paleozoic facies. The deformation front south of Melville Island coincides closely with the limit of Ordovician evaporites (Harrison 1995), whereas in northern Yukon the deformation front approximates the transition from carbonate platform to Road River shale facies. Areas underlain by Paleozoic platform carbonates are weakly affected. The subsurface geology of Banks Island is poorly known, and the front of Ellesmerian deformation is uncertain there (Fig. 11). However, it is largely underlain by Paleozoic carbonates, so Ellesmerian deformation, if present, may be weakly expressed there. Similarly, in the Black River quadrangle, northeastern Alaska, that straddles the northwestern margin of Yukon Stable Block (Fig. 10), a major unconformity is bracketed by Middle Devonian rocks below and “Upper Mississippian” rocks above (Brabb 1970). This is consistent with Ellesmerian deformation and too young for the Romanzof event, but additional dating may improve the age resolution. The area would have to represent an extreme southern limit for Ellesmerian tectonism because the Tatonduk River area lies nearby to the south, where the Late Devonian Nation River Formation (Imperial Formation correlative) forms part of a complete stratigraphic succession from Cambrian through Carboniferous time (Allison 1987; Gehrels et al. 1999).

The Mesozoic tectonic evolution of the Arctic region continues to be actively debated (Lane 1997 and references therein). The identification of Paleozoic facies belts, detrital age spectra, and deformation trends provide potential piercing points at the continental margin of northwestern Canada against which potential conjugate margins may be compared.

Conclusions

An east–west trending deformation front is delineated by seisimic reflection data in northeastern Eagle Plain. The deformation preserved there is correlated with similar structures observed in exposures in the adjacent Richardson Mountains and with small-displacement thrust faults imaged in seismic data extending for some 500 km northeastward. The age of this southward-verging deformation event is bracketed stratigraphically by the Late Devonian Imperial Formation and by the Serpukhovian (late Early Carboniferous) age of unconformably overlying strata. This event is correlated with the Ellesmerian Orogeny of the Canadian Arctic Islands. In northeastern Eagle Plain, these subsurface Ellesmerian folds are unconformably overlain by Mesozoic strata and represent an untested petroleum play.

A distinct Early Devonian deformation, the Romanzof Orogeny, produced intense isoclinal folds and north-directed thrust faults in northwestern Yukon and adjacent Arctic Alaska. The presence of Romanzof deformation in the north and its absence in the south, together with an associated southward prograding Early Devonian clastic wedge, imply that the Romanzof event reflects north to south tectonic transport and tectonic wedging on the northern margin of Laurentia. Published interpretations suggest that Paleozoic orogenesis in the Canadian Arctic Islands originated as the result of mainly sinistral transpressional collisions of allochthonous terrane(s) arriving from the north. This convergent plate margin was the site of Early Silurian accretion of Pearya, Late Silurian – Early Devonian sinistral transpression in Axel Heiberg and northern Ellesmere islands and Boothia Uplift, and latest Devonian – Early Carboniferous Ellesmerian Orogeny. It was also the site of the Early Devonian Romanzof Orogeny in Arctic Alaska and Yukon. Accordingly, at least four distinct deformation events occurred along the Franklinian continental margin between earliest Silurian and Early Carboniferous time. The Romanzof event is most similar in both timing and inferred kinematics to the Late Silurian – Early Devonian sinistral transpressive event affecting mainly northern Ellesmere and Axel Heiberg islands. These four events taken together likely record the approach and docking of a continent-scale allochthonous terrane (Siberia – northeast Russian outliers parts of Arctic Alaska?) culminating in its final Ellesmerian collision.

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