Polarforschung 68: 257 - 266, 1998 (erschienen 2000)

Facies Patterns and Conodont Biogeography in Arctic Alaska and the Canadian Arctic Islands: Evidence against Juxtaposition of These Areas during Early Paleozoic Time

By Julie A. Dumoulin[1], Anita G. Harris[2], Dwight C. Bradley[1], and Tim A. de Freitas[3]

THEME 14: Circum-Arctic Margins: The Search for Fits and Matches

Summary: Differences in lithofacies and biofacies suggest that lower Paleozoic rocks now exposed in Arctic Alaska and the Canadian Arctic Islands did not form as part of a single depositional system. Lithologic contrasts are noted in shallow- and deep-water strata and are especially marked in Ordovician and Silurian rocks. A widespread intraplatform basin of Early and Middle Ordovician age in northern Alaska has no counterpart in the Canadian Arctic, and the regional drowning and backstepping of the Silurian shelf margin in Canada has no known parallel in northern Alaska. Lower Paleozoic basinal facies in northern Alaska are chiefly siliciclastic, whereas resedimented carbonates are volumetrically important in Canada. Micro- and macrofossil assemblages from northern Alaska contain elements typical of both Siberian and Laurentian biotic provinces; coeval Canadian Arctic assemblages contain Laurentian forms but lack Siberian species. Siberian affinities in northern Alaskan biotas persist from at least Middle Cambrian through Mississippian time and appear to decrease in intensity from present-day west to east. Our lithologic and biogeographic data are most compatible with the hypothesis that northern Alaska-Chukotka formed a discrete tectonic block situated between Siberia and Laurentia in early Paleozoic time. If Arctic Alaska was juxtaposed with the Canadian Arctic prior to opening of the Canada basin, biotic constraints suggest that such juxtaposition took place no earlier than late Paleozoic time.

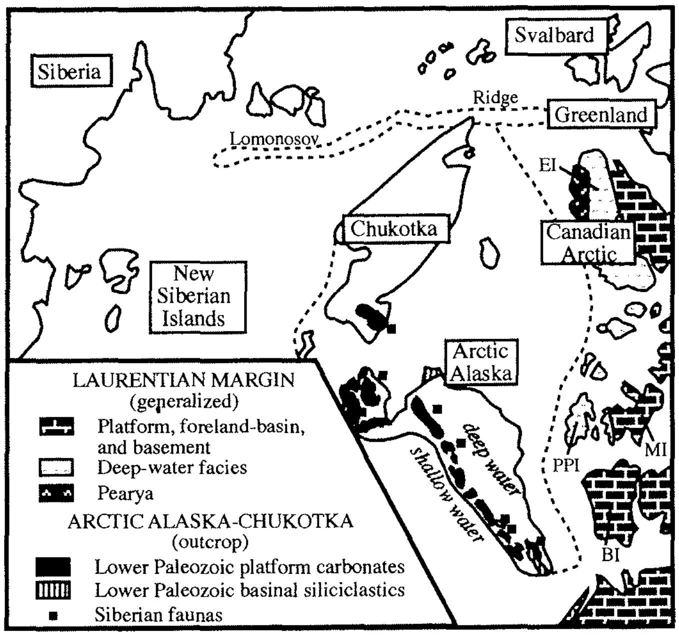

Fig. 1: Northern Alaska restored to a pre-Cretaceous position adjacent to the Canadian Arctic Islands, modified from HALGEDAHL & JARRARD (1987). A widely accepted model for the formation of the Canada Basin invokes counterclockwise rotation of Arctic Alaska away from the Canadian Arctic during the Cretaceous. Some proponents of this model (e.g., EMBRY 1988) have suggested that Canada and parts of Arctic Alaska were juxtaposed during Paleozoic, as well as most of Mesozoic, time. In this representation, Arctic Alaska includes the Chukotka region of northeastern Russia. BI, Banks Island; EI, Ellesmere Island; MI, Melville Island; PPI, Prince Patrick Island.

INTRODUCTION

The tectonic evolution of the western Arctic is controversial and hard to test because the age and spreading history of the ocean floor is poorly understood, a vast tract of submerged continental crust is virtually unknown, and much of the onshore geology is still known only from reconnaissance mapping. Paleozoic platformal carbonate rocks in Arctic Alaska and the Canadian Arctic are two pieces of this intriguing puzzle. To a first order, the two seem similar. They are roughly the same age and both are flanked to the north by coeval deep-water strata. Indeed, in otherwise opposed tectonic models (EMBRY 1988, LANE 1998), the two areas are postulated to have been so close during early Paleozoic that they would have shared similar depositional histories and faunas (Fig. 1). On the other hand, reports of "Siberian" early Paleozoic faunas from Arctic Alaska (e.g., PALMER et al. 1984) suggested to some workers that at least part of this microcontinent had an exotic origin (GRANTZ et al. 1991).

In this paper we look beyond the superficial similarities to make detailed stratigraphic and biogeographic comparisons between the lower Paleozoic successions of Arctic Alaska and the Canadian Arctic. The main focus will be the carbonate platforms, which, as a result of research on both sides of the international border, are far better known today than they were a decade ago (DUMOULIN & HARRIS 1994, TRETTIN et al. 1991, DE FREITAS et al. 1994, TRETTIN 1998). The Canadian Arctic platform is a clear target for comparison, because it can be seen in its broader context, first as part of a passive margin shelf, slope, and rise that faced an ocean to the north (present coordinates) during Cambrian and Ordovician, then in the foreland of the

[1] U.S. Geological Survey, 4200 University Drive, Anchorage, Alaska, 99508-4667, U.S.A.; <dumoulin@usgs.gov>, <dbradly@usgs.gov>

[2] U.S. Geological Survey, 926A National Center, Reston, Virginia, 20192, U.S.A., <ahcono@aol.com>

[3] de Freitas, Imperial Oil Resources, 3535 Research Road N.W., Calgary, Alberta, T2L 2K8, CANADA, <tim.defreitas@iol.ca.sprint.com>.

Manuscript received 04 January 1999; accepted 05 September 1999

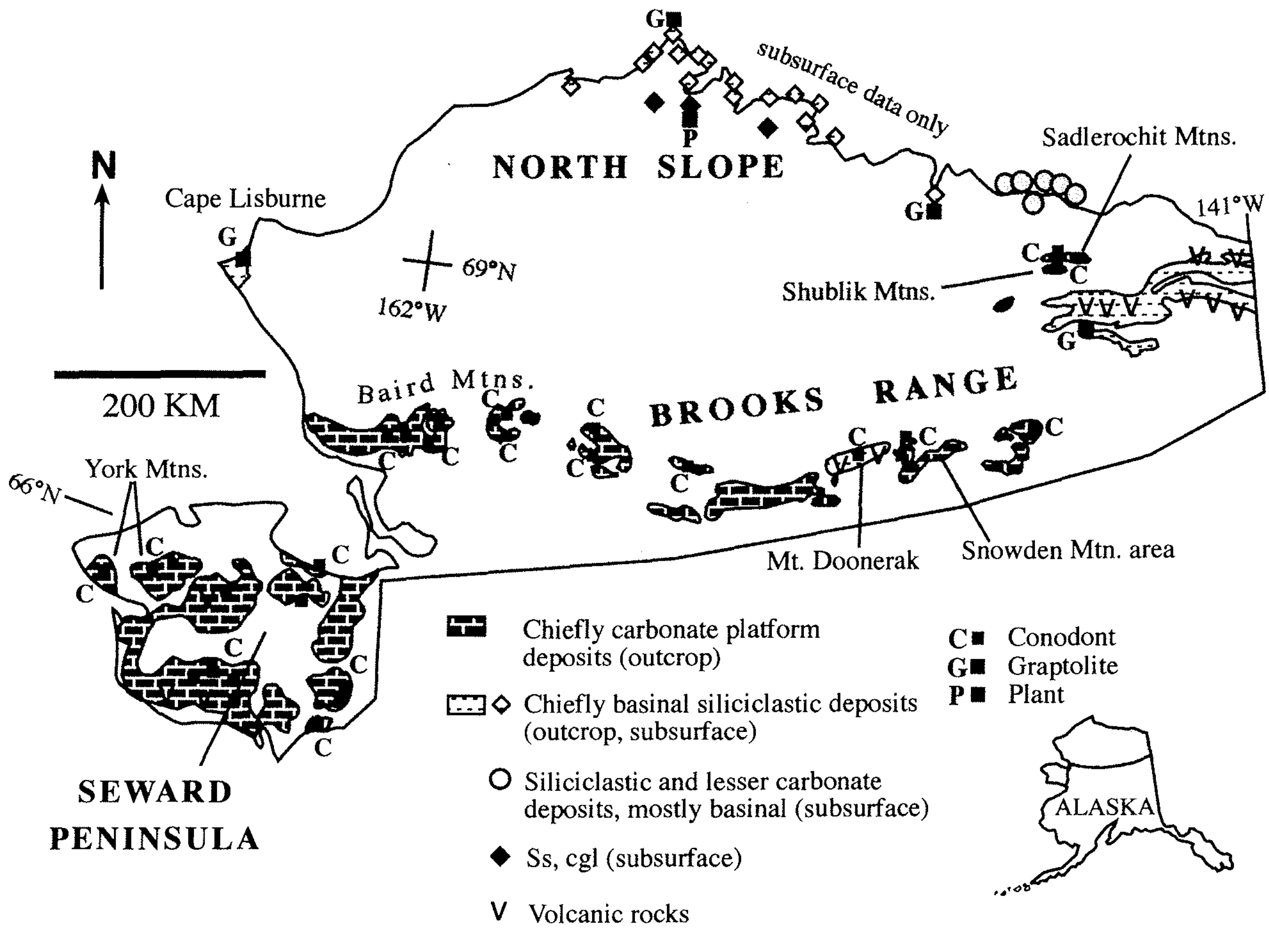

Fig. 2: Distribution of lower Paleozoic lithofacies and selected fossil localities across northern Alaska.

Ellesmerian orogen from latest Ordovician through Devonian. For Arctic Alaska, paleogeographic relationships between the lower Paleozoic platformal and deep-water strata are far less clear, owing to structural complications and an extensive cover of younger rocks. Nonetheless, detailed studies of key platform sections provide an ample basis for comparison with broadly equivalent facies in Canada. This comparison discloses striking dissimilarities in facies patterns, depositional histories, and biogeographic affinities, which in turn suggest that lower Paleozoic rocks now exposed in Arctic Alaska and the Canadian Arctic were *not* juxtaposed during their deposition.

NORTHERN ALASKA LITHOFACIES

Lower Paleozoic strata in northern Alaska crop out on Seward Peninsula, south of Cape Lisburne, and discontinuously throughout the Brooks Range, and have been encountered by exploratory wells drilled for petroleum beneath the North Slope (Fig. 2). South of 68 °N latitude, these strata are primarily platform carbonate rocks; to the north, deeper water siliciclastic rocks predominate. The present configuration of pre-Carboniferous rocks in northern Alaska is a result primarily of Mesozoic and Tertiary tectonism, but may also record effects of Paleozoic tectonic events (Moore et al. 1994, 1997). Original facies relations (such as those between shallow- and deep-water strata) have been disrupted and obscured by widespread thrust and perhaps extensional faulting. Paleogeographic reconstruction is further complicated by exposures of undated metasiliciclastic and subordinate metacarbonate rocks, particularly in the southern Brooks Range, that could include both shallow- and deep-water facies of early Paleozoic age. In the Brooks Range and North Slope, lower Paleozoic rocks are considered part of the Arctic Alaska terrane, whereas coeval strata on Seward Peninsula are called the York and Seward terranes (Silberling et al. 1994). Stratigraphic similarities suggest that lower Paleozoic carbonate successions in all three terranes formed along a single continental margin, but deep-water siliciclastic strata in the Arctic Alaska terrane cannot be depositionally tied to these carbonate rocks until Devonian time or later.

Platform Carbonate Successions

Carbonate successions of early Paleozoic age have been studied in some detail in the York Mountains (western Seward Peninsula), the central and eastern Seward Peninsula, the western and eastern Baird Mountains (western Brooks Range), the Snowden Mountain area (central Brooks Range), and the Shublik and Sadlerochit Mountains (eastern Brooks Range) (Fig. 2, Dumoulin & Harris 1994, Harris et al. 1995, and references therein). Strata in the York, Shublik, and Sadlerochit Mountains are unmetamorphosed. Successions elsewhere in northern Alaska are metamorphosed to greenschist and blueschist facies, but sedimentary features and faunal assemblages are locally well preserved. Stratigraphic and faunal evidence suggest that these strata were once part of a contiguous carbonate platform disrupted by later tectonic events (DUMOULIN & HARRIS 1994).

Rocks interpreted as "basement" to the carbonate platform succession are not widely exposed and have been little studied. In the eastern Baird Mountains, this basement consists of amphibolite facies metasedimentary rocks that have calculated Nd crustal residence ages of 2.0 Ga and are intruded by metagranites with Late Proterozoic (750±6 Ma) U-Pb zircon crystallization ages (NELSON et al. 1993). On central Seward Peninsula, pelitic schists intruded by orthogneiss bodies with U-Pb crystallization ages of 676±15 Ma and 681±3 Ma underlie lower Paleozoic carbonate rocks (PATRICK & MCCLELLAND 1995). In the Shublik and Sadlerochit Mountains, carbonate strata overlie metasedimentary rocks intruded by a mafic dike with an Rb-Sr age of 801±20 Ma (CLOUGH & GOLDHAMMER 1995).

Carbonate strata of Late Proterozoic and Cambrian age in northern Alaska are chiefly shallow-water facies (DUMOULIN & HARRIS 1994). Dolostones of known or inferred Late Proterozoic age crop out in the eastern Baird Mountains, Snowden Mountain area, and Shublik-Sadlerochit Mountains and contain abundant stromatolites and coated grains (both oncoids and ooids). These rocks are overlain by peritidal cycles of limestone and dolostone of Middle and Late Cambrian age in the eastern Baird and Shublik-Sadlerochit Mountains; fossils from these strata include protoconodonts, acrotretid brachiopods, and trilobites. Rare Lower (and lower Middle?) Cambrian carbonate rocks on central and eastern Seward Peninsula contain protoconodonts and the problematic microfossil *Lapworthella* sp., which indicates a shallow-water setting (TILL et al. 1986). Somewhat deeper-water facies of Middle Cambrian and older(?) age occur locally in the eastern Baird and Snowden successions. Pre-Ordovician strata are not recognized in the York or western Baird Mountains.

An intraplatform basin or basins developed in late Early Ordovician time and persisted throughout most of the Middle Ordovician. Basinal strata are longest-lived in the eastern Baird and Snowden Mountain areas, where they overlie shallower water strata of Cambrian and possibly Early Ordovician age. But deep-water rocks also crop out to the west, in the western Baird Mountains and on Seward Peninsula, where they are underlain by and intercalated with shallow-water carbonates of the inner and middle platform. Basinal lithofacies range from at least 50 to more than 200 m thick, are of Arenig to early Caradoc(?) age, and consist of graptolitic shale or phyllite grading upward into carbonate turbidites. On central and eastern Seward Peninsula, a continental platform succession was punctuated by at least one episode of Ordovician rifting, during which iron- and titanium-rich metagabbros that are compositionally similar to modern ridge tholeiites intruded a thick sequence of calcareous and volcanogenic sediments (TILL & DUMOULIN 1994).

Deposition of neritic carbonate resumed in the Late Ordovician across most of Seward Peninsula and the Brooks Range and persisted through the Silurian and locally into the Middle Devonian. In the western Baird and Snowden successions, Devonian platform carbonates are overlain by, and locally grade up into, interbedded limestones and quartz-rich sandstones of Middle and early Late Devonian age. These rocks in turn grade up into the siliciclastic Endicott Group (Upper Devonian and Lower Mississippian), which accumulated chiefly in shallow marine and nonmarine settings, contains abundant detrital chert, and is as much as 2600 m thick (MOORE & NILSEN 1984).

Deep-Water Siliciclastic Successions

Dominantly siliciclastic strata of known early Paleozoic age crop out at three localities in northern Alaska: to the west near Cape Lisburne, in the central Brooks Range at Mount Doonerak, and in the northeastern Brooks Range (Fig. 2). South of Cape Lisburne, Middle Ordovician argillites overlain by Upper Ordovician(?) and Lower Silurian quartzose turbidites were deposited in a slope and (or) basinal setting (MOORE et al. 1994, HARRIS et al. 1995, and references therein); the entire sequence may be as much as 1500 m thick. The lower Paleozoic section at Mount Doonerak consists chiefly of argillite, volcaniclastics, basalt, and minor marble. Rare fossils of Cambrian, Ordovician, and Silurian age are found in these rocks, which were interpreted by JULIAN & OLDOW (1998) as a subduction-related magmatic arc complex. Pre-Carboniferous strata exposed south and southeast of the Shublik and Sadlerochit Mountains and in adjacent areas of northwestern Yukon include argillite, chert, siliciclastic and carbonate metasedimentary rocks, and mafic to intermediate volcanics. Most of the succession appears to have formed in a slope and (or) basinal setting and yields sparse fossils of Cambrian, Ordovician, Silurian, and Early Devonian age (KELLEY et al. 1994, LANE & CECILE 1989, LANE et al. 1995, NORRIS 1986). Carbonate rocks of Cambrian and Late Proterozoic(?) age occur locally and contain rare trilobites and brachiopods, abundant coated grains, and distinctive clasts of rounded detrital quartz; faunal evidence suggests a shallow-water setting for at least some of these strata (DUTRO et al. 1972).

Lower Paleozoic deep-water siliciclastic successions at all three northern Alaska localities are overlain, apparently unconformably, by shallow-marine and nonmarine siliciclastic strata including chert-rich sandstone and conglomerate; these younger rocks are Mississippian near Cape Lisburne and Mount Doonerak but Middle Devonian to Early Mississippian in the northeastern Brooks Range (TAILLEUR 1965, ARMSTRONG et al. 1976, ANDERSON et al. 1994).

In the subsurface beneath Alaska's North Slope, rocks considered part of a Devonian and older "basement complex" are penetrated by at least 75 exploratory wells (Fig. 2, WITMER et al. 1981, BIRD 1982, 1988, and unpublished data, DUMOULIN 1999, and references therein). The chief lithology is dark argillite, locally interbedded with chert, siltstone, and sandstone, that contains Ordovician and Silurian chitinozoans and Silurian graptolites in wells near Barrow and Prudhoe Bay.

Appreciable carbonate rocks are found in the basement complex only east of longitude 146° 40' W, in wells such as Alaska State A-1, F-1, and D-1 (Dumoulin 1999). Basement strata in these wells are chiefly feldspathic siltstones and fine-grained sandstones, with intervals of limestone and dolostone as much as 5-50 m thick. Carbonate intervals contain abundant ooids and rounded detrital quartz, as well as rare phosphatic brachiopods and pelmatozoan debris; these rocks are strikingly similar in composition and texture to, and may be correlative with, Cambrian and Late Proterozoic(?) carbonate rocks in the northeastern Brooks Range. Sedimentary structures (graded bedding, incomplete Bouma sequences) suggest that some of the subsurface carbonate strata accumulated as turbidites in a deep water environment, but other beds may have formed in a shallow-water setting (Dumoulin 1999).

Chert-rich sandstone and conglomerate and lesser shale were penetrated in several wells in the north-central North Slope; in the Topagoruk well, this sequence contains plant fragments of probable late Early-early Middle Devonian age (Witmer et al. 1981). These strata are compositionally similar to, but somewhat older than, exposures of the Endicott Group to the south.

In summary, strata of known early Paleozoic age on Seward Peninsula and throughout the Brooks Range consist largely of platform carbonate rocks deposited on deformed and metamorphosed Late Proterozoic basement. Coeval strata exposed north of latitude 68 °N and penetrated beneath the North Slope are mainly siliciclastic basinal facies of Ordovician and Silurian age. With the exception of the platform carbonate succession in the Shublik and Sadlerochit Mountains, lower Paleozoic shallow-water carbonates north of 68 °N are rare and, where dated, of Cambrian age.

Both pre-Carboniferous platform carbonate strata and coeval deep-water siliciclastics now exposed to the north are overlain by chert-rich, siliciclastic shallow-marine and nonmarine rocks of Devonian and Mississippian age (Endicott Group and older unnamed or informally named Devonian siliciclastic units). These chert-rich younger siliciclastic strata may have been produced by a single depositional system that overlapped older Paleozoic rocks throughout northern Alaska, but no simple age progression for this overlap has been established. The basal contact of the Endicott Group is interpreted as an unconformity in the northeastern Brooks Range and beneath the North Slope, but it may be conformable in parts of the western and central Brooks Range. Basal deposits of the Endicott Group are generally Upper Devonian but are locally as young as Mississippian (eastern North Slope, Mount Doonerak); petrographically similar rocks are as old as Middle Devonian (Topagoruk well, northeastern Brooks Range).

ARCTIC ISLANDS LITHOFACIES

The rotational model for the opening of the Canada Basin restores rocks of northwestern and north-central Alaska to a pre-Cretaceous position adjacent to the western Canadian Arctic Islands (Melville, Prince Patrick, and adjacent islands) (Fig. 1). Pre-Devonian rocks in this area occur mainly in the subsurface, but borehole and seismic data constrain lower Paleozoic facies patterns. Lower Paleozoic lithofacies in the Canadian Arctic have been described in detail elsewhere (e.g., Trettin et al. 1991, De Freitas et al. 1994, Trettin 1998) and are only briefly summarized here. Four main sequences are recognized:
(1) a passive-margin platform that extends along the northern edge of the Laurentian continent from north Greenland, across the Canadian Arctic, to Prince Patrick Island;
(2) a deep-water basin that flanked the platform to the north;
(3) a synorogenic clastic succession deposited in a foreland basin that migrated southward through time, over the former platform, and
(4) in the extreme north, an exotic terrane known as Pearya, which was accreted to the continental margin during late Ordovician to Early Silurian time (Bjørnerud & Bradley 1994, Trettin 1998).

Shallow-Water Platform

Paleozoic platformal facies in the Arctic Islands were deposited on the Canadian Shield. The Shield consists of crystalline basement, metamorphosed in Archean and (or) Early Proterozoic time, unconformably overlain by slightly deformed, sedimentary and volcanic successions of Proterozoic age (Frisch & Trettin 1991). Shield exposures closest to Melville Island – and thus most germane to comparisons with Alaska – are those on Victoria Island, about 200 km to the south. Granodiorite in the metamorphic-plutonic basement here yielded a K-Ar age of 2391±125 Ma. These rocks are unconformably overlain by sporadically distributed Lower and lower Middle Proterozoic sedimentary deposits, and thick successions of Middle and Upper Proterozoic clastic and volcanic rocks. Basaltic flows and pyroclastic deposits in the youngest of these successions yielded K-Ar isochron dates of 635-640 Ma (Frisch & Trettin 1991).

Cambrian shelf and platform strata, exposed chiefly on Ellesmere and Cornwallis islands but recognized in subsurface beneath Melville and Bathurst islands, consist of intercalated siliciclastic and carbonate rocks. Sandstones include both arkoses and quartz arenites; ooids, oncoids, and stromatolites are locally abundant in the carbonates.

Ordovician strata were deposited on a broad, hypersaline shelf rimmed by microbial reefs; successions of Early-Middle Ordovician age are largely shallow water dolostones and evaporites. On southern Ellesmere Island, the Baumann Fiord Formation (Lower Ordovician) consists of about 300 m of shelf gypsum deposits; the Bay Fiord Formation comprises similar, slightly younger (Middle Ordovician) accumulations of gypsum and halite in the subsurface of Melville and adjacent islands.

A regional platform-drowning event, during latest Ordovician-Early Silurian time, marks the onset of foreland basin deposition. As the foreland basin advanced southward, the carbonate platform retreated and was eventually extinguished in the Eifelian (early Middle Devonian).

Deep-Water Basin

During Cambrian and Ordovician time, a deep-water basin lay north of the carbonate platform; strata deposited in this basin include resedimented, shelf-derived carbonates, graptolitic mudrock, chert, and minor sandstone. Although it has sometimes been referred to as the Hazen Trough, this basin was more likely a continental slope-rise facing an ocean of unknown width than a narrow, two-sided trough (Trettin et al. 1991). On northern Ellesmere Island, basinal sediments include Lower Cambrian resedimented oolitic and oncoidal grainstone and siliciclastic turbidites locally rich in feldspar. Elsewhere, basinal strata are chiefly resedimented calcilutite, dolostone, and carbonate conglomerate, mudrock, and radiolarian chert.

Foreland Basin

Beginning in the Late Ordovician, the deep-water basin and platform were successively inundated by synorogenic clastics deposited in a foreland basin. In the deep-water basin, this event is marked by an influx of orogenically-derived siliciclastic turbidites (flysch), transported along strike to the southwest. The shelf edge retreated southward several hundred kilometers (cf. figures 8B.32 and 8B.34 in Trettin et al. 1991); basinal strata of the Cape Phillips Formation and related units (uppermost Ordovician and Silurian graptolitic shale, resedimented carbonates, and minor chert) succeed shelf deposits over much of Melville and adjacent islands. Platform drowning at the onset of foreland-basin sedimentation was accompanied by normal faulting (well documented in north Greenland by Surlyk & Hurst 1983) and by the growth of isolated microbial pinnacle reefs at the former shelf edge (De Freitas & Nowlan 1998); this association is typical of flexural foreland basins in collisional settings (Bradley & Kidd 1991). Flysch eventually gave way to molasse, as thick, nonmarine sandstones of the Ellesmerian clastic wedge prograded southward onto the craton during the Middle and Late Devonian (Embry 1991). Sandstones in this wedge are rich in quartz and chert; chert content is particularly notable in Upper Devonian strata.

Pearya

Pearya is an exotic terrane with a history quite unlike that of the deep-water basin now located just to the south. As summarized by Trettin (1991), the basement of Pearya is a metasedimentary and metavolcanic complex intruded by ca. 1 Ga granitoids. Late Proterozoic(?) to earliest Ordovician strata consist largely of platformal carbonate, quartzite, and mudrock. An Early to Middle Ordovician assemblage includes volcanic rocks and mafic-ultramafic complexes, which were deformed during the Middle Ordovician M'Clintock orogeny, an orogeny not known along what was then the Laurentian margin. The M'Clintock unconformity is overlain by 7-8 km of arc volcanic and sedimentary rocks that range in age from Caradoc to Late Silurian (Trettin 1998). Trettin (1991, 1998) has related Pearya to the Appalachian-Caledonian orogenic system on the basis of its Grenville-age basement, Ordovician arc – and ophiolitic rocks, and Taconic-age orogeny.

LITHOFACIES COMPARISON

Lower Paleozoic lithofacies of Alaska and Arctic Canada show some similarities but also some notable differences. Platform strata are flanked to the north-northwest by basin facies in both areas. Rocks of known and inferred Cambrian age in northeastern Alaska, like coeval rocks in the Canadian Arctic, include feldspathic sandstones and carbonates rich in ooids and oncoids that were deposited in both shallow- and deep-water settings.

Lithofacies differences are particularly notable in Ordovician and Silurian strata. Platform carbonate strata contain local intercalations of volcanic rocks in Alaska (e.g., central Seward Peninsula) but not in the Arctic Islands. While a condensed deep-water sequence of Early-Middle Ordovician age was developing in northern Alaska, widespread evaporites formed in the Canadian Arctic. The regional Silurian drowning and backstepping of the shelf margin in Canada has no known parallel in northern Alaska. Basinal and (or) slope carbonates of Silurian age are recognized on northeastern and southeastern Seward Peninsula and in the central Brooks Range (Ambler River quadrangle), but these are limited, local occurrences that do not appear to represent a widespread retreat of the shelf margin. Basinal facies in northern Alaska are chiefly siliciclastic, whereas resedimented carbonate detritus is volumetrically important in Canada.

NORTHERN ALASKA BIOFACIES

Striking differences characterize early Paleozoic biofacies in northern Alaska and the Canadian Arctic. Macro- and microfossil assemblages from northern Alaska (Dumoulin & Harris 1994 and references therein) contain notable elements typical of Siberian faunal and floral provinces, as well as other forms typical of Laurentia (North American Midcontinent province of older usage, see for example Sweet et al. 1971). Laurentian taxa are common in platform faunas of the Canadian Arctic, but Siberian elements are absent throughout this region.

In northern Alaska, fossils with Siberian affinities occur in the same successions and commonly in the same stratigraphic horizons as forms with Laurentian provinciality. Conodonts illustrate this pattern of "mixed" affinities particularly well (Dumoulin et al. in press). Conodont provinciality worldwide is strongest during the Ordovician. Four Ordovician time intervals are characterized by an important component of Siberian Province conodonts in collections from the Brooks Range and Seward Peninsula (Tab. 1). These intervals – early Arenig, late Arenig-early Llanvirn, latest Llanvirn-early Caradoc, and middle(?) Ashgill – coincide approximately with global sea-level highstands. "Siberian" conodonts include *Fryxellodontus*? n. sp. (= *Acodina*? *bifida* Abaimova) in the earliest Arenig, acanthocodinids and acanthocordylodids in the late Arenig-early

Caradoc, *Stereoconus corrugatus* Moskalenko and *Plectodina*? cf. *P.*? *dolboricus* (Moskalenko) in the early Caradoc, and *Belodina*? *repens* Moskalenko in the middle(?) Ashgill. Our lower Paleozoic conodont data base for northern Alaska encompasses several hundred collections from more than 100 localities. Siberian elements are present in several tens of collections and are strikingly abundant in a few. However, typical Laurentian Province conodonts, such as species of *Clavohamulus* and *Chosonodina* in the early Arenig and *Aphelognathus divergens* in the mid-Ashgill, occur along with the Siberian forms and are locally abundant.

Northern Alaskan macrofossils also have "mixed" affinities (DUMOULIN & HARRIS 1994 and references therein). Fossils with Siberian affinities include Middle Cambrian trilobites from the central Brooks Range (both from the carbonate platform sequence and from volcaniclastic rocks at Mount Doonerak), Early and Late Ordovician trilobites from Seward Peninsula, Late Ordovician brachiopods and gastropods from Seward Peninsula strata in the Brooks Range and Seward Peninsula are chiefly cosmopolitan deep- and (or) cool-water species of the protopanderodid-periodontid biofacies (DUMOULIN & HARRIS 1994). However, some deep-water strata in the western and central Brooks Range yield low numbers of Siberian species such as *Plectodina*? cf. *P.*? *dolboricus* (Moskalenko).

Siberian faunal affinities appear to decrease in intensity from present-day west to east across northern Alaska. Siberian elements are most abundant and diverse in lower Paleozoic strata from the western Seward Peninsula and western Brooks Range, but even these collections contain some western Laurentian Province forms. Certain Siberian faunal elements (such as the pentamerid brachiopod *Tcherskidium* n. sp.) occur throughout northern Alaska and are found as far north and east as the Shublik Mountains (Fig. 2). At least part of the apparent eastward decline in Siberian forms reflects changes in depositional environment. Shallow-water facies of Early and Middle Ordovician age contain notable numbers of Siberian endemics

Taxon	Seward Peninsula	Western Brooks Range	Central & eastern Brooks Range	Farewell terrane central Alaska
Acanthodina sp. indet.				SA
Acanthocordylodus sp. indet.	SA	SA		SA
Belodina? repens Moskalenko	SA			SA
Diaphorodus sp.	LS			
Evencodus sibericus Moskalenko				SA
Fryxellodontus? n. sp. (= *Acodina? bifida* Abaimova)	SA	SA		SA
Histiodella n. sp. 2 of HARRIS et al. 1979		LS		
Loxodus? spp.				LS
Oistodus multicorrugatus Harris				LS
Parapanderodus? consimilis (Moskalenko)		LS		
Plectodina? cf. *P.*? *dolboricus* (Moskalenko)		SA	SA (Central Brook Range only)	
Scolopodus kelpi Repetski	LS			
Stereoconus corrugatus Moskalenko	SA	SA		SA

Tab. 1: Distribution of latest Cambrian and Ordovician conodont taxa of mixed faunal affinities in Seward Peninsula, Brooks Range, and Farewell terrane, Alaska. Thus far, latest Cambrian and Ordovician conodonts with Siberian affinities have not been reported from the eastern Brooks Range or in areas established as part of Laurentia. Abbreviations of faunal affinities: Siberian-Alaskan (SA), Laurentian-Siberian (LS). Species that are limited to Siberia and northern and (or) central Alaska are designated Siberian-Alaskan (SA) forms; these SA forms have not been recognized in areas established as parts of Laurentia. Similarly, species found in Ordovician Laurentia, western and central Alaska, Siberia, and peri-Siberian areas but unknown elsewhere, are designated Laurentian-Siberian (LS) forms. Table modified from DUMOULIN et al. (in press).

and the western and eastern Brooks Range, and Middle Devonian brachiopods (BAXTER & BLODGETT 1994) and Mississippian flora (SPICER & THOMAS 1987) from the northwestern and north-central Brooks Range. Laurentian forms include Early and Late Cambrian trilobites from the eastern Brooks Range, Late Ordovician corals and stromatoporoids from Seward Peninsula and the central Brooks Range, and Devonian corals and stromatoporoids from the western Brooks Range.

Deep-water faunas (e.g. graptolites) from both siliciclastic and carbonate facies in northern Alaska are mainly cosmopolitan and generally provide little specific biogeographic information. For example, conodonts from Early and Middle Ordovician basinal (particularly conodonts), but these facies are rare or absent to the east, where Ordovician basinal strata are best developed. Basinal strata, as noted above, contain largely cosmopolitan forms.

To sum up, both Siberian and Laurentian faunal elements occur at various times and in various fossil groups across northern Alaska. Siberian influences are noted from at least Middle Cambrian through Mississippian time. This pattern of "mixed" faunal influences is strikingly similar to that seen in the Farewell terrane of central Alaska (Tab. 1; DUMOULIN et al. 1998, in press).

ARCTIC ISLANDS BIOFACIES

Conodonts or other fossils with Siberian affinities are not reported from lower Paleozoic rocks of the Canadian Arctic, even though rocks of equivalent age and facies to those with Siberian forms in Alaska are present in Canada. As in Alaska, hundreds of lower Paleozoic samples have been analyzed, but Siberian conodont species that are locally abundant in Alaska do not occur in the Canadian Arctic. Instead, Laurentian Province forms predominate or occur in lower numbers with tropical cosmopolitan and cosmopolitan conodonts (Barnes 1974, Nowlan 1985, Uyeno 1990, G. Nowlan, Geol. Survey of Canada, written commun. 1998).

Some Pearyan biogeographic data were reported by Trettin (1991, 1998). A Late Ordovician unit contains a varied fauna that includes Siberian elements such as the coral *Sibiriolites sibiricus* Sokolov as well as elements characteristic of northern Greenland and the Canadian Arctic platform. Siberian conodonts like those known in Alaska (Tab. 1) are not found in Pearya, however (Trettin 1998, G. Nowlan, written commun., 1998).

DISCUSSION

The lower Paleozoic platforms of Arctic Alaska and the Canadian Arctic thus show significant differences in facies patterns, depositional histories, and biogeographic affinities. We now consider how these findings bear on some aspects of Arctic tectonic history. One interpretation, dating from long before plate tectonics but most recently advocated by Lane (1998), is that Arctic Alaska and the Canadian Arctic have occupied similar positions with respect to each other since the early Paleozoic. In Lane's model, Arctic Alaska formed a promontory at the northwestern (present direction) corner of Laurentia, and the northern margins of Arctic Alaska and of the Canadian Arctic formed when the Siberian craton rifted away during the Late Proterozoic. During the Ordovician, these two adjacent sectors of the Laurentian margin would have been situated in the northern tropics (Fig. 3A; Scotese 1997), a latitudinal belt in which east-to-west surface ocean currents would be expected (Ziegler et al. 1981). The observed Siberian faunal influences in Arctic Alaska and the complete lack thereof in the Canadian Arctic are not easily reconciled with the Lane reconstruction.

One possible way to integrate our biogeographic data with the Lane model is to invoke the Pearyan volcanic arc, located outboard of the Canadian Arctic margin during the early Paleozoic, as a barrier that prevented Siberian faunal elements from reaching this margin but allowed dispersal of these elements into northwestern Alaska (Fig. 3B). Further dispersal of Siberian forms into easternmost Alaska and western Canada could have been limited by latitudinal gradients and (or) the Ordovician intraplatform basin(s) discussed above. If Pearya indeed functioned as such a barrier, some Siberian faunal elements might be expected in Pearya itself. As noted above, such elements do occur in Pearya's macrofauna but have not been reported from its conodont fauna. Although only a few conodont assemblages of Ordovician age have been recovered from Pearya, these consist largely of Laurentian, tropical cosmopolitan, and cosmopolitan species (Trettin 1998).

Several variants exist on the widely accepted model whereby Arctic Alaska, including some or all of Chukotka, rotated away from a position adjacent to the Canadian Arctic during the Cretaceous (Fig. 3C). Our findings bear most directly on the interpretation of Embry (1988), who focused on Devonian foreland-basin deposits and their orogenic source lands. Figures 14 and 15 of Embry (1988) imply that unspecified carbonate platformal areas in the northern Yukon Territory and northern Alaska (presumably the northeastern Brooks Range) were contiguous with the platform of the Canadian Arctic Islands when they formed, and only came to be separated as a result of the Cretaceous opening of the Canada Basin. The presence of Siberian faunas at least as far east as the Shublik-Sadlerochit Mountains finds no easy explanation in this reconstruction.

Grantz et al. (1998) presented a version of the rotational model that specifically takes into consideration the distribution of pre-Devonian facies. In their restoration, deep-water lower Paleozoic strata of Alaska's North Slope are juxtaposed against the Banks Island sector of the Canadian margin. The Arctic Alaskan deep-water basin would, in this interpretation, be an along-strike continuation of the continental slope and rise of the lower Paleozoic Canadian Arctic passive margin. The lower Paleozoic platformal carbonates of the Brooks Range would, accordingly, restore to the opposite margin of the deep-water basin. Our biogeographic data constrain certain aspects of this model. Persistent Siberian affinities characterize the Alaskan side of this hypothetical basin, but are completely lacking on the Canadian side. Siberian faunal elements are found in Chukotka, on Seward Peninsula, throughout the Brooks Range, at Mount Doonerak in the siliciclastic-volcanic sequence, and in the Shublik-Sadlerochit Mountains, but are unknown in the Canadian Arctic Islands, the Canadian Cordillera, and east-central Alaska (Porcupine terrane of Silberling et al. 1994). For this postulated deep-water basin to have formed a persistent barrier between Siberian and Laurentian faunas, it would necessarily have been an ocean of considerable width (many hundreds or even thousands of kilometers).

If such an ocean basin did indeed exist, how and when might it have closed, to achieve a pre-Cretaceous Arctic restoration such as that of Grantz et al. (1998)? Middle Devonian "Ellesmerian" orogenesis in the northern Yukon and North Slope (e.g., Embry 1988) seems the most likely known event that could correspond to a collision involving an Arctic Alaskan microcontinent, bearing its Siberian faunas, and the northwestern corner of Laurentia. This seems plausible but several problems await resolution. A full discussion is far beyond the scope of this paper, but a few key points bear noting. One involves biogeography and timing: Middle Devonian collision would seem to be incompatible with reports of Siberian floras of Mississippian age from Arctic Alaska (Spicer & Thomas 1987). Because Mississippian phytogeographic data are lacking from northwestern Laurentia (Rowley et al. 1985), however, the Siberian flora from Alaska may not prove to be diagnostic. This line of evidence is certainly worthy of more attention. Another concern involves correlation of deformational

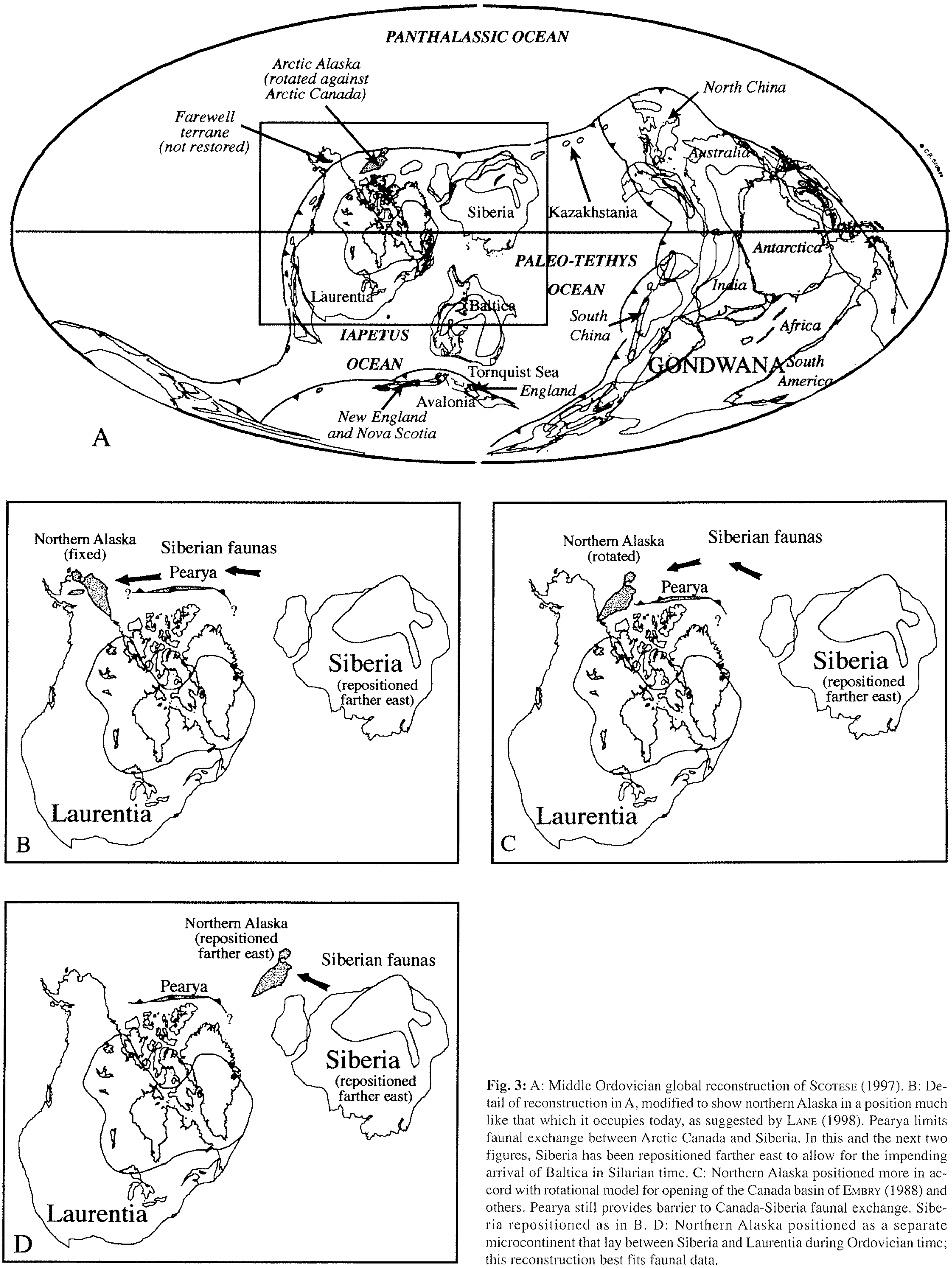

Fig. 3: A: Middle Ordovician global reconstruction of Scotese (1997). B: Detail of reconstruction in A, modified to show northern Alaska in a position much like that which it occupies today, as suggested by Lane (1998). Pearya limits faunal exchange between Arctic Canada and Siberia. In this and the next two figures, Siberia has been repositioned farther east to allow for the impending arrival of Baltica in Silurian time. C: Northern Alaska positioned more in accord with rotational model for opening of the Canada basin of Embry (1988) and others. Pearya still provides barrier to Canada-Siberia faunal exchange. Siberia repositioned as in B. D: Northern Alaska positioned as a separate microcontinent that lay between Siberia and Laurentia during Ordovician time; this reconstruction best fits faunal data.

events between Arctic Alaska and the Canadian Arctic. Although the timing of orogeny in both areas is broadly similar (i.e., Devonian), LANE (1997) suggests that in detail, the timing of specific tectonic events cannot be precisely matched.

Other problems with the hypothesis of a middle Paleozoic collision involving Arctic Alaska and Arctic Canada relate to the identity of the arc and subduction zone along which the postulated ocean closed, and the polarity of subduction. As outlined above, Pearya lies outboard of the lower Paleozoic passive margin of the Canadian Arctic, and the two areas are inferred to have been sutured during Late Ordovician to Early Silurian time after consumption of an ocean basin along a north-dipping (present direction) subduction zone (BJØRNERUD & BRADLEY 1994, TRETTIN 1998). Where it disappears to the southwest beneath younger rocks and the Arctic ice pack, Pearya trends generally toward Arctic Alaska (Fig. 1). Assuming the rotational opening of the Canada Basin and Paleozoic facies patterns similar to those outlined by GRANTZ et al. (1998), an along-strike continuation of the Pearyan subduction zone in Arctic Alaska would dip toward the south (present direction). In Arctic Alaska, Ordovician volcanic rocks at Mount Doonerak have been interpreted as the products of arc magmatism (JULIAN & OLDOW 1998). The pre-Brookian palinspastic position of the Doonerak arc with respect to other Paleozoic rocks is controversial (cf. MULL et al. 1987, KELLEY & BROSGE 1995), but in the interpretation of MULL et al. (1987), Doonerak area rocks restore to a pre-Mesozoic position between the platform carbonates of the Brooks Range and the deep-water facies of the North Slope. In this case, the Doonerak arc could conceivably represent a continuation of the subduction zone inferred to have dipped beneath Pearya – though not a piece of Pearya itself (dissimilarities between Pearya and the rocks of northern Alaska are discussed by TRETTIN 1998: 209).

Finally, our biogeographic analysis of conodonts from Arctic Alaska and the Farewell terrane of central Alaska provides a new twist to the notion of a "Siberian" origin for these terranes. Conodonts from each of these areas include both Siberian forms that are absent from the Laurentian craton, and Laurentian forms that are absent from the Siberian craton (Tab. 1; DUMOULIN et al. in press). BLODGETT (1998: 53, 58) suggested that most lower Paleozoic rocks in Alaska, including those in northern Alaska, represent fragments of "the Siberian continent" that rifted away sometime after the Early Devonian and were subsequently accreted to the Laurentian margin. In our view, the mixed Laurentian and Siberian faunas suggest, instead, that by Ordovician time, Arctic Alaska - Chukotka lay between Siberia proper and Laurentia proper, and was separated from each by a substantial ocean (Fig. 3D). This idea of Arctic Alaska as a separate microcontinent during early Paleozoic time has been advanced on other grounds by PATRICK & MCCLELLAND (1995) and SENGÖR & NATAL'IN (1996).

Many questions remain unresolved concerning Paleozoic paleogeography of the Arctic. But our data on lithofacies and biofacies patterns strongly suggest that lower Paleozoic platform carbonates now exposed in Arctic Alaska and the Canadian Arctic were *not* juxtaposed during their deposition.

References

Anderson, A.V., Wallace, W.K. & Mull, C.G. (1994): Depositional record of a major tectonic transition in northern Alaska: Middle Devonian to Mississippian rift-basin margin deposits, upper Kongakut River region, eastern Brooks Range, Alaska.- In: D.K. THURSTON & K. FUJITA (eds.), 1992 Proc. International Conf. on Arctic Margins: U.S. Min. Management Serv. Outer Continental Shelf Study MMS 94-0040, Anchorage, Alaska, 71-76.

Armstrong, A.K., Mamet, B.L., Brosgé, W.P. & Reiser, H.N. (1976): Carboniferous section and unconformity at Mount Doonerak, Brooks Range, northern Alaska.- Amer. Assoc. Petrol. Geol. Bull. 60: 962-972.

Barnes, C.R. (1974): Ordovician conodont biostratigraphy of the Canadian Arctic.- In: J.D. AITKEN & D.J. GLASS (eds.), Proceedings of the Symposium on the Geology of the Canadian Arctic, Geol. Assoc. Canada, Canadian Soc. Petrol. Geol., Saskatoon, Saskatchewan, 221-240.

Baxter, M.E. & Blodgett, R.B. (1994): A new species of *Droharhynchia* (Brachiopoda) from the lower Middle Devonian (Eifelian) of west-central Alaska.- J. Paleont. 68: 1235-1240.

Bird K.J. (1982): Rock unit report of 228 wells drilled on the North Slope, Alaska.- U.S. Geol. Surv. Open-File Rept 82-278: 106 pp.

Bird K.J. (1988): Alaskan North Slope stratigraphic nomenclature and data summary for government-drilled wells.- In: G. GRYC (ed.), Geology and exploration of the National Petroleum Reserve in Alaska, 1974 to 1982: U.S. Geol. Surv. Prof. Paper 1399: 317-353.

Bjørnerud, M.G. & Bradley, D.C. (1994): Silurian foredeep and accretionary prism in northern Ellesmere Island: Implications for the nature of the Ellesmerian orogeny.- In: D.K. THURSTON & K. FUJITA (eds.), 1992 Proc. International Conf. on Arctic Margins: U.S. Min. Management Serv. Outer Continental Shelf Study MMS 94-0040, Anchorage, Alaska, 129-133.

Blodgett, R.B. (1998): Emsian (late Early Devonian) fossils indicate a Siberian origin for the Farewell Terrane.- In: J.G. CLOUGH & F. LARSON (eds.), Short notes on Alaska Geology 1997, Alaska Div. Geol. & Geophys. Surv. Prof. Rep. 118: 53-61.

Bradley, D.C. & Kidd, W.S.F. (1991): Flexural extension of the upper continental crust in collisional foredeeps.- Geol. Soc. Amer. Bull. 103: 1416-1438.

Clough, J.G. & Goldhammer, R.K. (1995): Deposition on a Late Proterozoic carbonate ramp, Katakturuk Dolomite, northeast Brooks Range, Alaska.- Geol. Soc. Amer. Abstracts 27: 10.

de Freitas, T.A. & Nowlan, G.S. (1998): A new, major Silurian reef tract and overview of regional Silurian reef development, Canadian Arctic and north Greenland.- Bull. Can. Petrol. Geol. 46: 327-349.

de Freitas, T., Mayr, U. & Harrison, J.C. (1994): Lower Paleozoic T-R sequence stratigraphy, central Canadian Arctic.- In: D.K. THURSTON & K. FUJITA (eds.), 1992 Proc. International Conf. on Arctic Margins, U.S. Min. Management Serv. Outer Continental Shelf Study MMS 94-0040, Anchorage, Alaska, 123-128.

Dumoulin, J.A. (1999): Carboniferous and older carbonate rocks: lithofacies, extent, and reservoir quality.- In: The oil and gas resource potential of the Arctic National Wildlife Refuge 1002 area, Alaska: U.S. Geol. Surv. Open-File Rept. 98-34.

Dumoulin, J.A., Bradley, D.C., Harris, A.G. & Repetski, J.E. (1998): Sedimentology, conodont biogeography, and subsidence history of the Nixon Fork terrane, Medfra quadrangle, Alaska.- III International Conf. on Arctic Margins Abstracts, Celle, Germany, 49.

Dumoulin, J.A. & Harris, A.G. (1994): Depositional framework and regional correlation of pre-Carboniferous metacarbonate rocks of the Snowden Mountain area, central Brooks Range, northern Alaska.- U.S. Geol. Surv. Prof. Paper 1545: 74 pp.

Dumoulin, J.A., Harris, A.G., Gagiev, M., Bradley, D.C. & Repetski, J.E. (in press): Lithostratigraphic and faunal links between lower Paleozoic strata in northern and central Alaska and northeastern Russia.- In: E.L. MILLER, S. KLEMPERER & A. GRANTZ (eds.), Tectonic evolution of the Bering Shelf-Chukchi Sea-Arctic Margin, and adjacent landmasses, Geol. Soc. Amer. Special Paper.

Dutro, J.T. Jr., Brosgé W.P. & Reiser, H.N. (1972): Significance of recently discovered Cambrian fossils and reinterpretation of Neruokpuk Formation, Northeastern Alaska.- Amer. Assoc. Petrol. Geol. Bull. 56: 808-815.

Embry, A.F. (1988): Middle-Upper Devonian sedimentation in the Canadian Arctic Islands and the Ellesmerian Orogeny.- In: A.F. McMILLIN, A.F.

EMBRY & D.J. GLASS (eds.), Devonian of the world, Can. Soc. Petrol. Geol. Mem. 14, v. 2: 15-28.

Embry, A.F. (1991): Middle-Upper Devonian clastic wedge of the Arctic Islands.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Boulder, Colo., Geol. Soc. Amer., The Geology of North America E-3: 263-279.

Frisch, T. & Trettin, H.P. (1991): Precambrian successions in the northernmost part of the Canadian Shield.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Boulder, Colo., Geol. Soc. Amer., The Geology of North America E-3: 103-108.

Grantz, A., Clark, D.L., Phillips, R.L. & Srivastava, S.P. (1998): Phanerozoic stratigraphy of Northwind Ridge, magnetic anomalies in the Canada basin, and the geometry and timing of rifting in the Amerasia basin, Arctic Ocean.- Geol. Soc. Amer. Bull. 110: 801-820.

Grantz, A., Moore, T.E. & Roeske, S.M. (1991): Continent-ocean transect A-3—Gulf of Alaska to Arctic Ocean.- Geol. Soc. Amer., 72 pp., 3 sheets, scale 1:500,000.

Halgedahl, S. & Jarrard, R. (1987): Paleomagnetism of the Kuparuk River Formation from oriented drill core: evidence for rotation of the Arctic Alaska Plate.- In: I. TAILLEUR & P. WEIMER (eds.), Alaskan North Slope geology, Bakersfield, California, Pacific Sec. SEPM & Alaska Geol. Soc., Book 50, v. 2: 581-617.

Harris, A.G., Dumoulin, J.A., Repetski, J.E. & Carter, C. (1995): Correlation of Ordovician rocks of northern Alaska.- In: J.D. COOPER, M.L. DROSER & S.C. FINNEY (eds.), Ordovician odyssey: Short papers for the 7th International Symp. on the Ordovician system, Fullerton, California, Pacific Sec. for Sedimentary Geol. (SEPM), Book 77, 21-26.

Julian, F.E. & Oldow, J.S. (1998): Structure and lithology of the lower Paleozoic Apoon assemblage, eastern Doonerak window, central Brooks Range, Alaska.- In: J.S. OLDOW & H.G. AVÉ LALLEMANT (eds.), Architecture of the central Brooks Range fold and thrust belt, Arctic Alaska: Geol. Soc. Amer. Spec. Paper 324: 65-80.

Kelley J.S. & Brosgé, W.P. (1995): Geologic framework of a transect of the central Brooks Range: regional relations and an alternative to the Endicott Mountains allochthon.- AAPG Bull. 79: 1087-1115.

Kelley J.S., Wrucke, C.T. & Lane, L.S. (1994): Pre-Mississippian rocks in the Clarence and Malcolm Rivers area, Alaska, and the Yukon Territory.- In: D.K. THURSTON & K. FUJITA (eds.), 1992 Proc. International Conf. on Arctic Margins: U.S. Min. Management Serv. Outer Continental Shelf Study MMS 94-0040, Anchorage, Alaska, 59-64.

Lane, L.S. (1997): Canada Basin, Arctic Ocean: Evidence against a rotational origin.- Tectonics 16: 363-387.

Lane, L.S. (1998): "Fixist" origin for Arctic Alaska: the Rodinia reconstruction.- III International Conf. on Arctic Margins Abstracts, Celle, Germany, 107-108.

Lane, L.S. & Cecile, M.P. (1989): Stratigraphy and structure of the Neruokpuk Formation, northern Yukon.- In: Current Research, Part G, Geol. Surv. Canada Paper 89-1G: 57-62.

Lane, L.S., Kelley, J.S. & Wrucke, C.T. (1995): Stratigraphy and structure of the Clarence River area, Yukon-Alaska north slope: A USGS-GSC co-operative project. - In: Geol. Surv. Canada Current Research, 1995-E: 1-9.

Moore, T.E.& Nilsen, T.H. (1984): Regional sedimentological variations in the Upper Devonian and Lower Mississippian(?) Kanayut Conglomerate, Brooks Range, Alaska.- Sedimentary Geol. 38: 465-497.

Moore, T.E., Wallace, W.K., Bird, K.J., Karl, S.M., Mull, C.G. & Dillon, J.T. (1994): Geology of northern Alaska.- In: G. PLAFKER & H.C. BERG (eds.), The Geology of Alaska, Boulder, Colo., Geol. Soc. Amer., The Geology of North America G-1: 49-140.

Moore, T.E., Wallace, W.K., Mull, C.G., Adams, K.E., Plafker, G. & Nokleberg, W.J. (1997): Crustal implications of bedrock geology along the Trans-Alaska Crustal Transect (TACT) in the Brooks Range, northern Alaska.- J. Geophys. Res. 102: 20,645-20,684.

Mull, C.G., Roeder, D.H., Tailleur, I.L., Pessel, G.H., Grantz, A. & May, S.D. (1987): Geologic sections and maps across Brooks Range and Arctic Slope to Beaufort Sea, Alaska.- Geol. Soc. Amer. Map Chart Ser. MC28S.

Nelson, B.K., Nelson, S.W. & Till, A.B. (1993): Nd- and Sr-isotope evidence for Proterozoic and Paleozoic crustal evolution in the Brooks Range, northern Alaska.- J. Geol. 101: 435-450.

Norris, D.K. (1986): Lower Devonian Road River Formation on the north flank of the Romanzof Uplift, northern Yukon Territory.- In: Current Research Part A, Geol. Surv. Canada Paper 86-1A, p. 801-802.

Nowlan, G.S. (1985): Late Cambrian and Early Ordovician conodonts from the Franklinian Miogeosyncline, Canadian Arctic Islands.- J. Paleontol. 59: 96-102.

Palmer, A.R., Dillon, J., and Dutro, J.T., Jr. (1984): Middle Cambrian trilobites with Siberian affinities from the central Brooks Range.- Geol. Soc. Amer. Abstracts w. Programs 16: 327.

Patrick, B.E. & McClelland, W.C. (1995): Late Proterozoic granitic magmatism on Seward Peninsula and a Barentian origin for Arctic Alaska-Chukotka.- Geol. 23: 81-84.

Rowley, D.B., Raymond, A., Parrish, J.T., Lottes, A.L., Scotese, C.R. & Ziegler, A.M. (1985): Carboniferous paleogeographic, phytogeographic, and paleoclimate reconstructions.- Int. J. Coal Geol. 5: 7-42.

Scotese, C.R. (1997): Paleogeographic Atlas.- PALEOMAP Progress Report 90-0497, Dept. Geol., Univ. Texas at Arlington, 37 pp.

Sengör, A.M.C. & Natal'in, B.A. (1996): Paleotectonics of Asia: fragments of a synthesis.- In: A. YIN & M. HARRISON (eds.), The tectonic evolution of Asia: Rubey Colloquium, Cambridge University Press, Cambridge, 486-640.

Silberling, N.J., Jones, D.L., Monger, J.W.H., Coney, P.J., Berg, H.C. & Plafker, G. (1994): Lithotectonic terrane map of Alaska and adjacent parts of Canada.- In: G. PLAFKER & H.C. BERG (eds.), The geology of Alaska, Boulder, Colo., Geol. Soc. Amer., The Geology of North America G-1, plate 3, 1 sheet, scale 1:2,500,000.

Spicer, R.A. & Thomas, B.A. (1987): A Mississippian Alaska-Siberia connection: evidence from plant megafossils.- In: I. TAILLEUR & P. WEIMER (eds.), Alaskan North Slope geology, Bakersfield, California, Pacific Sec. SEPM & Alaska Geol. Soc., Book 50, v. 1: 355-358.

Surlyk, F. & Hurst, J.M. (1983): Evolution of the early Paleozoic deep-water basin of north Greenland—aulacogen or narrow ocean?- Geol. 11: 77-81.

Sweet, W.C., Ethington, R.L. & Barnes, C.R. (1971): North American Middle and Upper Ordovician conodont faunas.- In: W.C. SWEET & S.M. BERGSTRÖM (eds.), Symposium on conodont biostratigraphy, Geol. Soc. Amer. Memoir 127: 163-193.

Tailleur, I.L. (1965): Low-volatile bituminous coal of Mississippian age on the Lisburne Peninsula, northwestern Alaska.- In: Geol. Surv. Research 1965, U.S. Geol. Surv. Prof. Paper 525-B: B34-B38.

Till, A.B. & Dumoulin, J.A. (1994): Seward Peninsula: The Seward and York terranes.- In: G. PLAFKER & H.C. BERG (eds.), The geology of Alaska, Boulder, Colo., Geol. Soc. Amer., The Geology of North America G-1: 141-152.

Till, A.B., Dumoulin, J.A., Gamble, B.M., Kaufman, D.S. & Carroll, P.I. (1986): Preliminary geologic map and fossil data, Solomon, Bendeleben, and southern Kotzebue quadrangles, Seward Peninsula, Alaska.- U.S. Geol. Surv. Open-File Report 86-276, 74 pp., 3 sheets, scale 1:250,000.

Trettin, H.P. (1991): The Proterozoic to Late Silurian record of Pearya.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Boulder, Colo., Geol. Soc. Amer., The Geology of North America E-3: 239-260.

Trettin, H.P. (1998): Pre-Carboniferous geology of the northern part of the Arctic Islands.- Geol. Surv. Canada, Bull. 425, 401 pp.

Trettin, H.P., Mayr, U., Long, G.D.F. & Packard, J.J. (1991): Cambrian to early Devonian basin development, sedimentation, and volcanism, Arctic Islands.- In: H.P. TRETTIN (ed.), Geology of the Innuitian Orogen and Arctic Platform of Canada and Greenland, Boulder, Colo., Geol. Soc. Amer., The Geology of North America E-3: 165-238.

Uyeno, T.T. (1990): Biostratigraphy and conodont faunas of Upper Ordovician through Middle Devonian rocks, eastern Arctic Archipelago.- Geol. Surv. Canada, Bull. 401, 210 pp.

Witmer, R.J., Haga, H. & Mickey, M.B. (1981): Biostratigraphic report of thirty-three wells drilled from 1975 to 1981 in National Petroleum Reserve in Alaska.- U.S. Geol. Surv. Open-File Rept. 81-1166.

Ziegler, A.M., Bambach, R.K., Parrish, J.T., Barrett, S.F., Gierlowski, E.H., Parker, W.C., Raymond, A. & Sepkoski, J.J., Jr. (1981): Paleozoic biogeography and climatology.- In K.J. NIKLAS (ed.), Paleobotany, Paleoecology, and Evolution, Vol. 2, Praeger Press, New York: 231-266.