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Lower Paleozoic Deep-Water Facies of the Medfra Area, Central Alaska[1]

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Abstract

Deep-water facies, chiefly hemipelagic deposits and turbidites, of Cambrian through Devonian age are widely exposed in the Medfra and Mt. McKinley quadrangles. These strata include the upper part of the Telsitna Formation (Middle-Upper Ordovician) and the Paradise Fork Formation (Lower Silurian–Lower Devonian) in the Nixon Fork terrane, the East Fork Hills Formation (Upper Cambrian–Lower Devonian) in the East Fork subterrane of the Minchumina terrane, and the chert and argillite unit (Ordovician) and the argillite and quartzite unit (Silurian-Devonian? and possibly older) in the Telida subterrane of the Minchumina terrane.

In the western part of the study area (Medfra quadrangle), both hemipelagic deposits and turbidites are largely calcareous and were derived from the Nixon Fork carbonate platform. Eastern exposures (Mt. McKinley quadrangle; eastern part of the Telida subterrane) contain much less carbonate; hemipelagic strata are mostly chert, and turbidites contain abundant rounded quartz and lesser plagioclase and potassium feldspar. Deep-water facies in the Medfra quadrangle correlate well with rocks of the Dillinger terrane exposed to the south (McGrath quadrangle), but coeval strata in the Mt. McKinley quadrangle are compositionally similar to rocks to the northeast (Livengood quadrangle). Petrographic data thus suggest that the Telida subterrane as presently defined is an artificial construct made up of two distinct sequences of disparate provenance.

Restoration of 90 and 150 km of dextral strike-slip on the Iditarod and Farewell faults, respectively, aligns the deep-water strata of the Minchumina and Dillinger terranes in a position east of the Nixon Fork carbonate platform. This restoration supports the interpretation that lower Paleozoic rocks in the Nixon Fork and Dillinger terranes, and in the western part of the Minchumina terrane (East Fork subterrane and western part of the Telida subterrane), formed along a single continental margin. Rocks in the eastern part of the Telida subterrane are compositionally distinct from those to the west and may have had a different origin and history.

Introduction

Lower Paleozoic rocks deposited in deep-water, off-platform settings occur widely throughout central Alaska. In this paper we describe the lithofacies, biostratigraphy, depositional environments, and regional correlation of Upper Cambrian through Lower Devonian deep-water strata exposed in parts of the Medfra and Mt. McKinley 1:250,000 quadrangles (figs. 1, 2). These rocks have been variously correlated but have received little detailed study. They were assigned to the Nixon Fork and Minchumina terranes by Patton and others (1994) but were included in the White Mountain sequence of the Farewell terrane by Decker and others (1994).

The terminology used for lower Paleozoic rocks in central Alaska is confusing and contentious. Deep-water strata in the McGrath and Lime Hills quadrangles south of the Medfra area, considered part of the White Mountain sequence by Decker and others (1994), have also been called the Dillinger terrane (Jones and others, 1981; Silberling and others, 1994) or sequence (Gilbert and Bundtzen, 1984). Coeval platform facies in this area, called Nixon Fork terrane or sequence by other authors (Silberling and others, 1994; Gilbert and Bundtzen, 1984), are included by Decker and others (1994) in their White Mountain sequence. We agree with Decker and others (1994) that lower Paleozoic strata in their Farewell terrane probably formed along a single continental margin but find their terminology for subdivisions of the Farewell awkward and inadequate. In this paper we follow the terrane terminology of Silberling and others (1994) except where noted and refer to lower Paleozoic deep-water facies in the McGrath and Lime Hills quadrangles as the "Dillinger terrane" (fig. 1). We use terrane, however, in the older sense of the word to indicate a belt of related rocks and not as redefined (e.g., Jones and others, 1981) to require fault boundaries and imply "exotic" origins for these belts.

Our lithologic and biostratigraphic data indicate that lower Paleozoic deep-water facies of the Medfra quadrangle correlate relatively well with deep-water facies of the Dillinger terrane

[1] During field work in 1998, we discovered a previously unreported belt of Silurian-Devonian deep-water facies in the northeastern corner of the Medfra quadrangle. These rocks are described in Dumoulin, J.A., Bradley, D.C., and Harris, A.G., in press, Paleozoic strata of the Dyckman Mountain area, northeastern Medfra quadrangle, Alaska, *in* Kelley, K.D., and Gough, L.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1998: U.S. Geological Survey Professional Paper 1615.

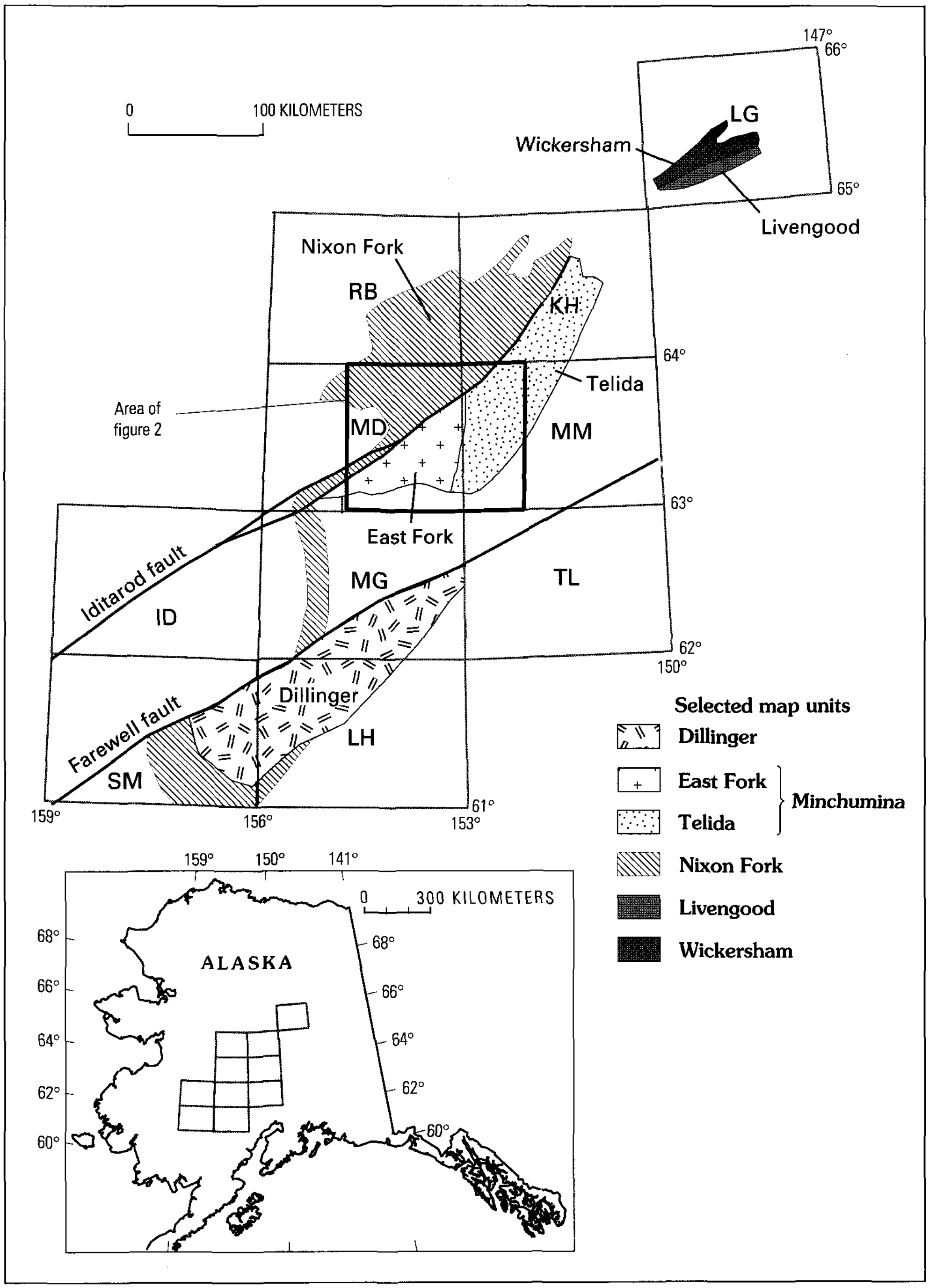

Figure 1. Location of quadrangles and selected tectonostratigraphic terranes and subterranes mentioned in text; East Fork and Telida are subterranes of Minchumina terrane. Dillinger and Nixon Fork south of lat 63°N. modified from Decker and others (1994) and Silberling and others (1994); East Fork, Nixon Fork north of lat 63°N., and Telida from Patton and others (1994); Livengood and Wickersham from Silberling and others (1994). The Farewell terrane of Decker and others (1994) includes the Nixon Fork, Minchumina, and Dillinger terranes shown here. Quadrangles: ID, Iditarod; KH, Kantishna River; LG, Livengood, LH, Lime Hills; MD, Medfra; MG, McGrath; MM, Mt. McKinley; RB, Ruby; SM, Sleetmute; TL, Talkeetna.

exposed to the south (McGrath quadrangle). Coeval deep-water strata in the Mt. McKinley quadrangle have stronger lithologic similarities to rocks of the Wickersham and Livengood terranes to the northeast (Livengood quadrangle).

Previous Work and Methods

Lower Paleozoic deep-water strata in the Medfra quadrangle were briefly described by Patton and others (1980) and Dutro

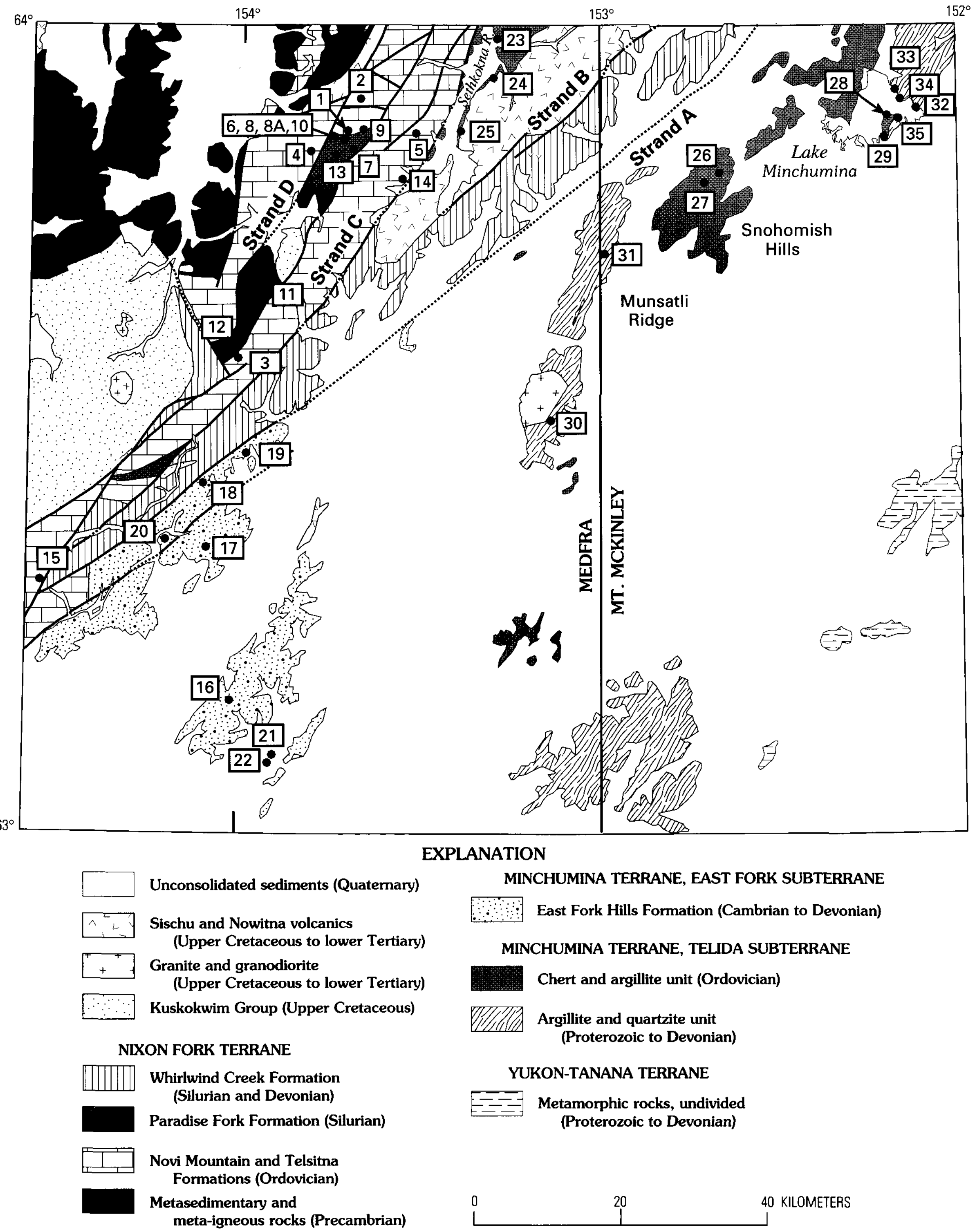

Figure 2. Location of lithologic and fossil collections and structural data from study area in Medfra (MD) and Mt. McKinley (MM) quadrangles. Geologic mapping from Patton and others (1980) (MD) and Wilson and others (1998) (MM). Letters A, B, C, and D refer to strands of the Iditarod fault system mentioned in text. Outcrops between Iditarod fault strands B and C shown here as chert and argillite unit were mapped as Pzc by Patton and others (1980). Novi Mountain and Telsitna Formations as shown include outcrops of Whirlwind Creek Formation too small to show at scale of map. Newly recognized deep-water facies mentioned in footnote on first page of this article are located between localities 25 and 31 in belt shown as Whirlwind Creek Formation.

and Patton (1982); sparse lithologic and fossil data from correlative rocks in the Mt. McKinley and Kantishna River quadrangles were reported by Chapman and others (1975), Chapman and Yeend (1981), Chapman and others (1981), and Patton and others (1994).

We examined lower Paleozoic rocks in the Medfra area at 36 localities. Microlithofacies were established through field observations and study of about 80 thin sections. Conodont age and biofacies determinations are based on 14 new collections and 13 older, unpublished collections reexamined for this paper (table 1). Interpretations of depositional environments follow models in Wilson (1975), Cook and others (1983), and Scholle and others (1983).

Lithofacies, Age, and Depositional Environment

Deep-water strata described here belong to three formations (Dutro and Patton, 1982) and several unnamed map units (Patton and others, 1980; Chapman and Yeend, 1981) that have been grouped into two terranes (Patton and others, 1994). We follow below the terrane terminology of Patton and others (1994) unless otherwise noted.

Nixon Fork Terrane

Precambrian through Mesozoic strata of the Nixon Fork terrane form a southwest-trending belt in the eastern and central Medfra quadrangle (fig. 1). Some 5,500 m of Ordovician through Devonian rocks in this terrane comprise a chiefly platform carbonate succession interrupted by an interval of deeper water facies. Four formations are recognized (Dutro and Patton, 1982); deep-water strata occur in the uppermost part of the Telsitna Formation (Ordovician) and throughout the Paradise Fork Formation (Silurian and Lower Devonian). The Novi Mountain Formation (Lower Ordovician) and the Whirlwind Creek Formation (Upper Silurian and Devonian) consist exclusively of shallow-water facies. In this report, we focus on deep-water facies within the lower Paleozoic succession. The Nixon Fork terrane is cut by a series of northeast-striking faults (Patton and others, 1980); details of stratigraphy, lithofacies, and thermal history differ across these faults, as will be detailed below.

Telsitna Formation

The Telsitna Formation consists of about 2,000 m of limestone and lesser dolostone (Dutro and Patton, 1982) deposited largely in supratidal to shallow subtidal settings (Measures and others, 1992). In a section just south of the type section (fig. 2, loc. 1), the uppermost part of the Telsitna is light-gray-weathering, dark-brownish-gray micrite, partly dolomitized, in 10- to 30-cm-thick beds. Stringers and nodules of tan, gray, or black chert, generally a few centimeters thick, parallel bedding. Bioherms a few meters across, made up of corals and (or) stromatoporoids, are locally abundant. These beds contain conodonts of probable Late Ordovician age deposited in a warm, shallow-water setting (table 1, loc. 1; fig. 3*A*). Lithologically similar strata comprise the upper part of the type section, 4.5 km to the north (fig. 2, loc. 2). Conodonts near the top of this section are early Late Ordovician (middle Edenian–early Maysvillian) and indicate a tropical, shallow-water environment (table 1, loc. 2). Corals and brachiopods in the uppermost beds in this section are also of Maysvillian age (Dutro and Patton, 1982).

Distinctly different facies, however, characterize the uppermost Telsitna Formation in an elongate fault block southeast of the type section (fig. 2, loc. 3). In this area, several hundred meters of dark-gray-weathering, grayish-black micrite, in platy to irregular beds a few millimeters to 20 cm thick, forms the top of the Telsitna. Subordinate silt- to sand-sized clasts are disseminated throughout this micrite and are locally concentrated into graded layers a few millimeters thick. Clasts include peloids, calcitized radiolarians, and calcareous and siliceous sponge spicules (some radiolarians and spicules are pyritized) (figs. 3*B*, 3*C*). A few samples contain fragments of pelmatozoans, brachiopods, ostracodes, trilobites, and possible algae. These beds produced three conodont collections; the most diagnostic samples are very latest Ordovician (table 1, loc. 3; figs. 4*M*–4*AA*). All collections are distal winnows deposited in a deep-shelf to basinal setting.

Conodonts indicative of a deep-water depositional environment were also recovered from the upper part of the Telsitna Formation in fault blocks west and east of the type area (table 1, locs. 4, 5). Strata at both localities are fine-grained, brownish-gray, locally bioclastic limestone. The western collection (loc. 4) is late Middle Ordovician; the eastern faunule (loc. 5) is correlative or slightly younger.

Lithologic and paleontologic data thus demonstrate that different sections of the uppermost Telsitna Formation are not precisely coeval and formed in distinctly different depositional environments. Upper Ordovician strata in and south of the type section (table 1, locs. 1 and 2) accumulated in a shallow-water, inner-shelf or platform setting. The slightly younger section at locality 3 consists of hemipelagic sediment derived from a carbonate platform but deposited in a slope or basin environment. Sections at localities 4 and 5 appear intermediate between these two extremes and probably formed in an outer-shelf or outer-platform setting.

Telsitna Formation conodonts from locality 3 have notably higher color alteration indices (CAI's) than do those from the type area (4.5 vs. 2 and 3.5). Similarly sharp contrasts in conodont CAI's from correlative strata occur in other parts of the Nixon Fork terrane (Savage and others, 1995; A.G. Harris and J.E. Repetski, unpub. data, 1997). CAI contrasts—along with the differences in lithofacies, age, and depositional environment documented above—suggest that discrete fault blocks in the Medfra quadrangle preserve fragments of the Nixon Fork platform with divergent depositional and thermal histories. These differences are not confined to Upper Ordovician rocks, as will be seen below.

Paradise Fork Formation

The Paradise Fork Formation is a sequence of dark-gray, thin-bedded limestone and black shale that forms a southwest-trending, 40-km-long synform through the northeastern part of

Table 1. Conodont data for localities shown on figure 2.

[Localities discussed in text but not sampled for conodonts not listed below. Letters in field number refer to collector: AD, J.A. Dumoulin; ADw, D.C. Bradley; APa, W.W. Patton, Jr. and (or) J.T. Dutro, Jr. Abbreviations: CAI, color alteration index; indets., indeterminate bar, blade, platform, and coniform fragments]

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
1 (Nixon Fork; Telsitna Fm.)	Medfra D-2 63°51.90' 153°43.18'	3 belodinids of probable Late Ordovician morphotype 7 *Panderodus gracilis* (Branson & Mehl) 1 unassigned coniform CAI=2 [97AD14B; 11504-CO]	Middle-Late Ordovician, probably Late Ordovician on the basis of the belodinid morphotype.	Indeterminate (too few conodonts); probably, warm, shallow-water depositional environment.	Medium-gray-weathering, light-gray, fine-grained dolostone containing abundant colonial corals. Sample weight 8.8 kg.
2 (Nixon Fork; Telsitna Fm.)	Medfra D-2 63°54.50' 153°40.50'	1 belodinid 1 *Culumbodina occidentalis* Sweet 1 *Drepanoistodus* sp. indet. 1 *Panderodus* sp. 4 indet. coniform fragments CAI=3.5 [79APa99a; 11524-CO]	Age is middle Edenian-early Maysvillian (early-middle Late Ordovician), probably early Maysvillian because corals and brachiopods from this interval indicate a Maysvillian age.	Indeterminate (too few conodonts). Conodonts are indicative of a tropical shallow-water depositional setting. *C. occidentalis* is the most biostratigraphically diagnostic element and a component of the western North American Midcontinent province.	Thick-bedded limestone at ~5,700 ft. above base of type section.
3 (Nixon Fork; Telsitna Fm.)	Medfra C-3 63°35.89' 154°01.76'	1 ozarkodinid P element (fig. 4V) 36 *Panderodus* sp. *Paroistodus*? n. sp. A of Nowlan and others, 1988 28 M & 46 S elements (figs. 4O-S) *Periodon grandis* (Ethington)? 1 Pa, 1 M & 2 Sc elements (figs. 4W-Y) 4 *Pseudooneotodus mitratus* (Moskalenko) (figs. 4M, N) 13 indet. fragments 6 *Strachanognathus parvus* Rhodes (figs. 4T, U) CAI=4.5 [97AD34A; 11510-CO)	Age is late Middle-middle Late Ordovician, probably Late Ordovician on the basis of the morphology of the ozarkodinid P element.	Paroistodid-panderodid biofacies: faunule represents a distal (deep shelf to basinal) winnow. Cosmopolitan and (or) cool-water faunule.	Dark-gray-weathering, grayish-black micrite in irregular 20-cm beds; contains graded laminae of peloids and bioclasts (chiefly calcitized radiolarians and calcareous and pyritized sponge spicules, lesser pelmatozoan and brachiopod fragments). Sample weight 10.4 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
3 (cont.) (Nixon Fork; Telsitna Fm.)	Medfra C-3 63°35.89' 154°01.80'	1 Pb *Ozarkodina hassi* (Pollock, Rexroad & Nicoll)? (fig. 4AA) 12 juvenile *Panderodus* spp. 4 M elements *Paroistodus* sp. 1 unassigned multidenticulate Sc element 5 indet. fragments 3 scolecodont fragments 2 *Ptiloncodus simplex* Harris (not a conodont; fig. 4Z) CAI=4.5. [97ADw124A;11515-CO]	Age is very latest Late Ordovician	Indeterminate; because all conodonts are extremely small, the faunule undoubtedly represents a distal winnow. The entire fauna (ostracodes, trilobite fragments [including spines], and probable radiolarians) suggests a slope or basin depositional setting.	Subcrop of dark micrite, beds 2-10 cm thick; contains graded laminae of peloids and bioclasts (chiefly calcitized radiolarians and calcareous and siliceous sponge spicules, lesser ostracodes and pelmatozoan fragments). A few hundred meters west of 97AD34. Heavy-mineral concentrate includes ferruginous hollow spines, spine steinkerns, phosphatized tubes, and lesser phosphatized ostracode carapaces (mostly smooth forms), phosphatic brachiopod fragments, composite small phosphatic grains, possible minor radiolarians, and rare trilobite fragments. Sample weight 7.5 kg.
		2 *Dapsilodus* sp. 1 M *Paroistodus* sp. indet. *Ozarkodina sesquipedalis* Nowlan & McCracken 1 Pa (fragment), 1 Pb & 1 Sb elements 2 *Panderodus* sp. 7 indet. fragments CAI=4.5 [76APa58; 8680-CO]	Age is very latest Ordovician	Indeterminate (too few conodonts). The only other reported occurrence of *O. sesquipedalis* is 50-74 m below the Ordovician-Silurian boundary in two sections in the Mackenzie Mountains, Northwest Territories (Nowlan and others, 1988); these sections are Selwyn basin margin facies near the platform edge. The conodonts are more typical of outer shelf facies, however, and were probably hydraulically transported basinward.	Dark-gray to black, very fine grained, thin-bedded to platy limestone. Same general locality as 97AD34 and 97ADw124. Sample weight 2 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
4 (Nixon Fork; Telsitna Fm.)	Medfra D-2 63°50.42' 153°49.33'	1 *Belodina compressa* (Branson & Mehl) 1 juvenile *Belodina* sp. 2 *Paroistodus* sp. 2 *Drepanoistodus* sp. 10 *Panderodus unicostatus* (Branson & Mehl) 2 *Paroistodus* sp. *Periodon aculeatus* Hadding 3 Pa, 4 M, 1 Sb & 4 Sc element fragments 1 *Staufferella* sp. 1 *Strachanognathus parvus* Rhodes 6 unassigned coniform fragments and juveniles CAI=3.5 [76APa34A; 8660-CO]	Age is late Middle Ordovician; *B. compressa* Zone (late Blackriveran, late early Caradocian)	Mixed biofacies but chiefly pelagic realm cosmopolitan (e.g., *Periodon, Dapsilodus, Strachanognathus*)), pandemic (*Panderodus*), and rare tropical cosmopolitan (*Belodina*) taxa. Rock probably represents outer shelf or off-shelf depositional setting.	Light-gray to brownish-gray, thin-bedded, fine-grained limestone. Sample weight 2 kg.
4 (Nixon Fork; Whirlwind Creek Fm.?)	Medfra D-2 63°52.11' 153°50.32'	*Ozarkodina confluens* (Branson & Mehl) 6 Pa, 1 Pb, 1 M, 1 Sa, 1 Sb & 1 Sc elements digyrate apparatus (oulodid?) 2 Pb element fragments 17 indet. fragments CAI=2.5-3 [97ADw143B; 12599-SD]	Ludlovian-Pridolian (Late Silurian and probably not early Ludlovian)	Indeterminate (too few conodonts); *O. confluens* as well as the amphiporids suggest at least partial restriction.	*Amphipora*-bearing dolostone and dolomicrite rubble. Patton and others (1980) mapped these rocks as Od, but the conodonts indicate Whirlwind Creek Formation. 2 km northwest of, and apparently overlying, 76APA34A. Sample weight 9.5 kg.
5 (Nixon Fork; Telsitna Fm.)	Medfra D-2 63°51.50' 153°31.33'	8 *Belodina*? *repens* Moskalenko s.f. 5 juvenile belodinids 2 M elements *Drepanoistodus* sp. 13 *Panderodus* sp. 6 *Plectodina*? *tunguskaensis* (Moskalenko) 1 unassigned Pb element CAI=3.5 [76APa39; 8679-CO]	Age is late Middle-Late Ordovician, possibly Late Ordovician	Indeterminate; likely a distal winnow into deeper water facies. The species association is chiefly Siberian-Alaskan with minor pandemics.	Massive-bedded, brownish-gray, fine-grained to finely crystalline limestone containing gastropods, trilobites, and cephalopods of probable Ordovician age. Sample weight 2 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
6 (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°51.80' 153°43.08'	120 *Panderodus unicostatus* (Branson & Mehl) *Ozarkodina excavata* (Branson & Mehl) 1 Pa, 1 Pb & 2 Sc elements *Pterospathodus procerus* (Walliser) (figs. 4NN-PP) 7 Pa & 2 Pb elements 5 indet. fragments CAI=2.5 [97ADw103; 12598-SD]	*Pt. celloni* Zone into *K. ranuliformis* Zone (= late Llandoverian-very early Wenlockian; = middle Early Silurian)	Panderodid biofacies: postmortem transport from or within a mid shelf or slope depositional setting.	Dark-gray, finely laminated, fissile micrite. Overlies 97AD14 (loc. 1) and underlies 97AD13C (loc. 8); near base of formation. Same general locality as 77APa112 (table 2). Heavy-mineral concentrate includes pyritized sponge spicules. Sample weight 7.9 kg.
7 (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°50.92' 153°41.33'	1 incomplete, robust, hyaline, coniform-like Sc element of Middle Ordovician-Silurian morphotype CAI=2 or 3 [97AD8B]	Middle Ordovician-Silurian	Indeterminate (too few conodonts).	Light-gray-weathering, grayish-black, fine-grained limestone in beds 2-5 cm thick, with graded laminae of silt- to sand-sized micritic clasts. Upper part of unit. Heavy-mineral concentrate includes minor schistose (chloritic-muscovitic) lithoclasts. Sample weight 9.7 kg.
8 (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°51.67' 153°43.08'	*Kockelella patula* Walliser 1 Pa, 1 Pb & 1 Sb elements (figs. 4QQ-SS) 2 unassigned Sc (2 morphotypes) elements 4 indet. fragments CAI=2 [97AD13; 12594-SD]	*K. patula* Zone (= *K. ranuliformis* + *K. amsdeni* Zones of Barrick and Klapper, 1976). *K. patula* has been found with *Cyrtograptus rigidus* Zone graptolites in the Carnic Alps (Jaeger, 1975). Kleffner (1995), on the basis of graphic correlation, indicates the range of *K. patula* is within the *C. lundgreni* Zone which, according to him, occupies most of the middle Wenlockian.	Indeterminate (too few conodonts); the kockelellids were derived from a shelf or platform depositional environment. *K. patula* is common in Europe but rare in North America.	Medium-gray-weathering, grayish-black, finely laminated micrite with minor calcitized radiolarians. Several hundred meters stratigraphically above 97ADw103 (loc. 6). Heavy-mineral concentrate includes minor schistose (chloritic-muscovitic) lithoclasts. Sample weight 9.7 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
8A (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°51.50' 153°42.50'	7 juvenile *Dapsilodus* sp. indet. elements 1 juvenile Sb? element *Oulodus*? sp. indet. 1 Pa element fragment *Ozarkodina excavata* (Branson & Mehl)? 1 *Panderodus unicostatus* (Branson & Mehl) element 1 juvenile Pa element *Polygnathus* sp. indet. of late Emsian or younger Devonian morphotype 1 *Pseudooneotodus bicornis* Drygant element CAI=2-2.5 [98ADw206; 12616-SD]	Conodonts in this sample represent two ages: late Llandoverian to at least latest Ludlovian (*Ps. bicornis*) and late Emsian or even younger Devonian (juvenile polygnathid). *Ps. bicornis* has recently been shown to range at least into the *Oz. remscheidensis* Zone in Sardinia (Corradini and others, 1998); until the Sardininian report the species had not been reported above the Wenlockian (Kleffner, 1995). About 20% of the slabs in 98ADw206 contained the graptolite *Monograptus uniformis* of early Lochkovian age (table 2). We interpret this sample as a mix of Llandoverian-Ludlovian, early Lochkovian, and late Emsian (or younger Devonian) weakly laminated limestones.	Indeterminate (too few conodonts); those that are present are mainly extremely small coniform elements that indicate a distal winnow. The conodonts and graptolites from this collection indicate mixed ages, making the sample ineligible for biofacies analysis.	Dark gray, weakly laminated calcisiltstone with rare micrite clasts and small fossil fragments. Sample weight 8.1 kg. Heavy-mineral concentrate includes minor metacarbonate rock fragments (talc-actinolite-tremolite) and rare phosphatic brachiopod fragments.
11 (Nixon Fork; Paradise Fork Fm.)	Medfra C-2 63°40.33' 153°57.52'	*Kockelella* sp. indet. or another Silurian digyrate apparatus 3 Pb, 3 M & 2 Sb elements CAI=2.5-3 [77APa130; 9145-CO]	Silurian, late Llandoverian into late Ludlovian	Indeterminate (too few conodonts). Normal-marine depositional setting.	Brownish-gray limestone. Sample weight 2.5 kg.
12 (Nixon Fork; Paradise Fork Fm.)	Medfra C-3 63°37' 154°00.75'	3 *Panderodus* sp. 10 indet. coniform fragments CAI=4.5 [77APa134; 9146-CO]	Middle Ordovician-Silurian (other coniform elements are not Devonian morphotypes)	Indeterminate (too few conodonts).	Light-brownish-gray limestone. Sample weight 2.7 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
13 (Nixon Fork; Whirlwind Creek Fm.)	Medfra D-2 63°50.23' 153°44.47'	BARREN [97AD12]			Thick-bedded to massive, light-gray, vuggy dolostone, locally cherty, with molds of brachiopods(?), underlies *Amphipora*-bearing dolostone. Mapped by Patton and others (1980) as Paradise Fork Formation [Sls] but represents shallow-water facies. Lies just above Sls. Sample weight 9.1 kg.
	Medfra D-2 63°50.08' 153°45.30'	1 *Dapsilodus* sp. element 2 Sb elements of "*Ligonodina*" *confluens confluens* of Jeppsson (1972) *Ozarkodina confluens* (Branson & Mehl) (at least 3 morphotypes) 19 Pa, 7 Pb, & 2 Sb elements *Ozarkodina excavata* (Branson & Mehl) 1 Sa and 1 Sb elements 4 *Panderodus unicostatus* (Branson & Mehl) elements CAI=2.5 [98ADw211; 12617-SD]	Late Silurian; within *A. ploeckensis* Zone to very high in the *Oz. remscheidensis* Zone (middle Gorstian [=within early Ludlovian] to within the late Pridolian)	Ozarkodinid biofacies; these conodonts were deposited in the shallow part of the ozarkodinid biofacies, as *Oz. confluens* is chiefly a shallow-water species.	Thick-bedded, finely crystalline dolostone; 1 km west of, and at a stratigraphic level close to, 97AD12. Sample weight 10.3 kg.
14 (Nixon Fork; Whirlwind Creek Fm.)	Medfra D-2 63°48.80' 153°33.27'	1 Pb element fragment *Oulodus* sp. indet. *Ozarkodina remscheidensis* (Ziegler) 8 Pa elements (mostly incomplete) *Ozarkodina confluens* (Branson & Mehl) or *Pandorinellina optima* (Moskalenko) 7 Pa elements (mostly incomplete) *Ozarkodina* spp. indet. 2 Pa, 3 Pb (2 morphotypes), 4 M, 2 Sa, 10 Sb & 5 Sc elements 99 chiefly incomplete *Panderodus* spp. elements 174 indet. fragments CAI=4	Age is late Ludlovian-Pridolian (Late but not earliest Late Silurian) or late Lochkovian (late early Early Devonian); probably the Silurian range because of the variety of *O. remscheidensis* morphotypes and because the 7 Pa elements attributed to either *O. confluens* (a Late Silurian species) or *Pa. optima* (a late Lochkovian species) are more like *O. confluens.*	Panderodid biofacies; the panderodids and the type of ozarkodinids indicate a shallow-water depositional setting. The abundant but chiefly broken conodonts indicate a high-energy setting.	Skeletal packstone in 3-20 cm beds; about 2-3 m of section here. Mapped by Patton and others (1980) as Telsitna Ridge Formation [Od], but the conodonts suggest this sample is from the Whirlwind Creek Formation. Strata appear to overlie Od. Sample weight 9.9 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
15 (Nixon Fork; Whirlwind Creek Fm.)	Medfra B-4 63°18.67' 154°34.17'	*Oulodus* n. sp. 2 Pa, 1 Pb, 4 Sa, 2 Sb & 2 Sc elements (distinctive oulodid with outer lower margin of cusp extended as prong on the Pa, Sa & Sb elements) *Ozarkodina confluens* (Branson & Mehl)? 1 Pa, 2 Pb, 3 M, 1 Sa & 6 Sc elements 4 indet. fragments CAI=3.5 [79APa82B; 11994-SD]	Wenlockian-middle Pridolian (late Early-Late, but not latest, Silurian.)	Oulodid-ozarkodinid biofacies: shallow-water, relatively high energy depositional setting.	Limestone in thrust sheet at Limestone Hill, mapped as Telsitna Formation [Od] by Patton and others (1980). Sample weight 6.0 kg.
16 (East Fork; East Fork Hills Fm.)	Medfra A-3 63°09.25' 154°02.29'	2 *Cordylodus proavus* Müller 1 *Hirsutodontus hirsutus* Miller 2 indet. coniform elements CAI=5 [97AD30B; 11508-CO]	Age is latest Late Cambrian (*Co. proavus* Zone through succeeding *Co. intermedius* Zone)	Indeterminate (too few conodonts).	Subcrop of medium-gray-weathering, medium-gray, fine-grained limestone in beds 0.5 to 5 cm thick with grayish-orange dolomitic layers, parallel- and cross-laminated. Minor quartz and plagioclase silt. Type section of East Fork Hills Formation. Heavy-mineral concentrate includes muscovite, lithoclasts, and rare phosphatic brachiopod fragments. Sample weight 7.5 kg.
		3 indet. coniform elements CAI=4.5 [D8-26]	Age is latest Cambrian-Devonian	Indeterminate (too few conodonts).	Schistose limestone. Same general locality as 97AD30B. Sample weight 2.9 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
17 (East Fork; East Fork Hills Fm.)	Medfra B-3 63°21.10' 154°06.44'	Many conodonts are deformed. 31 *Cordylodus proavus* Müller (fig. 4D) 9 *Eoconodontus notchpeakensis* (Miller) (fig. 4E) 22 *Hirsutodontus hirsutus* Miller (figs. 4A-C) 57 *Teridontus nakamurai* (Nogami) (fig. 4F) 109 indet. and unassigned fragments CAI=5-5.5 [97AD32C; 11509-CO]	Age is latest Late Cambrian (*Co. proavus* Zone through succeeding *Co. intermedius* Zone)	Cordylodid biofacies: fauna includes chiefly open-marine pandemic forms (cordylodids, teridontids, and eoconodontids) and minor tropical cosmopolites (*H. hirsutus*). Outer shelf or deeper depositional setting.	Good outcrop of gray- and yellow-weathering, very fine grained limestone in mm to 8-cm beds with parallel- and cross-laminations and climbing ripples. Silty laminae contain dolomite, quartz, plagioclase, white mica, and metamorphic lithic clasts. Sample weight 9.3 kg.
		1 *Cordylodus proavus* Müller 1 *Teridontus nakamurai* (Nogami) CAI=about 5 [P5-27; 8841-CO]	Age is latest Cambrian-very early Early Ordovician	Indeterminate (too few conodonts); conodonts are pandemics but would not likely occur in restricted shallow-water marine deposits.	Silty limestone. Same general locality as 97AD32C. Sample weight 2.8 kg.
18 (East Fork; East Fork Hills Fm.)	Medfra B-3 63°25.99' 154°07.40'	*Ansella* sp. indet. 1 Pa, 1 M, 1 Sb & 1 Sc elements 2 *Belodina* sp. 3 *Drepanoistodus* sp. *Erraticodon balticus* Dzik 1 Pa, 2 M, 2 Sb & 1 Sc elements 13 *Panderodus* sp. 2 *Paroistodus*? *mutatus* (Rhodes) *Periodon aculeatus* Hadding 25 Pa, 8 Pb, 51 M, 7 Sa, 26 Sb & 27 Sc elements 33 *Protopanderodus* cf. *P. varicostatus* (Sweet & Bergström) *Pygodus anserinus* Lamont & Lindström 3 P & 20 S elements 1 *Spinodus ramosus* (Hadding) 57 indet. fragments CAI=4.5 [97AD29C; 11507-CO]	*Pygodus anserinus* Zone (middle Middle Ordovician)	Periodontid-protopanderodid biofacies: slope to basinal depositional setting.	Medium-gray-weathering, dark-gray, fine-grained limestone in 2- to 5-cm beds that are delineated by orange silty laminae; interbedded with tan-weathering, dark-gray to black cherty argillite. Limestone contains 5-15% bioclasts, mostly radiolarians (some calcitized) and lesser pelmatozoan fragments. Heavy-mineral concentrate includes phosphatized grains and bioclasts and phosphatic brachiopod fragments. Sample weight 9.7 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
19 (East Fork; East Fork Hills Fm.)	Medfra B-3 63°28.28 153°59.80'	1 *Panderodus* sp. indet. CAI=indet. [97AD28A]	Middle Ordovician-Middle Devonian	Indeterminate (too few conodonts).	Medium-gray-weathering, medium-dark-gray, fine-grained limestone in 1- to 2-cm beds with yellow, dolomitic, peloidal laminae. Sample weight 9.7 kg.
		1 juvenile belodinid 1 juvenile *Panderodus* sp. indet. CAI=6-6.5 [D7-24; 8861-CO]	Age is early, but not earliest, Middle and Late Ordovician	Indeterminate (too few conodonts); postmortem winnow.	Medium-dark-gray limestone. Same general locality as 97AD28A. Sample weight 3.0 kg.
20 (East Fork; East Fork Hills Fm.)	Medfra B-3 63°21' 154°13'	3 small coniform elements of an icriodid(?) or an Early Ordovician coniform apparatus CAI=4.5-5 [78ADu24; 9977-SD]	Ordovician-Devonian	Indeterminate (too few conodonts); distal winnow.	Sample weight 3.2 kg.
21 (East Fork; East Fork Hills Fm.)	Medfra A-2 63°05.77' 153°53.83'	3 coniform elements Late Ordovician-earliest Devonian morphotype 1 P element fragment of Silurian-Devonian morphotype CAI=5.5 [76APa112; 9731-SD]	Silurian-early Early Devonian	Indeterminate (too few conodonts); normal-marine depositional setting.	Dark-gray, laminated, fine-grained limestone.
22 (East Fork; East Fork Hills Fm.)	Medfra A-2 63°05.13' 153°54.45'	1 Pa *Eognathodus* cf. *E. sulcatus* (Philip) 1 Pa *Ozarkodina* sp. indet. CAI=5.5 [78ADu27; 9978-SD]	Pragian (middle Early Devonian)	Indeterminate (too few conodonts); normal-marine depositional setting.	Sample weight 2 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
23 (Telida; chert and argillite unit)	Medfra D-1 63°59.17' 153°17.67'	2 *Cordylodus intermedius* Furnish (fig. 4G) 6 *Drepanoistodus* cf. *D. pervetus* Nowlan (fig. 4H) 18 unassigned drepanodontiform elements 18 *Laurentoscandodus triangularis* (Furnish) (fig. 4J) 1 New genus & new species? 4 *Oneotodus simplex* Furnish 3 "*Oneotodus*" cf. "*O.*" *variabilis* Lindström 13 *Rossodus manitouensis* Repetski & Ethington (fig. 4I) 3 *Rossodus*? sp. 1 unassigned scandodontiform element 8 *Scolopodus sulcatus* Furnish (fig. 4K) 6 *Variabiloconus bassleri* (Furnish) (fig. 4L) 7 unassigned coniform elements CAI=4 [97ADw116A; 11513-CO]	Age is early Early Ordovician (*Rossodus manitouensis* Zone; early Ibexian). This collection is the same age and contains many of the same conodont species as the oldest samples from the type section of the Novi Mountain Formation in the Medfra D-1 quadrangle.	Laurentoscandodid-rossodid biofacies; tropical, normal-marine shelf or platform depositional setting. Species association includes some North American Midcontinent elements, but tropical cosmopolites and some pandemics predominate.	Distal, thin-bedded, silty limestone turbidites with local black carbonaceous partings. Sample is from 12-cm-thick bed of medium-dark-gray, fine-grained, dolomitic limestone with parallel- and cross-laminations and starved ripples; laminae contain peloids and lesser quartz and plagioclase silt. Pzc map unit of Patton and others (1980). Heavy-mineral concentrate includes schistose grains. Sample weight 8.6 kg.

Table 1. Conodont data for localities shown on figure 2—*Continued.*

Locality no., (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Conodont fauna and CAI [field no.; USGS collection no.]	Age	Biofacies	Remarks
33 (Telida; argillite and quartzite unit)	Mt. McKinley D-5 63°55.08' 152°10'	*Aspelundia expansa* Armstrong 4 Pb and 1 M elements (figs. 4BB-DD) *Aspelundia fluegeli* (Walliser) 3 Pa, 4 Pb, 1 Sb1 & 1 Sb2 elements (figs. 4EE-GG) *Aspelundia* spp. vicarious elements 8 M, 2 Sb & 9 Sc (some of the Sc elements could belong in *Ozarkodina*) (fig. 4HH) 1 fragment *Carniodus*? sp. indet. *Dapsilodus obliquicostatus* (Branson & Mehl) (figs. 4JJ-MM) 4 M & 30 S elements 1 Sb element *Distomodus* sp. indet. (fig. 4II) 1 unassigned oistodontiform element of Ordovician morphotype 1 Pa? element *Ozarkodina*? sp. indet. 31 *Panderodus unicostatus* (Branson & Mehl) 2 *Walliserodus* sp. indet. 1 unassigned Sb element 1 unassigned Sc element of deep-water morphotype 94 indet. fragments CAI=4-4.5 [97AD54C; 12597-SD]	Age is early Early Silurian; middle-late Llandoverian but could be middle Llandoverian. According to Armstrong (1990), *Aspelundia expansa* may not extend above the middle Llandoverian.	Aspelundid-coniform biofacies. Post-mortem transport from or within this biofacies, which represents outer shelf or slope depositional setting according to Armstrong (1990).	Light-olive-gray-weathering, medium-dark- to dark-gray, very fine grained dolomitic micrite with silty laminae rich in calcareous sponge spicules, quartz, and lesser plagioclase. From 20-cm chunk presumed fallen from adjacent cliffs and interbedded with argillite and sandstone. Heavy-mineral concentrate includes phosphatized bioclasts and rare phosphatic brachiopod fragments and phosphatized radiolarians. Sample weight 4.2 kg.

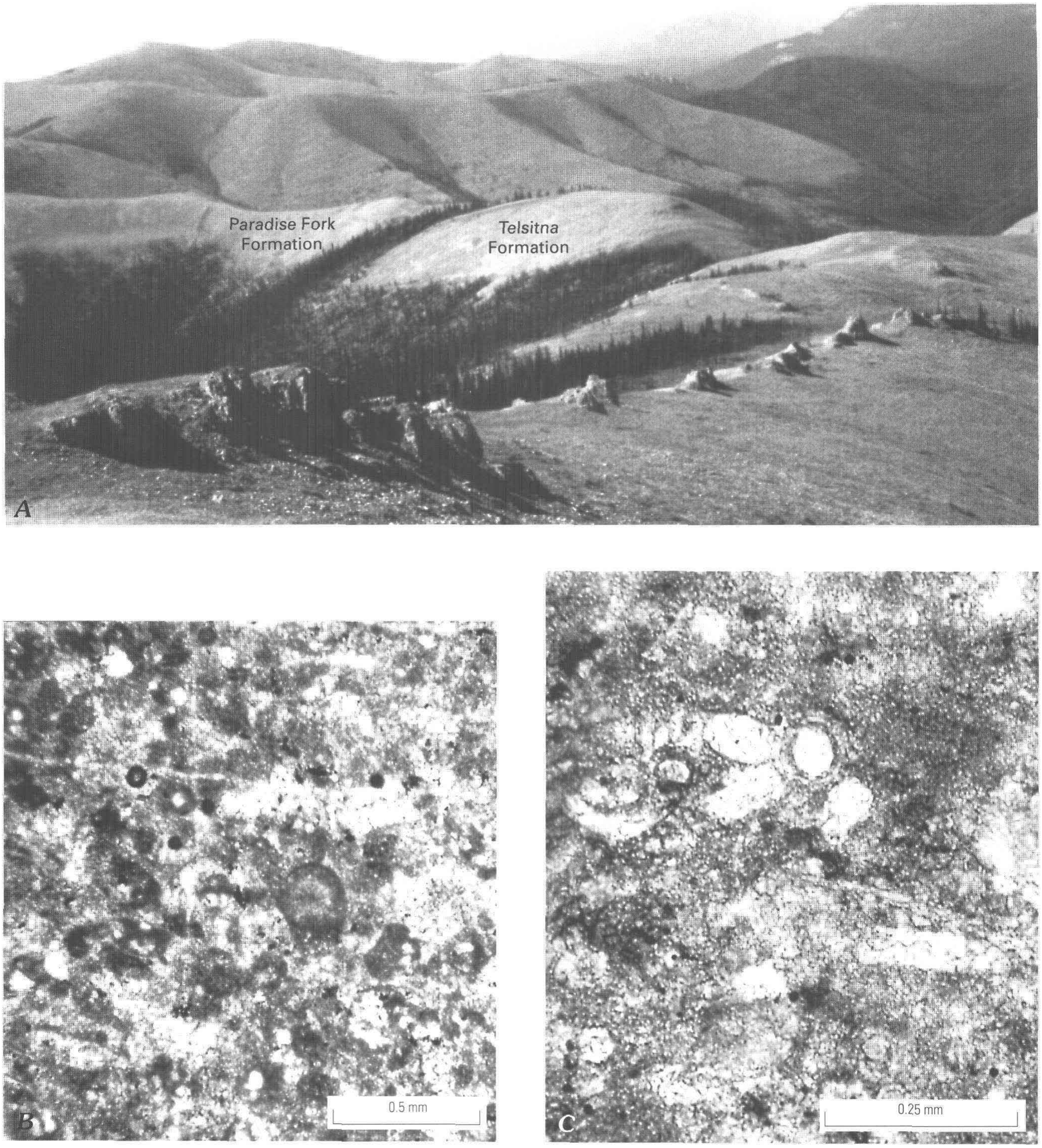

Figure 3. *A*, View to south of shallow-water facies (coralline dolostone) in the upper part of the Telsitna Formation (fig. 2, loc. 1) overlain by deep-water facies (shale and fissile to laminated limestone) in the lower part of the Paradise Fork Formation (fig. 2, locs. 6, 8); Nixon Fork terrane. *B, C,* Sedimentary features of the upper part of the Telsitna Formation (fig. 2, loc. 3). *B*, Lamina rich in peloids and calcitized radiolarians; station 97AD34. *C*, Calcareous sponge spicules in micrite; station 97ADw124.

the Medfra quadrangle (Patton and others, 1980). It is generally poorly exposed, but appears to be at least 1,000 m thick (Dutro and Patton, 1982). Dutro and Patton (1982) assigned a middle Early Silurian age to the Paradise Fork based on graptolites and ostracodes and suggested that the unit was deposited in a relatively deep water setting. Our studies confirm a deep-water depositional environmental for this unit but indicate that it is, in part, as young as Early Devonian.

We examined the Paradise Fork Formation at six partial sections in and near its type locality (fig. 2, locs. 6–10) and reexamined conodont collections from two additional sections (fig. 2 and table 1, locs. 11, 12). The lower part of the Paradise Fork (locs. 6, 8, 9) is grayish-brown-weathering, dark-gray to black, fissile to laminated limestone and limy shale in 3- to 5-cm-thick beds. Limestones are micrite and calcareous siltstone with 5–20 percent calcitized radiolarians and rare calcareous and pyritized sponge spicules (figs. 5*B*, 5*C*); fine dolomite rhombs and rare quartz silt form the laminae. The upper part of the formation (locs. 7, 10) is chiefly light-gray-weathering, medium-gray to black limestone with tan-weathering dolomitic partings (fig. 5*A*). Beds are 1–15 cm thick (most ≤5 cm), with well-developed parallel- and cross-laminae, and consist of graded alternations of fine- to medium-grained calcareous sandstone, siltstone, and micrite. Sandy layers contain rounded to irregular micrite clasts (40–400 μm) in a sparry matrix (fig. 5*D*); rare bioclasts in these strata include pelmatozoan debris (locally silicified), ostracodes, calcareous sponge spicules, and calcitized radiolarians. Minor metamorphic lithic clasts occur in coarser layers and laminae throughout the formation (table 1, locs. 7, 8, 8A). The uppermost part of the Paradise Fork, known only from a single rubble outcrop (loc. 8A), is dark-gray, weakly laminated calcisiltstone with rare micritic clasts and fossil fragments.

Conodont collections support a middle Early Silurian age for much of the Paradise Fork Formation, but the uppermost part of the unit is at least as young as Early Devonian. Fissile, very finely laminated limestone near the base of the unit, at about the same locality and horizon that produced late Llandoverian to early Wenlockian graptolites (table 2, loc. 6) (Dutro and Patton, 1982), yielded late Llandoverian to very early Wenlockian conodonts that indicate post-mortem transport from or within a mid-shelf or slope depositional setting (table 1, loc. 6; figs. 4*NN*–4*PP*). Laminated limestone a few hundred meters higher in the section contains early to middle Wenlockian conodonts (table 1, loc. 8; figs. 4*QQ*–4*SS*) redeposited from a shelf or platform environment. Dutro and Patton (1982) reported ostracodes of probable Wenlockian age from near the top of the Paradise Fork, and no fossils younger than Wenlockian have been found in outcrop. An isolated rubble outcrop, however, 0.5 km southeast of locality 8 (tables 1 and 2, loc 8A), yielded a mixed fauna that indicates a surprisingly young age for the uppermost part of the Paradise Fork. A single collection of apparently uniform lithology from this locality contained numerous specimens of the early Lochkovian graptolite *Monograptus uniformis*. Conodonts from the same collection are of two ages: late Llandoverian to at least latest Ludlovian and late Emsian or even younger Devonian. This collection most likely represents rubble derived from a relatively condensed section of Wenlockian to Emsian (or possibly even younger Devonian) age.

The Paradise Fork Formation originated as hemipelagic deposits and distal turbidites derived from a carbonate platform. Fine-grained "background" sediment (laminated radiolarian-bearing micrite) predominates in the lower part of the unit. Turbidites (calcareous siltstone and sandstone) are most notable in the upper part of the section and increase upward in thickness and abundance. The uppermost section appears extremely condensed.

In the southern part of its type locality (fig. 2, loc. 13), the Paradise Fork Formation interfingers with shallow-water strata. These rocks are thick- to massive-bedded, light-gray, vuggy dolostone with locally abundant tubular stromatoporoids (*Amphipora* sp.). A sample from locality 13 contained conodonts of early Ludlovian to late Pridolian age; strata here are lithologically similar to, and probably correlative with, the lower part of the Whirlwind Creek Formation of Late Silurian–Early Devonian age (Dutro and Patton, 1982).

Fault blocks adjacent to those containing the Paradise Fork Formation display a different Silurian stratigraphy. Six kilometers west of the Paradise Fork type locality (fig. 2, loc. 4), Ordovician deep-water limestone at the top of the Telsitna Formation is overlain by Upper Silurian amphiporid dolostone; strata equivalent in age and lithology to the lower part of the Paradise Fork are missing. A similar sequence occurs 8 km east of the Paradise Fork type locality (fig. 2 and table 1, loc. 14), where shallow-water skeletal packstone of probable late Late Silurian age overlies deep-water Ordovician facies. Deep-water Silurian rocks are also absent from Nixon Fork sections throughout the southern half of the Medfra quadrangle (Patton and others, 1980). In this area, shallow-water facies of the Whirlwind Creek Formation directly overlie the Telsitna Formation (Dutro and Patton, 1982). The age of the lower part of the Whirlwind Creek is not well constrained. Dutro and Patton (1982) suggested that the basal strata are Ludlovian or younger, but a conodont collection that could be as old as Wenlockian was obtained from locality 15 (table 1).

Deep-water strata of the Paradise Fork Formation are thus quite limited in extent but not in age. They appear to have formed in a small, relatively long lived basin that developed within the Nixon Fork platform. Deep-water facies found in some sections of the upper Telsitna Formation suggest that basinal conditions were locally established by Late (possibly late Middle) Ordovician time. Shallow-water strata precisely coeval with the thick Lower Silurian part of the Paradise Fork Formation have not yet been identified in the Nixon Fork terrane. The condensed, upper part of the Paradise Fork interfingers with shallow-water facies of Late Silurian age.

Minchumina Terrane

The Minchumina terrane lies directly southeast of the Nixon Fork terrane in the Medfra and Mt. McKinley quadrangles and extends some 300 km into the Kantishna River quadrangle (fig. 1). Two subterranes are recognized (Patton and others, 1994). The East Fork subterrane is confined to the Medfra quadrangle and comprises the East Fork Hills Formation (Upper Cambrian through Lower Devonian; age revised herein). The more extensive Telida subterrane consists of sparse, discontinuous exposures of Precambrian(?) and Paleozoic rocks.

East Fork Subterrane

The East Fork Hills Formation is a sequence of laminated, locally dolomitic limestone that forms a northeast-trending belt at least 60 km long and 40 km wide in the southeastern part of the Medfra quadrangle (Patton and others, 1980) (fig. 1). The unit was named by Dutro and Patton (1982), who reported a thickness of several hundred meters, an age (based on sparse conodont collections) of Early Ordovician to Middle Devonian, and a deep-water depositional environment. Exposures of the East Fork Hills Formation are uniformly poor, and relations with other units are obscure. Shallow-water facies of the Nixon Fork

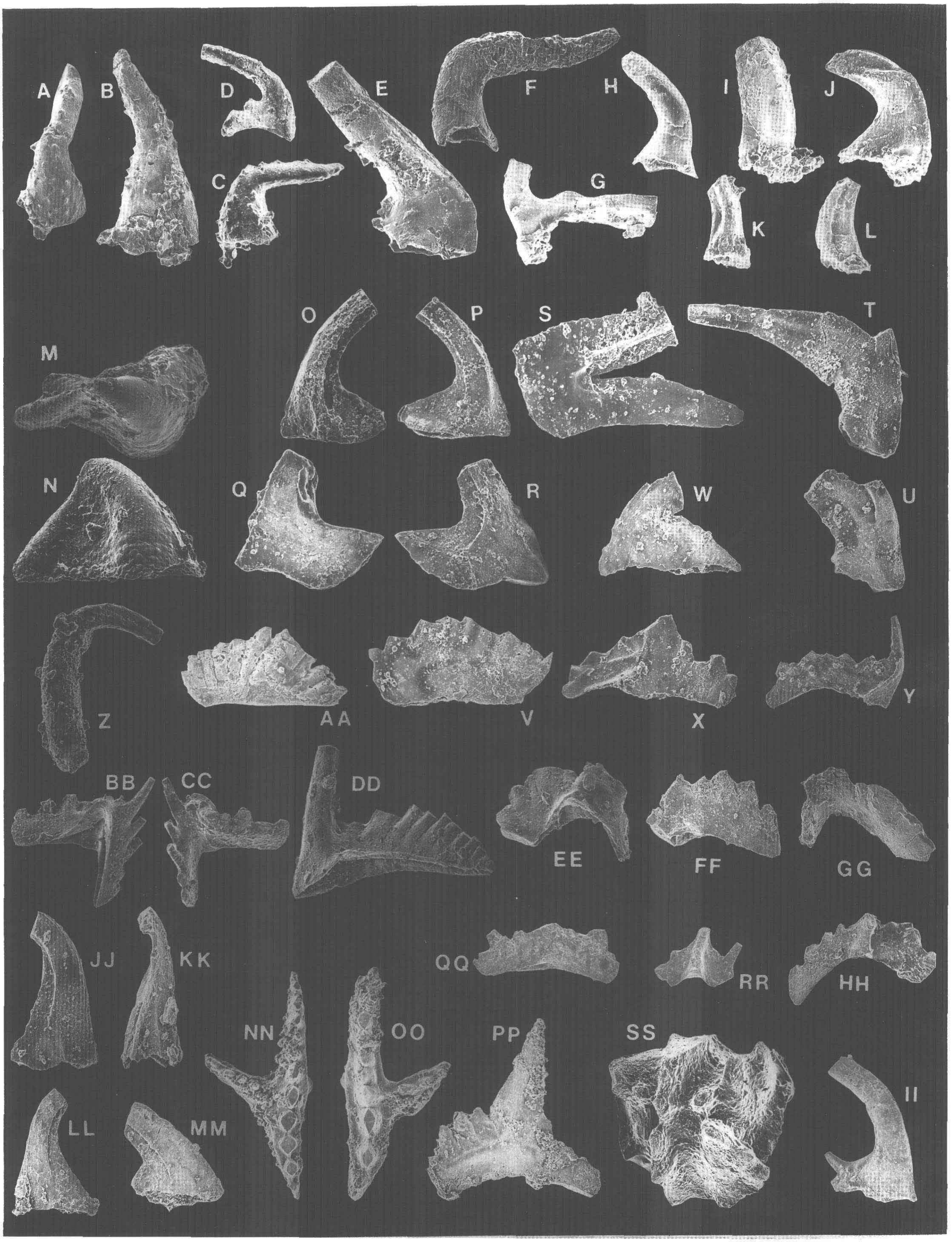
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Figure 4. Early Paleozoic conodonts from deep-water facies in the Medfra area, central Alaska (scanning electron photomicrographs); figure 4*Z* is not a conodont. Illustrated specimens are reposited in the U.S. National Museum, USNM, Washington, D.C. See table 1 for lithostratigraphic description, faunal analysis, and age assignment of collections and figure 2 for their geographic and geologic position.

A–F, very Late Cambrian, East Fork Hills Formation, USGS colln. 11509-CO (fig. 2, loc. 17), x100 except D x50.
A–C, *Hirsutodontus hirsutus* Miller, antero-lateral and two lateral views, USNM 497666-68.
D, *Cordylodus proavus* Müller, outer lateral view, USNM 497669.
E, *Eoconodontus notchpeakensis* (Miller), outer lateral view, USNM 497670.
F, *Teridontus nakamurai* (Nogami), outer lateral view, USNM 497671.

G–L, *Rossodus manitouensis* Zone, early Early Ordovician, argillite and quartzite unit, Telida subterrane, USGS colln. 11513-CO (fig. 2, loc. 23), x100.
G, *Cordylodus intermedius* Furnish, outer lateral view, USNM 497672.
H, *Drepanoistodus cf. D. pervetus* Nowlan, outer lateral view, USNM 497673.
I, *Rossodus manitouensis* Repetski and Ethington, antero-lateral view, USNM 497674.
J, *Laurentoscandodus triangularis* (Furnish), outer lateral view, USNM 497675.
K, *Scolopodus sulcatus* Furnish, postero-lateral view, USNM 497676.
L, *Variabiloconus bassleri* (Furnish), inner lateral view, USNM 497677.

M–Y, late Middle-Late Ordovician, upper part of Telsitna Formation, USGS colln. 11510-CO (fig. 2, loc. 3), x100.
M, N, *Pseudooneotodus mitratus* (Moskalenko), upper and lateral views, USNM 497678.
O–S, *Paroistodus?* sp. A of Nowlan and others (1988), inner and outer lateral views of two S elements and inner lateral view of M element, USNM 497679-81.
T, U, *Strachanognathus parvus* Rhodes, outer and inner lateral views, USNM 497683-84.
V, Ozarkodinid P element, outer lateral view, USNM 497685.
W–Y, *Periodon grandis* (Ethington)?, M, Pa, and Sb elements, two inner and an outer lateral views, USNM 497686-88.

Z, AA, very latest Late Ordovician, upper part of Telsitna Formation, USGS colln. 11515-CO (fig. 2, loc. 3).
Z, *Ptiloncodus simplex* Harris, lateral view, x125, USNM 497689. This phosphatic microfossil is known chiefly as discrete elements but does occur in clusters (Tipnis, 1979); its taxonomic affinities remain uncertain. It is rare to common in late Early to Late Ordovician conodont collections in North America.
AA, *Ozarkodina hassi* (Pollock, Rexroad, and Nicoll)?, Pb element, inner lateral view, x75, USNM 497690.

BB–MM, middle and late Llandoverian, argillite and quartzite unit, Telida subterrane, USGS colln. 12597-SD (fig. 2, loc. 33), x75 except DD x65.
BB–DD, *Aspelundia expansa* Armstrong, Pb and M elements, inner and outer lateral views of Pb and inner lateral view of M, USNM 497691-92.
EE–GG, *Aspelundia fleugli* (Walliser), Pb, Pa, and Pb elements, inner, inner, and outer lateral views, USNM 497693-95.
HH, *Aspelundia* sp. indet. vicarious Sb element, inner lateral view, USNM 497696.
II, *Distomodus* sp. indet., Sb element, inner lateral view, USNM 497697.
JJ–MM, *Dapsilodus obliquicostatus* (Branson & Mehl), three S and 1 M (fig. 4MM) elements, two inner and two outer lateral views, USNM 497698-700.

NN–PP, *Pterospathodus celloni* Zone into *K. ranuliformis* Zone, late Llandoverian and very early Wenlockian, lower part of Paradise Fork Formation, USGS colln. 12598-SD (fig. 2, loc. 6), *Pt. procerus* (Walliser), Pa and Pb elements, upper and inner lateral views, x75, USNM 497701-03.

QQ–SS, *Kockelella patula* Zone, lower part of Paradise Fork Formation, USGS colln. 12594-SD (fig. 2, loc. 8), *K. patula* Walliser, Pb, Sb, and Pa elements, inner lateral and upper views, x50, USNM 497704-06.

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terrane occur in fault contact to the northwest and deeper water facies of the Telida subterrane are exposed to the east and northeast (Patton and others, 1980) (fig. 2).

Our studies revise the age of the East Fork Hills Formation to Late Cambrian through Early Devonian and indicate that at least three subunits can be distinguished based on lithofacies and conodont faunas. The first subunit makes up the central part of the outcrop belt (fig. 2, locs. 16, 17) and includes the type locality (loc. 16) along the crest of the East Fork Hills. Thin-bedded (0.5 to 8 cm), fine-grained, medium-gray limestone and grayish-orange silty limestone comprise this subunit; beds contain parallel-laminae and small-scale cross-laminae, climbing ripples, and possible flute casts. Limestone layers are chiefly slightly recrystallized micrite. Silty layers are finely crystalline (40–60 µm) dolomite with 1–15 percent detrital grains (mostly quartz, plagioclase feldspar, white mica, and metamorphic lithic clasts). Collections from this subunit produced phosphatic brachiopod fragments and latest Late Cambrian conodonts indicative of an outer-shelf or deeper depositional setting (table 1, locs. 16, 17; figs. 4*A*–4*F*).

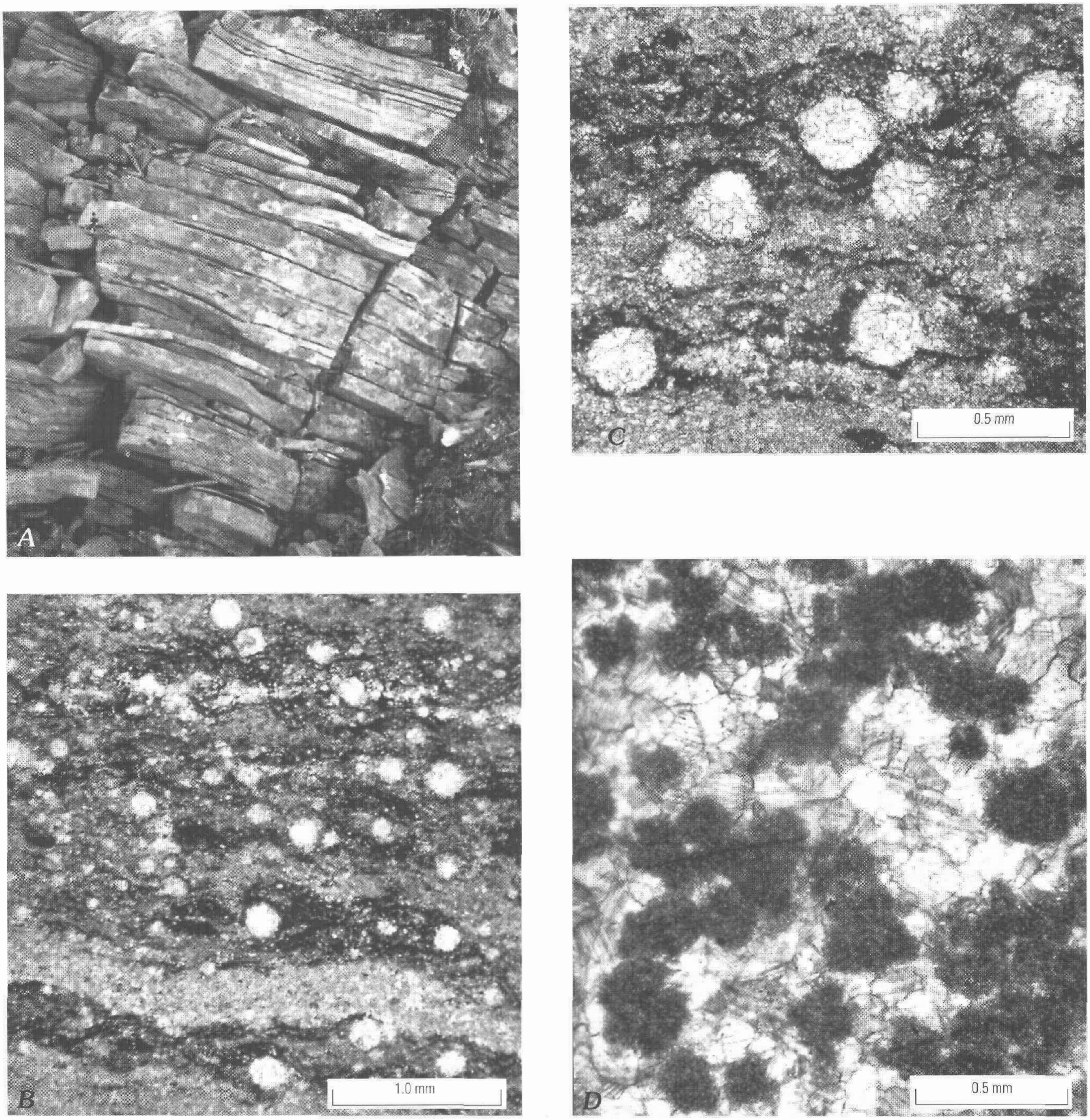


Figure 5. *Sedimentary features of the Paradise Fork Formation, Nixon Fork terrane. A, Thin-bedded, fine-grained, distal carbonate turbidites;* upper part of unit (fig. 2, loc. 7). *B, C.* Photomicrographs of calcitized radiolarians in micrite matrix; lower part of unit (fig. 2, loc. 8). *D,* Photomicrograph of turbidites shown in *A,* made up of sand- to silt-sized micrite clasts in sparry calcite matrix.

The second subunit forms a fault-bounded block along the northwestern edge of the outcrop belt (fig. 2, locs. 18, 19, 20). It consists chiefly of limestone with subordinate dark chert and siliceous siltstone; basalt rubble occurs at locality 18. Limestone is slightly recrystallized micrite with thin concentrations of peloids and (or) bioclasts, including locally abundant calcitized radiolarians and rare pelmatozoan and brachiopod fragments. Some samples contain thin laminae of chert or dolomite; noncarbonate detritus (<5 percent of most samples) is largely white mica and clasts of silty argillite. Where biostratigraphically diagnostic, conodonts from this subunit are of middle Middle Ordovician age and indicate a slope to basinal setting (table 1, loc. 18).

A distinctive conodont fauna delineates a third subunit of the East Fork Hills Formation in the southeastern part of the outcrop belt. Dark-gray, fine-grained, laminated limestone at two localities contains the youngest conodonts definitively identified from this formation (fig. 2 and table 1, locs. 21, 22). One collection could be as old as Silurian but is no younger than early Early Devonian (Lochkovian); the other is of middle Early Devonian (Pragian) age. Conodonts from both samples denote a normal-marine depositional setting.

Lithofacies, sedimentary structures, and conodont biofacies suggest an outer-shelf or deeper depositional setting for all three subunits of the East Fork Hills Formation. Laminated limestones

Table 2. Other fossil data for localities shown on figure 2.

[Letters in field number refer to collector: CH, R. Chapman and M. Churkin; Dw, D.C. Bradley; Pa, W.W. Patton, Jr.; Rb and Wr, F.R. Weber]

Locality no. (terrane or subterrane; unit)	Quadrangle latitude/ longitude	Fauna [field no.; USGS collection no.]	Age	Source
6 (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°51.80′ 153°43.08′	Graptolites: *Monograptus* cf. *M. parapriodon* Boucek, *Paraplectograptus* aff. *P. eiseli* (Manck) [77APa112B]	Early Silurian (late Llandoverian-early Wenlock; probably late Llandoverian, *Monoclimacis crenulata* Zone	Written report from C. Carter to W.W. Patton, Jr., 1978
8A (Nixon Fork; Paradise Fork Fm.)	Medfra D-2 63°51.50′ 153°42.50′	Graptolites: *Monograptus uniformis* Pribyl [98ADw206]	Age is early Early Devonian (Lochkovian; *Monograptus uniformis* Zone)	Written report from S. Finney, California State University (Long Beach), to D. Bradley, 1998
28 (Telida; chert and argillite unit)	Mt. McKinley D-5 63°53.17′ 152°11′	Graptolites: poorly preserved *Orthograptus*(?) cf. *O. quadrimucronatus* (Hall) [79CH89]	Middle Ordovician (approx. *C. tubuliferous* Zone)	Written report from C. Carter to R. Chapman, 1979
29 (Telida; chert and argillite unit)	Mt. McKinley D-5 63°51.5′ 152°12′	Graptolites: *Orthoretiolites hami* Whittington and *Orthograptus* sp. [79CH88]	Middle Ordovician (approx. *C. tubuliferous* Zone)	Written report from C. Carter to R. Chapman, 1979
35 (Telida; argillite and quartzite unit)	Mt. McKinley D-5 63°53′ 152°9.5′	Corals: *Favosites*(?) [59ARb86] (in place) and *Xystriphyllum* sp. [78AWr8] (float—may not be from argillite and quartzite unit)	Silurian or Devonian; *Xystriphyllum* sp. is restricted to latest Silurian (Pridolian)-early Middle Devonian	Written report from W.A. Oliver, Jr., to F.R. Weber, 1997. *Favosites*(?) was originally identified (Oliver and others, 1975; Chapman and others, 1981) as *Saffordophyllum* sp. of Middle-Late Ordovician age

formed as hemipelagic deposits and distal turbidites derived from a carbonate platform. "Common" penecontemporaneous slump structures reported by Patton and others (1980) imply a slope environment for at least some parts of the unit. Radiolarians and periodontid and protopanderodid conodonts in the second subunit indicate that it may have accumulated in somewhat deeper water conditions than did the rest of the East Fork Hills Formation.

Telida Subterrane

Exposures in the Telida subterrane are scarce, discontinuous, and have yielded few fossils, so the detailed stratigraphy of these rocks remains uncertain. Patton and others (1994) recognized four units, in ascending stratigraphic order: (1) pre-Ordovician limestone and phyllite; (2) pre-Ordovician(?) and Ordovician argillite and quartzite; (3) Ordovician (and younger?) chert and argillite; and (4) Middle to Upper Devonian limestone. We report here new lithologic and paleontologic data from the argillite and quartzite unit and the chert and argillite unit in the Medfra and Mt. McKinley quadrangles. Our studies suggest that the chert and argillite unit is older than at least some parts of the argillite and quartzite unit.

Chert and Argillite Unit

The chert and argillite unit includes map units Pzc (lower Paleozoic chert and phyllite of Patton and others, 1980) in the Medfra quadrangle, DOc (Ordovician through Devonian chert) in the northwestern part of the Mt. McKinley quadrangle (Chapman and Yeend, 1981), and Oc (Ordovician chert and slate unit) in the western Kantishna River quadrangle (Chapman and others, 1975). We examined this unit at six localities in the study area (fig. 2, locs. 23–28).

The westernmost outcrops of the chert and argillite unit occur in a fault block bounded by fragments of the Nixon Fork terrane (figs. 1, 2; locs. 23–25). Discontinuous exposures along the Sethkokna River consist of fine-grained limestone, silty dolostone, argillite, and chert; all lithologies are thin bedded (<0.5–12 cm, most 2–5 cm) with black carbonaceous partings. Carbonate rocks are medium to dark gray, weather olive gray to dark yellowish brown, and are locally graded, with well-developed parallel- and cross-laminae, starved ripples, and load casts (figs. 6*A*, 6*B*). Samples consist of slightly recrystallized calcite and (or) dolomicrite, locally abundant peloids and calcareous sponge spicules, and <5–50 percent detrital quartz, plagioclase, and metamorphic lithoclasts (fig. 6*C*). Chert is dark gray to brown to black and contains siliceous sponge spicules and radiolarian ghosts (fig. 6*D*).

Exposures of the chert and argillite unit in the Mt. McKinley quadrangle are similar to those in the Medfra quadrangle but lack a carbonate component (fig. 2, locs. 26–28). Rubble in the Snohomish Hills is laminated, very light gray to black, spiculitic, radiolarian chert and lesser tan argillite; outcrops at Lake Minchumina are light olive gray silty argillite.

The chert and argillite unit yields fossils of Early and Middle Ordovician age (table 1, loc. 23; table 2, locs. 28, 29). Limestone in the Medfra quadrangle (loc. 23) produced abundant conodonts of early Early Ordovician age (*Rossodus manitouensis* Zone; figs. 4*G*–4*L*); this fauna is the same age as the oldest part of the Novi Mountain Formation in the Nixon Fork terrane and contains many of the same species found in Novi Mountain samples. Argillite contains late Middle Ordovician (Caradocian) graptolites at Lake Minchumina (fig. 2 and table 2, locs. 28, 29) and a less diagnostic fauna of Middle(?) Ordovician age in the southwestern part of the Kantishna River quadrangle, 50 km to the north (Chapman and others, 1981).

Lithofacies, sedimentary structures, and biofacies indicate an off-platform setting for the chert and argillite unit. Calcareous beds are distal turbidites, derived at least in part from the Nixon Fork terrane. Argillite and chert formed as hemipelagic deposits.

Argillite and Quartzite Unit

We examined the argillite and quartzite unit at five localities (fig. 2, locs. 30–34). These rocks are mapped as Pzp€q (Precambrian or lower Paleozoic quartzite, grit, and argillite) in the Medfra quadrangle (Patton and others, 1980), DOs (Ordovician to Devonian shaly rocks) in the northwestern part of the Mt. McKinley quadrangle (Chapman and Yeend, 1981), and €qs (Cambrian quartzite, metasiltstone, slate, and grit) in the western Kantishna River quadrangle (Chapman and others, 1975).

Along Munsatli Ridge (fig. 2, locs. 30, 31) and on the east side of Lake Minchumina (fig. 2, loc. 32), the argillite and quartzite unit consists chiefly of sandstone, pebbly sandstone, and fine-grained conglomerate in slabby beds 3–10 cm thick. Fresh surfaces are parallel-laminated and range from very pale orange to olive or blue-gray. Some sandstones are graded, and some contain thin argillite interbeds. Sandstone samples are very poorly sorted; most are medium grained but contain notable (5–10 percent) outsized clasts, 4–10 mm in diameter. Clasts are angular to rounded and are chiefly monocrystalline quartz (Qm) with undulous extinction (Qm=60–95 percent, generally >80 percent). Other framework grains include feldspar (both plagioclase and microcline, based on twinning), polycrystalline quartz, metasedimentary lithic clasts, and rare tourmaline. Matrix, mostly finely intergrown quartz and phyllosilicates, makes up <5 to >30 percent of the samples examined. Grain boundaries are generally recrystallized, and some samples are semischists.

More heterogeneous strata also included in the argillite and quartzite unit crop out along the northeastern shore of Lake Minchumina (fig. 2, locs. 33, 34). These rocks consist of strongly cleaved, silty to cherty argillite, phyllite, and chert, intercalated with intervals of sandstone and carbonate that are 20 cm to 1.5 m thick (fig. 7*A*). Finer grained rocks range from reddish brown to silvery gray to black; siliceous sponge spicules and radiolarian ghosts are locally abundant in some cherty layers. Sandstones weather white to orange to brownish gray and are medium to dark gray, very fine to medium grained, poorly sorted, and locally cross-laminated and graded. Some samples are mostly rounded to angular monocrystalline quartz with lesser plagioclase and microcline feldspar and are virtually identical to strata described above from Munsatli Ridge. Others contain a similar suite of quartz and subordinate feldspar as well as 10 to 70 percent carbonate, chiefly dolomite, that occurs as clasts and matrix (figs. 7*B*–7*D*). Clasts are finely crystalline dolomite mosaics and lesser pelmatozoan fragments. Rare carbonate layers are mostly finely crystalline (5–40 μm) dolomite with abundant calcareous sponge spicules, lesser calcitized radiolarians, and minor detrital quartz and feldspar (fig. 7*E*).

No fossils have been obtained from the argillite and quartzite unit along Munsatli Ridge, but several collections constrain the age of the rocks at Lake Minchumina. Fine-grained dolostone from locality 33 (fig. 2; table 1) contains abundant conodonts of Early Silurian (middle-late Llandoverian, possibly middle Llandoverian) age (figs. 4*BB*–4*MM*); the heavy-mineral concentrate from this sample contains rare phosphatic brachiopod fragments and phosphatized radiolarians. The conodont faunule represents postmortem transport from or within the aspelundid-coniform biofacies, which indicates an outer-shelf or slope depositional setting.

Several collections of corals from locality 35 (fig. 2; table 2, loc. 35) are of Silurian or Devonian age (W.A. Oliver, Jr., 1997; written commun. to F. Weber). The most diagnostic form is a ptenophylid coral—*Xystriphyllum* sp., of latest Silurian (Pridolian) to early Middle Devonian age—found in a beach cobble that may not have come from the argillite and quartzite unit (Chapman and others, 1981). A second coral was collected from outcrop. This specimen was originally identified as *Saffordophyllum* sp. of Middle to Late Ordovician age (Oliver and others, 1975; Chapman and others, 1981) but is now identified as *Favosites*? sp. of Silurian or Devonian age (W.A. Oliver, Jr., 1997; written commun. to F. Weber). Two-hole crinoid columnals, indicative of a late Early-early Middle Devonian (Emisian-Eifelian) age, are also reported from beach float found near locality 35 (R.B. Blodgett, Oregon State University, 1997, written commun. to F. Weber).

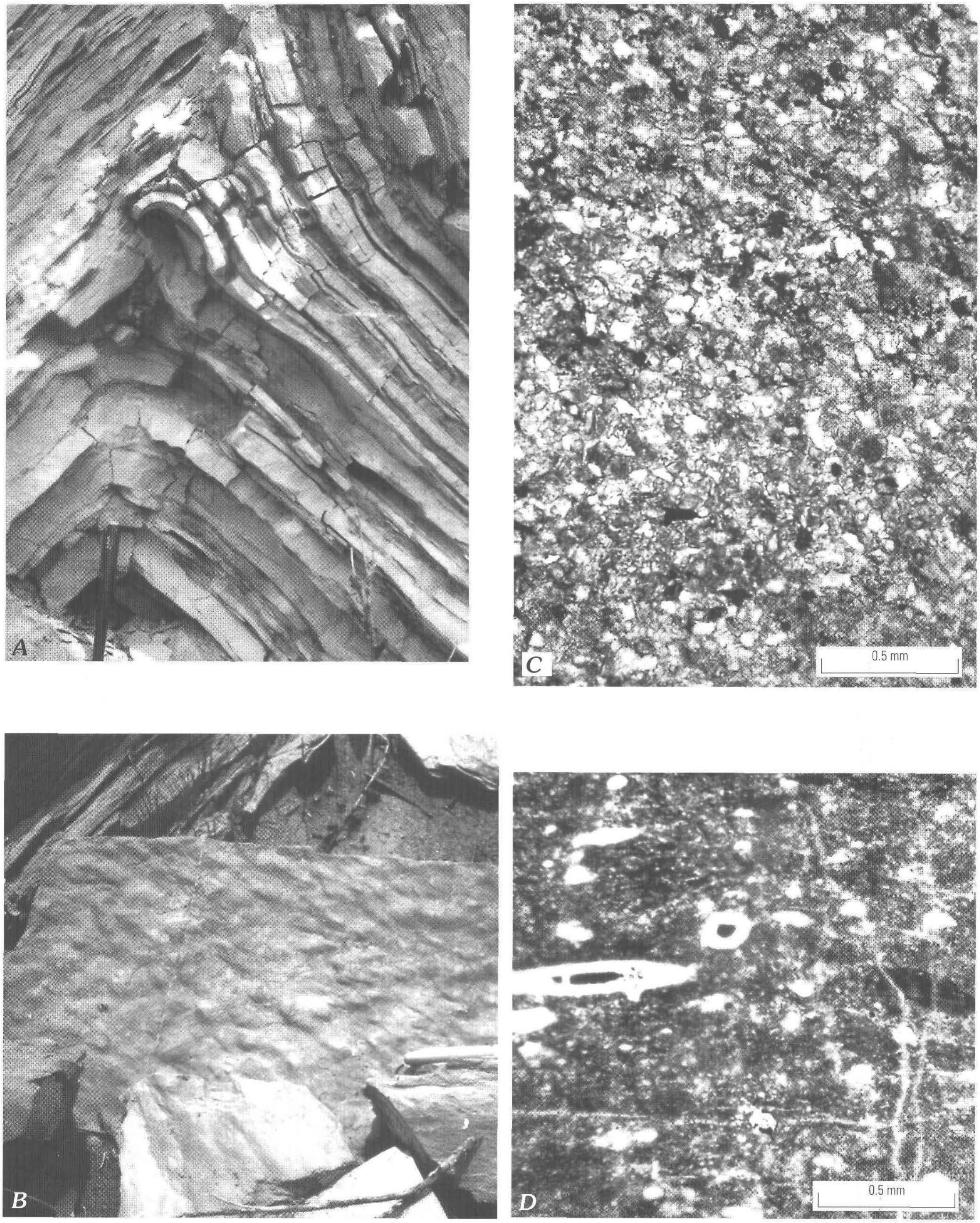
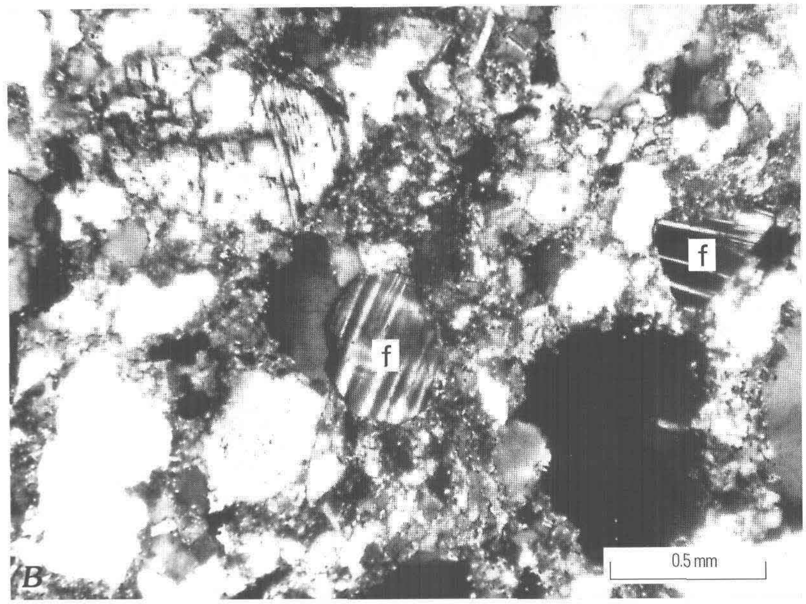


Figure 6. Sedimentary features of the chert and argillite unit, Telida subterrane, Minchumina terrane. *A–C*, Outcrop views and photomicrograph (*C*) of distal, thin-bedded, silty limestone turbidites (fig. 2, loc. 23). Note black carbonaceous partings in *A*, load casts on bed bottom in *B*, and parallel laminae rich in peloids (dark grains) and quartz and lesser plagioclase silt (light grains) in *C*. *D*, Photomicrograph of chert with abundant siliceous sponge spicules; some spicule centers are pyritized (fig. 2, loc. 24).



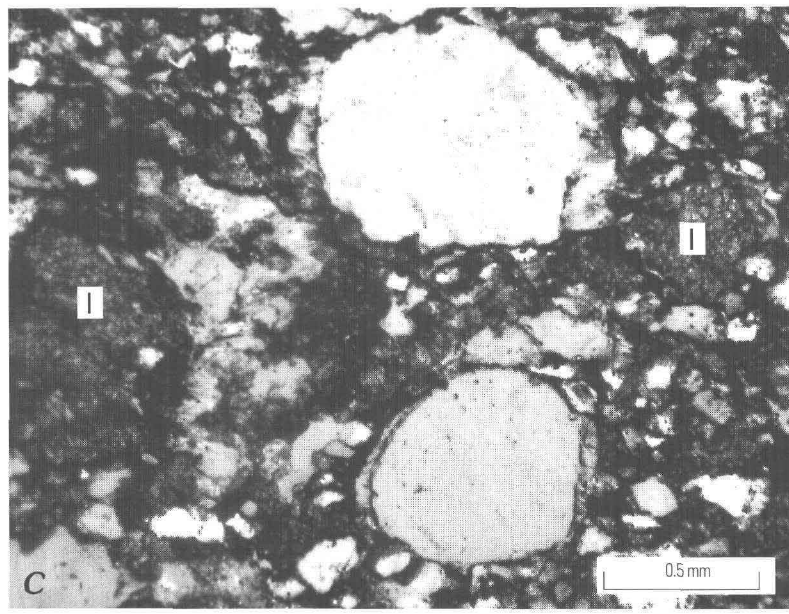
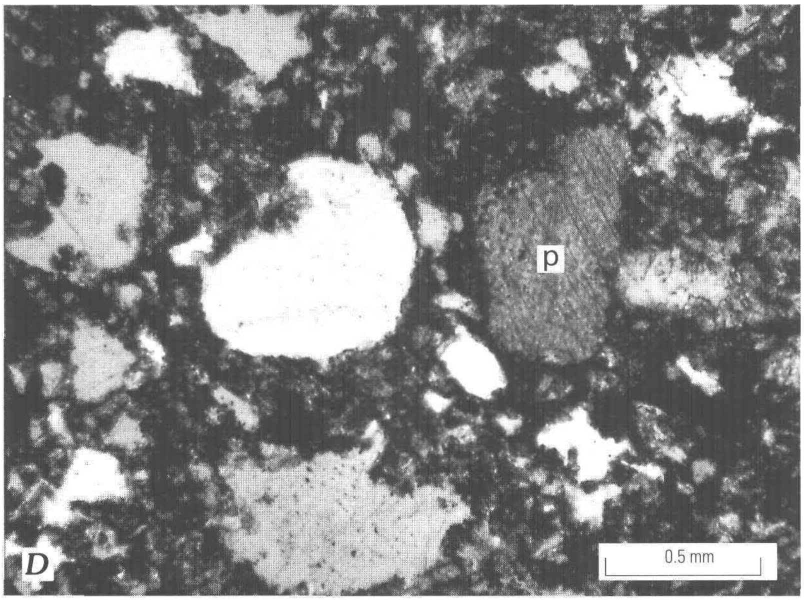


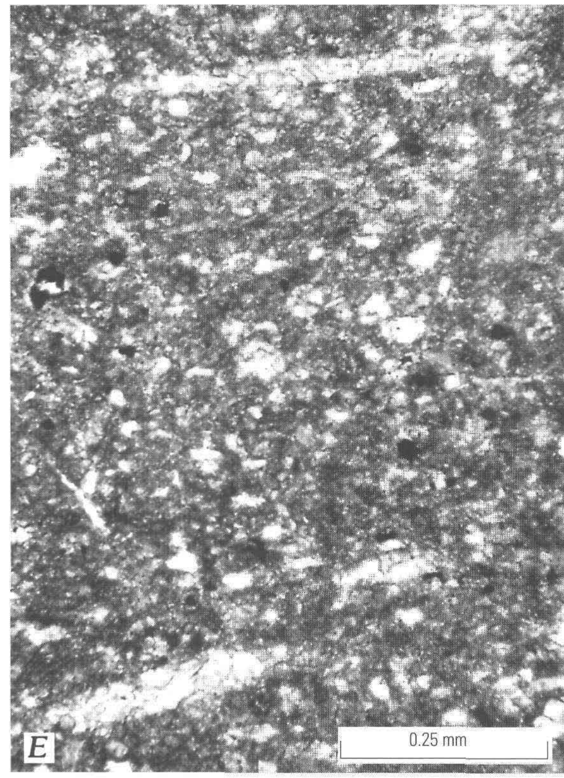
Figure 7 (above and facing page). Sedimentary features of the argillite and quartzite unit, Telida subterrane, Minchumina terrane. Outcrop view (*A*) and photomicrographs (*B–D*; *B*, crossed nicols) of sandstone turbidites, intercalated with argillite and thin carbonate layers (*E*, photomicrograph) (fig. 2, loc. 33). Sandstone contains abundant, rounded quartz, lesser plagioclase and potassium feldspar (f), polycrystalline carbonate lithic clasts (l) and pelmatozoan fragments (p). Carbonate layer shown in *E* is dolomitic micrite with silty laminae rich in calcareous sponge spicules, quartz, and lesser plagioclase.

Like the chert and argillite unit, the argillite and quartzite unit probably represents chiefly turbidites and hemipelagic deposits. Quartz-rich, locally calcareous sandstones are graded, poorly sorted, and were likely deposited as turbidites. They are coarser grained and more abundant than the calcareous turbidites in the chert and argillite unit; they appear to have had a different source and may have accumulated in a less distal position. Fine-grained calcareous, siliceous, and argillaceous strata in the argillite and quartzite unit formed as "background" sedimentation between pulses of turbidite deposition.

Stratigraphy of the Telida Subterrane

Our studies indicate that, at Lake Minchumina, the chert and argillite unit is older than the argillite and quartzite unit. Previous workers considered the chert and argillite unit to be the younger of the two, but assigned all strata at Yutokh Hill (the area between locs. 28, 29, and 35 on fig. 2) to the argillite and quartzite unit (Chapman and others, 1981; Patton and others, 1994). If graptolite-bearing strata on the north and south sides of Yutokh Hill are included in the chert and argillite unit, however, a different stratigraphy results (F. Weber, written commun., 1997). In this interpretation, the argillite and quartzite unit, exposed at the top and on the east side of Yutokh Hill, unconformably overlies the chert and argillite unit (the contact could also be a low-angle thrust fault). Although structure in this area is complex (see further discussion below) our new fossil data, and the reinterpreted age of the in situ coral from Yutokh Hill, suggest that the chert and argillite unit at Lake Minchumina is Ordovician and the argillite and quartzite unit is Silurian and perhaps, in part, Devonian. It is possible, however, that the argillite and quartzite unit includes strata of several ages. Previous workers (Patton and others, 1980; Chapman and others, 1975) correlated this unit with Cambrian-Upper Proterozoic rocks, such as the Wickersham unit in the Livengood quadrangle, on





lithologic grounds—grits in the Wickersham are bimodal quartzite with locally abundant potassium and plagioclase feldspar (Weber and others, 1992). The compositional ties that we noted in our study area between calcareous and noncalcareous turbidites in the argillite and quartzite unit need not signify stratigraphic equivalence but could instead indicate erosion and reworking of older material into younger turbidites. Thus, undated, noncalcareous parts of the argillite and quartzite unit (for example, rocks at Munsatli Ridge) could be Cambrian or older and could have provided a source for the coarse quartz and feldspar found in the Silurian turbidites at Lake Minchumina.

Correlation

Lithologic and paleontologic data detailed above constrain correlations between the Nixon Fork and Minchumina terranes and provide a basis for regional comparison of these strata with coeval deep-water facies exposed to the south (Dillinger terrane). In this section, we compare Upper Cambrian to Lower Devonian deep-water sequences in the Nixon Fork, Minchumina, and Dillinger terranes and consider depositional and tectonic factors affecting their correlation.

Stratigraphic Constraints and Implications

The lower Paleozoic stratigraphies of the Nixon Fork, Minchumina, and Dillinger terranes are compared in figure 8. Gaps remain in these stratigraphies (particularly for the Minchumina terrane), but the available data outline several interesting patterns. In the discussion that follows, "Nixon Fork terrane" refers only to rocks in the Medfra quadrangle and not to correlative strata in the McGrath and Lime Hills quadrangles to the south that some workers have included in this terrane.

Nixon Fork Terrane

Deep-water facies in the Nixon Fork terrane accumulated primarily at times when deposition is not recorded in adjacent deep-water sequences. In the Nixon Fork, deep-water sediments formed chiefly during the Late Ordovician, Early Silurian, and Early Devonian, but strata of Late Ordovician age and some intervals in the Early Silurian have not been identified in the Minchumina terrane or in the paleontologically well constrained Dillinger terrane. If these terranes indeed represent parts of a single continental margin, depositional patterns suggest that the shelf edge along this margin stepped back (retreated landward) in Late Ordovician and Early Silurian time. During this period, turbidites and hemipelagic material were trapped near the platform in sequences such as the Paradise Fork Formation and did not reach more distal sequences such as the Dillinger that formed farther from the continental margin.

East Fork Subterrane of the Minchumina Terrane

Well-dated intervals in the East Fork subterrane correlate in part with platform facies of the Nixon Fork terrane, do not match dated intervals in the Telida subterrane, and correlate well with the Dillinger terrane. The general correlation between Nixon Fork and East Fork rocks supports the suggestion that deep-water facies in the East Fork were derived from the Nixon Fork platform. Strata as old as the Late Cambrian part of the East Fork, however, have not been identified in the Nixon Fork terrane in the Medfra quadrangle. The base of the Novi Mountain Formation, the oldest dated unit in the Nixon Fork terrane in this area, is paleontologically well constrained at its type section as early Early Ordovician (*R. manitouensis* Zone) (A.G. Harris and J.E. Repetski, unpub. data, 1997). Not all sections of the Novi

Mountain have been dated, however, and it is possible that, outside its type area, the unit is as old as Late Cambrian. Alternatively, Cambrian strata in the East Fork may have accumulated before the Nixon Fork platform was established and may have derived from a more distant source. Upper Cambrian beds in the East Fork correlate well, biostratigraphically and lithologically, with the Lyman Hills Formation (Bundtzen and others, 1994) in the Dillinger terrane and could have had the same provenance.

Middle Ordovician and Lower Devonian strata in the East Fork subterrane correlate well with, and could have been derived from, the Nixon Fork platform. Ordovician and Devonian East Fork rocks also correlate with parts of the Post River Formation and the Barren Ridge Limestone, respectively, in the Dillinger terrane (fig. 8). However, the Dillinger terrane is characterized by a thick sandstone turbidite unit of Silurian age, the Terra Cotta Mountains Sandstone (Churkin and Carter, 1996). No lithologic or biostratigraphic match for this unit has been found in the East Fork subterrane.

Our biostratigraphic data indicate that strata in the East Fork subterrane accumulated during Late Cambrian, Middle Ordovician, and Early Devonian time. These data could be an artifact of the poor exposures characteristic of this subterrane. It is also possible, however, that carbonate turbidites and associated hemipelagites were generated chiefly at certain times during the long history of the Nixon Fork platform, and the stratigraphy of the East Fork subterrane reflects this discontinuous generation. Episodic transfer of sediment from shelf to basin could be due to tectonic events, eustatic fluctuations, and (or) autocyclic changes in platform sedimentation, among other factors.

Telida Subterrane of the Minchumina Terrane

Lower Ordovician strata in the Telida subterrane have the strongest ties to the Nixon Fork platform of all deep-water rocks in the study area. Conodonts from calcareous turbidites at locality 23 (fig. 2) match those from the lower part of the Novi Mountain Formation species for species (table 1) (A.G. Harris and J.E. Repetski, unpub. data, 1997). These Telida strata also correlate well, biostratigraphically and lithologically, with the lower siltstone member of the Post River Formation in the Dillinger terrane (Churkin and Carter, 1996). Middle Ordovician rocks in the Telida subterrane correlate with broadly dated parts of the Nixon Fork platform and with the middle part of the Graptolite Canyon Member of the Post River Formation. Telida sandstones at Lake Minchumina correlate with, or are just slightly older than, the lower part of the Paradise Fork Formation in the Nixon Fork terrane and correlate well with the upper part of the Post River Formation. Lake Minchumina sandstones are at least in part older than, and differ in composition from, the Terra Cotta Mountains Sandstone in the Dillinger terrane, as will be discussed below.

Compositional Trends

Several notable patterns in the composition of Medfra-area deep-water facies can be discerned. These patterns reflect variations in the proportion of carbonate to noncarbonate detritus, and in the types of noncarbonate detritus, that are found in deep-water strata of the Nixon Fork and Minchumina terranes.

Carbonate Input

Turbidites and hemipelagic strata show similar carbonate-to-noncarbonate ratios in the study area. In the Nixon Fork terrane, the East Fork subterrane, and the westernmost exposures of the Telida subterrane, turbidites consist chiefly of carbonate material and were derived principally from a shallow-water carbonate platform, presumably the Nixon Fork platform. Turbidites in the eastern exposures of the Telida subterrane are much less calcareous and include detritus—such as coarse, rounded quartz grains and microcline—not found in turbidites in the other sequences. Finer grained strata show similar trends. In the Nixon Fork terrane, the East Fork subterrane, and the western Telida subterrane, hemipelagic deposits are chiefly micrite and shale, but in the eastern part of the Telida subterrane these deposits are much less terrigenous and consist predominantly of chert. The chert and argillite unit of the Telida subterrane is lithologically similar to, but somewhat older than, the Livengood Dome chert (Upper Ordovician; Chapman and others, 1980) in the Livengood quadrangle to the northeast (Livengood terrane of Silberling and others, 1994) (fig. 1).

Compositional data thus suggest that strata in the eastern Telida subterrane accumulated farthest from the continental margins, experienced relatively little input from carbonate platforms adjacent to these margins, and received some noncarbonate detritus that did not reach the other deep-water sequences in the study area.

Noncarbonate Components

Noncarbonate detritus occurs sparsely in most parts of the Nixon Fork terrane and the East Fork subterrane but is a significant component in turbidites in the western part of the Telida subterrane. Plagioclase feldspar and metamorphic lithic clasts made up of quartz, chlorite, and (or) white mica are notable minor constituents of Upper Cambrian strata in the East Fork subterrane, Lower Ordovician turbidites in the western Telida subterrane, and Lower Ordovician rocks in the Nixon Fork platform succession; rare metamorphic clasts were also noted in the Silurian-Lower Devonian Paradise Fork Formation. The clasts, and perhaps the feldspar, may have been derived from metamorphosed basement rocks that underlie the Nixon Fork platform succession; these rocks are of early Paleozoic or Precambrian age and include quartz-chlorite-muscovite schist and quartz-plagioclase porphyry (map units Pzp€p and Pzp€v of Patton and others, 1980).

Noncarbonate detritus is a significant component in turbidites of the argillite and quartzite unit in the Telida subterrane. Correlation of these turbidites with the Terra Cotta Mountains Sandstone in the Dillinger terrane has been suggested (T. Bundtzen, Pacific Rim Inc., oral commun., 1997) and is broadly supported by age data from the exposures at Lake Minchumina, although the Minchumina strata are slightly older than the base of the Terra Cotta in its type area (fig. 8) (Churkin and Carter, 1996). Published petrographic descriptions of the Terra Cotta, however, suggest significant compositional differences between the two units. Slate clasts, polycrystalline quartz, and white mica are important constituents of the Terra

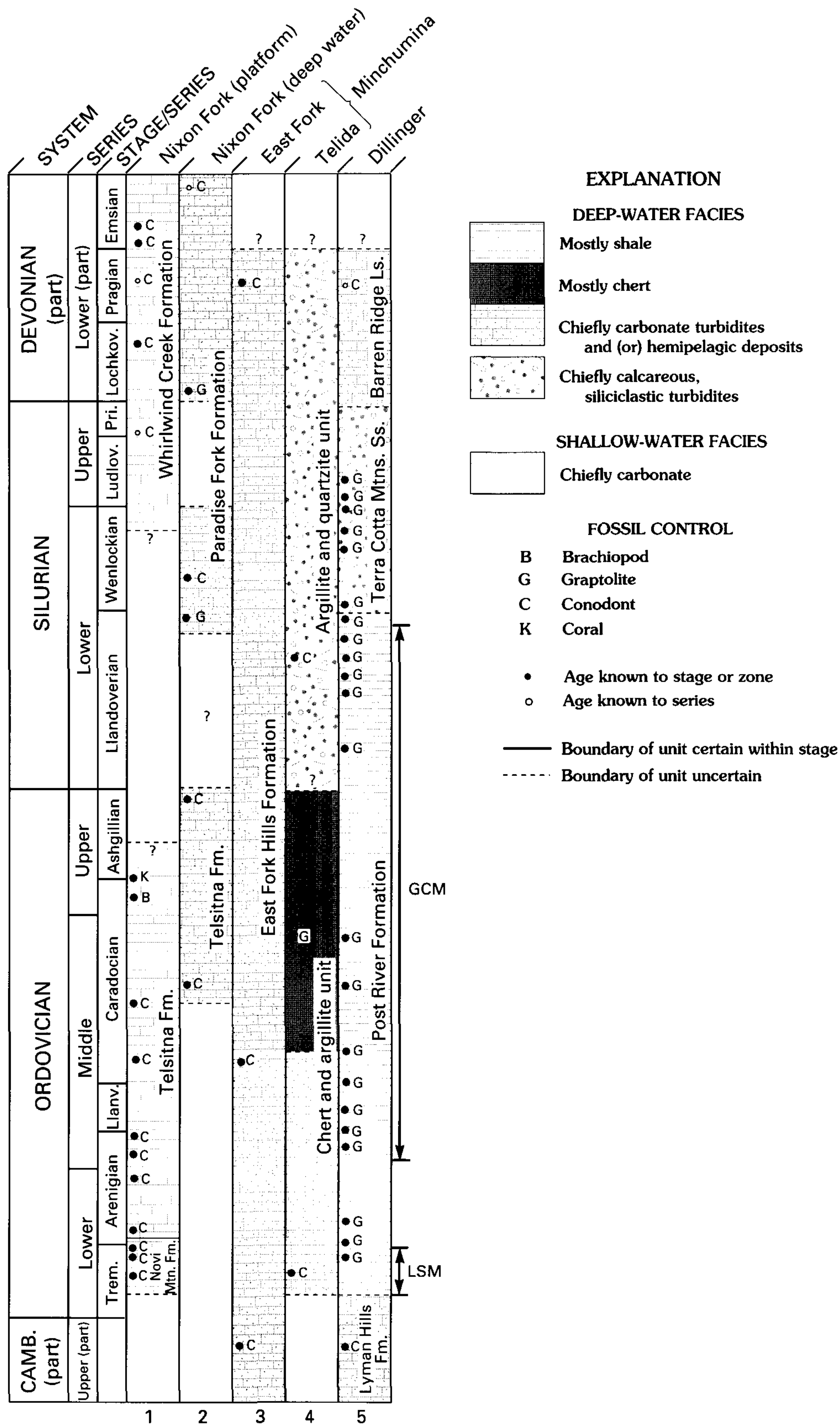


Figure 8. Correlation, lithologies, fossil control, and depositional environments of uppermost Cambrian to Lower Devonian rocks in selected areas of central Alaska. Only fossil groups that most narrowly restrict age of collection or unit are listed. Age of argillite and quartzite unit (column 4) is poorly constrained. Parts of this unit could be older than chert and argillite unit but youngest beds could be as young as Devonian; see text for discussion. Arrows adjacent to column 5 indicate lower siltstone member (LSM) and Graptolite Canyon Member (GCM) of the Post River Formation. Data sources as follows: column 1, Dutro and Patton (1982), A.G. Harris and J.E. Repetski, unpub. data; columns 2–4, this paper; column 5, Bundtzen and others (1994), Churkin and Carter (1996). The former Llandeilian Series is now considered a stage of the Llanvirnian Series (Fortey and others, 1995).

Cotta (Bundtzen and others, 1994; Churkin and Carter, 1996) but are rare or absent in Telida turbidites, whereas the potassium feldspar and rounded, bimodal, monocrystalline quartz that are so notable in the Telida turbidites are not reported from the Terra Cotta.

As noted above, parts of the argillite and quartzite unit in the Telida subterrane could be of Cambrian-Precambrian age and equivalent to the Wickersham unit (and related rocks) in the Livengood area to the north (Wickersham terrane of Silberling and others, 1994) (fig. 1). Erosion of these older Telida rocks could then have provided quartz and feldspar to the Silurian turbidites at Lake Minchumina. If all parts of the argillite and quartzite unit are of Silurian and younger age, grits such as the Wickersham still seem to be a likely source for the quartz and feldspar found in Telida subterrane turbidites. Whatever the age of the turbidites in the argillite and quartzite unit, their composition implies ties to rocks currently exposed to the northeast (Livengood quadrangle) rather than to the south (McGrath quadrangle). Petrographic data thus indicate that the Telida subterrane contains at least two distinct sequences, each derived from a different source, and these sequences need not have had a shared Paleozoic history.

Structure

Paleozoic rocks of the study area have been affected by two principal deformations: an earlier folding about northeast axes, followed by dextral strike-slip on the Iditarod fault system. The focus will be here on aspects of the structure that bear on the palinspastic relations among the strata of interest.

The Iditarod fault is one of the most significant strike-slip faults in Alaska (Grantz, 1966). In the Iditarod quadrangle, the fault cuts a Late Cretaceous to early Tertiary volcano-plutonic complex and separates its two halves—the Iditarod Volcanics and the Beaver Mountains volcanic field—by 88 to 94 km in a dextral sense (Miller and Bundtzen, 1988). Similarly, in the McGrath and Medfra quadrangles, the eastern contact between Cretaceous siliciclastic strata of the Kuskokwim Group and Paleozoic carbonate rocks of the Nixon Fork terrane shows a dextral map separation of about 90 km. Although the Iditarod fault has only one strand of any significance in the Iditarod quadrangle (Miller and Bundtzen, 1988), several splays are mapped in the Medfra quadrangle (Patton and others, 1980). Presumably, dextral displacement across all of the splays sums to at least ~90 km—or even more if some dextral strike-slip preceded deposition of the Kuskokwim Group. There are no piercing points on any of these splays, so map separation cannot be measured; they are presumed to be dextral strike-slip faults because of their continuity and subparallelism with the Iditarod fault in the Iditarod quadrangle.

In the area of figure 2, the Iditarod fault has four main strands, labeled A through D (fig. 9), and several minor ones. Strand A juxtaposes deep-water facies of the Minchumina terrane against shallow-marine carbonate rocks of the Upper Silurian–Devonian Whirlwind Creek Formation. Strand A is presumably the main strand of the Iditarod fault system in this area; horizontal displacement is likely to be several tens of kilometers. Strand B juxtaposes the Whirlwind Creek Formation against the Upper Cretaceous to lower Tertiary Sischu volcanics. There is no direct evidence for the amount of displacement but it is inferred to have a small component of northwest-side-down vertical displacement and perhaps a few to a few tens of kilometers of dextral horizontal displacement. Strand C juxtaposes deep-water facies of the chert and argillite unit, which depositionally underlie the Sischu volcanics, against coeval shallow-marine facies of the Nixon Fork terrane. As noted above, an Early Ordovician conodont fauna in the chert and argillite unit precisely matches the conodont fauna of the age-equivalent Novi Mountain Formation. Significant fault displacement, either strike-slip, thrusting, or both, is needed to explain the current close juxtaposition of environments that must once have been farther apart.

A second regional-scale dextral strike-slip fault, the Farewell, lies to the south of the present study area, but it does bear on the palinspastic relations betweeen the Minchumina and Dillinger terranes. In the McGrath and Lime Hills quadrangles, a Late Silurian to Early Devonian algal barrier reef complex in the Nixon Fork terrane shows a dextral map separation of 145 to 153 km (Blodgett and Clough, 1985).

The Paleozoic rocks that were rearranged along these various strike-slip faults had already been folded. Fold axial traces trend roughly northeast-southwest in both the Nixon Fork and Minchumina terranes. Nixon Fork strata typically are deformed into open to tight folds with wavelengths as long as a few kilometers. On this basis, we suggest that each of the fault-bounded tracts containing Nixon Fork strata were probably not much wider prior to shortening than they are today—perhaps 10–20 percent wider. Shortening across the Minchumina terrane cannot be estimated with confidence but was undoubtedly far greater than in the Nixon Fork. Shoreline exposures at Lake Minchumina disclose the presence of inverted subhorizonal beds and nearly recumbent isoclinal folds (T.M. Kusky, Boston University, unpub. data, 1997) that require extreme amounts of shortening for at least some rocks in the belt. Large amounts of shortening are *not* suggested by the simple map pattern of the Minchumina terrane (fig. 2), but this is strictly an artifact of the mapping conditions: outcrops and helicopter landings are so sparse that entire mountains were assigned to a single unit on the basis of one or two rubble outcrops. It seems likely that the belt of northwest-directed thrust faults mapped in the Livengood quadrangle (Weber and others, 1992) continues along strike into the area of figure 2 and that the structure in the Minchumina terrane is as complex as in the southeastern part of the Livengood quadrangle.

Figure 9 shows the palinspastic distribution of our sample localities. On the Farewell fault, we restored 150 km of dextral map-separation (Blodgett and Clough, 1985). Where the Iditarod fault has a single strand (extreme western part of fig. 9, and beyond), we restored 90 km of dextral map separation (Miller and Bundtzen, 1988). For lack of any concrete evidence, we arbitrarily restored 30, 20, 20, and 20 km of dextral map separation across strands A, B, C, and D, respectively. Regardless of the displacements assigned to the individual strands, the total on all four should sum to 90 km; the relative positions of rocks northwest of strand D and southeast of strand A are the same regardless of the details. Figure 9 does not restore any shortening—only strike-slip. As noted above, shortening was relatively minor in the Nixon Fork terrane but probably quite severe in the

Minchumina terrane. The distance across the Minchumina terrane between the Farewell fault and Iditarod fault systems was undoubtedly wider than at present.

In figure 9, deep-water strata between strands B and C remain isolated from the broader tract of the Minchumina terrane, and there seems no way to bring these tracts together given *only* 90 km of only dextral displacement on strands A through D combined. One possible explanation for this map pattern is that deeper water strata between strands B and C accumulated in an intrashelf basin in the Nixon Fork platform, as implied by the restoration in figure 9. A second possibility is that these deep-water facies record a northwestward Ordovician transgression across the Nixon Fork platform that was followed by southeastward progradation of this platform during Silurian-Devonian time, prior to any shuffling on strike-slip faults. A third possibility is that rocks between strands B and C represent a piece of the Minchumina terrane that was thrust into position from the southeast, prior to any shuffling on strike-slip faults, over shallow-water strata of the Nixon Fork platform that lie between strands A and B. A fourth possibility is that the shallow-water rocks between strands A and B belong to the Minchumina and not the Nixon Fork terrane; in this interpretation, fault strand C, not strand A, marks the boundary between the Nixon Fork and Minchumina terranes (Patton and others, 1984; Patton and others, 1994). These alternatives cannot be evaluated without more information.

Biogeography

The ultimate origin of lower Paleozoic rocks in central Alaska remains contentious. Some authors have suggested that the Nixon Fork, Minchumina, and Dillinger terranes represent

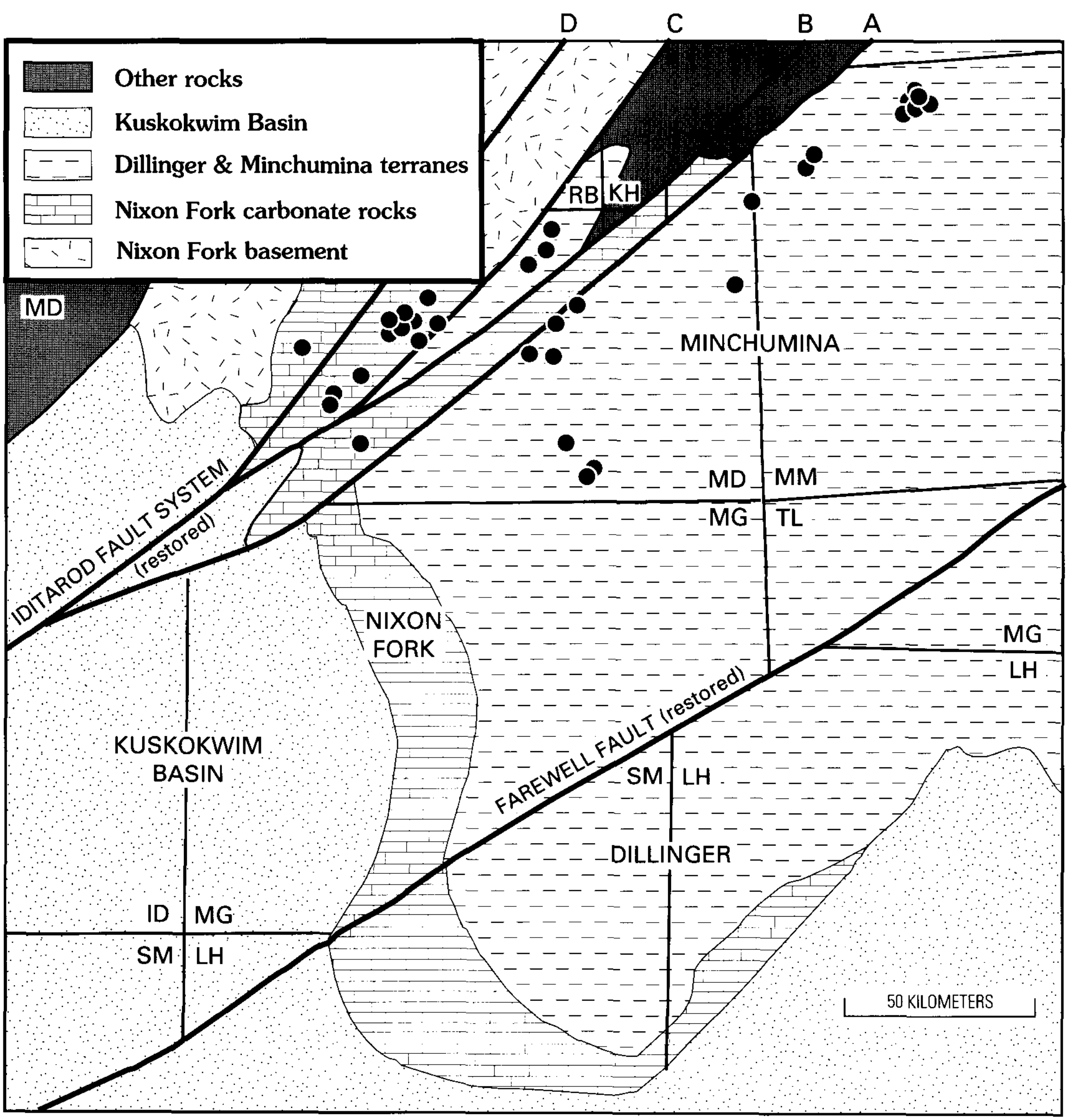


Figure 9. Palinspastic map of study area. Letters A, B, C, and D refer to strands of the Iditarod fault system mentioned in text. Restoration of 90 and 150 km of dextral strike-slip on the Iditarod and Farewell faults, respectively, aligns the deep-water Dillinger and Minchumina terranes in a position east of the Nixon Fork carbonate platform. Terrane affinity of lower Paleozoic rocks between fault strands A and C is uncertain; see text for dicussion. Black dots are locations plotted in figure 2. Fine lines are quadrangle boundaries; quadrangle abbreviations as in figure 1.

displaced fragments of the North American continental margin (Decker and others, 1994), but, more recently, others have interpreted these terranes as a sequence rifted away from the Siberian craton (Blodgett and Brease, 1997).

Biogeographic affinities of lower Paleozoic faunas can constrain the paleogeographic position of central Alaska, but the faunas discussed above are not particularly useful for such analyses. Deep-water conodont faunas, and most conodont faunas of Silurian and Devonian age, are relatively cosmopolitan. With the exception of a faunule from the upper part of the Telsitna Formation in the Nixon Fork terrane (loc. 5, fig. 2; table 1), conodont collections from deep-water facies in the Medfra area consist of tropical cosmopolites, pandemics, and North American Midcontinent species. The collection at locality 5, however, of late Middle-Late Ordovician age, consists chiefly of Siberian-Alaskan province (SAP) elements with minor pandemics.

SAP elements are common in some collections from shallow-water facies of the Nixon Fork terrane, particularly those of late Early-Middle Ordovician age (Dumoulin, Bradley, and others, 1998). They are also noteworthy in some Early, Middle, and Late Ordovician faunas from the western and central Brooks Range and Seward Peninsula of northern Alaska (Dumoulin and Harris, 1994). A full explication of the biogeography of lower Paleozoic rocks in central Alaska is beyond the scope of this paper, but it is worth noting here that Siberian-Alaskan province elements have not been identified from Paleozoic conodont faunas of east-central Alaska or northwestern Canada (Dumoulin, Harris, and de Freitas, 1998; A.G. Harris, unpub. data).

Conclusions

Deep-water facies of Cambrian through Devonian age crop out widely in the eastern Medfra and western Mt. McKinley quadrangles and have been included in several discrete terranes. Calcareous hemipelagic deposits and fine-grained carbonate turbidites comprise the upper part of the Telsitna Formation (Middle-Upper Ordovician) and the Paradise Fork Formation (Lower Silurian–Lower Devonian) in the Nixon Fork terrane, the East Fork Hills Formation (Upper Cambrian–Lower Devonian) in the East Fork subterrane of the Minchumina terrane, and western exposures of the chert and argillite unit (Ordovician) in the Telida subterrane of the Minchumina terrane. These strata were derived largely from the Nixon Fork carbonate platform and correlate well with parts of the Dillinger terrane exposed to the south. The chert and argillite unit (eastern outcrops) and the argillite and quartzite unit (Silurian-Devonian? and possibly older) in the Telida subterrane of the Minchumina terrane consist chiefly of siliceous hemipelagic deposits and quartzofeldspathic turbidites and may correlate with parts of the Wickersham and Livengood terranes to the northeast (Livengood quadrangle). The Telida subterrane as presently defined thus includes two roughly coeval sequences of disparate origin.

Deep-water strata of the Minchumina and Dillinger terranes restore to a position east of the Nixon Fork carbonate platform when 90 and 150 km of dextral strike-slip on the Iditarod and Farewell faults, respectively, are removed. This restoration and our petrographic and paleontologic data suggest that lower Paleozoic rocks in the Nixon Fork and Dillinger terranes, as well as those in the western part of the Minchumina terrane, formed along a single continental margin. Strata in the eastern part of the Minchumina terrane (eastern part of the Telida subterrane) differ in composition and provenance from those to the west and may have had a distinct geologic history.

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References Cited

Armstrong, H.A., 1990, Conodonts from the Upper Ordovician–Lower Silurian carbonate platform of north Greenland: Gronlands Geologiske Undersogelse Bulletin 159, 151 p.

Barrick, J.E., and Klapper, G., 1976, Multielement Silurian (late Llandoverian-Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of *Kockelella*: Geologica et Palaeontologica, v. 10, p. 59–100.

Blodgett, R.B., and Clough, J.G., 1985, The Nixon Fork Terrane—Part of an *in situ* peninsular extension of the Paleozoic North American continent [abs.]: Geological Society of America, Abstracts with Programs, v. 17, no. 6, p. 342.

Blodgett, R.B., and Brease, P.F., 1997, Emsian (late Early Devonian) brachiopods from Shellabarger Pass, Talkeetna C-6 quadrangle, Denali National Park, Alaska indicate Siberian origin for Farewell terrane [abs.]: Geological Society of America, Abstracts with Programs, v. 29, no. 5, p. 5.

Bundtzen, T.K., Laird, G.M., Blodgett, R.B., Clautice, K.H., and Harris, E.E., 1994, Geology of the Gagaryah River area, Lime Hills C-5 and C-6 quadrangles, southwest Alaska: Alaska Divison of Geological & Geophysical Surveys Public Data File 94-40, 17 p., 1 plate, scale 1:63,360.

Chapman, R.M., Churkin, Michael, Jr., Carter, Claire, and Trexler, J.H., Jr., 1981, Ordovician graptolites and early Paleozoic radiolarians in the Lake Minchumina area date a regional shale and chert belt, *in* Albert, N.R.D., and Hudson, Travis, eds., The U.S. Geological Survey in Alaska: Accomplishments During 1979: U.S. Geological Survey Circular 823-B, p. B32–B34.

Chapman, R.M., Weber, F.R., Churkin, Michael, Jr., and Carter, Claire, 1980, The Livengood Dome Chert: A new Ordovician formation in central Alaska and its relevance to displacement on the Tintina fault, *in* Shorter Contributions to Stratigraphy and Structural Geology, 1979: U.S. Geological Survey Professional Paper 1126-F, p. F1–F13.

Chapman, R.M., and Yeend, Warren, 1981, Geologic reconnaissance of the east half of Kantishna River quadrangle and adjacent areas, *in* Albert, N.R.D., and Hudson, Travis, eds., The U.S. Geological Survey in Alaska: Accomplishments During 1979: U.S. Geological Survey Circular 823-B, p. B30–B32.

Chapman, R.M., Yeend, W.E., and Patton, W.W., Jr., 1975, Preliminary reconnaissance map of the western half of Kantishna River quadrangle, Alaska: U.S. Geological Survey Open-File Map 75-351, scale 1:250,000.

Churkin, Michael, Jr., and Carter, Claire, 1996, Stratigraphy, structure, and graptolites of an Ordovician and Silurian sequence in the Terra Cotta Mountains, Alaska Range, Alaska: U.S. Geological Survey Professional Paper 1555, 84 p.

Cook, H.E., Hine, A.C., and Mullins, H.T., 1983, Platform margin and deep water carbonates: Society of Economic Paleontologists and Mineralogists Short Course Notes No. 12, 573 p.

Corradini, Carlo, Ferretti, Annalisa, Serpagli, Enrico, and Barca, Sebastiano, 1998, The Ludlow-Pridoli section Genna Ciuerciu, west of Silius: Giornale di Geologia, ser. 3, Special Issue, ECOS VII-Sardinia Guidebook, p. 112–118.

Decker, John, Bergman, S.C., Blodgett, R.B., Box, S.E., Bundtzen, T.K., Clough, J.G., Coonrad, W.L., Gilbert, W.G., Miller, M.L., Murphy, J.M., Robinson, M.S., and Wallace, W.K., 1994, Geology of southwestern Alaska, *in* Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colo., Geological Society of America, The Geology of North America, v. G-1, p. 285–310.

Dumoulin, J.A., Bradley, D.C., Harris, A.G., and Repetski, J.E., 1998, Sedimentology, conodont biogeography, and subsidence history of the Nixon Fork terrane, Medfra quadrangle, Alaska [abs.]: Celle, Germany, III International Conference on Arctic Margins Abstracts, p. 49.

Dumoulin, J.A., and 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. Geological Survey Professional Paper 1545, 74 p.

Dumoulin, J.A., Harris, A.G., and de Freitas, T.A., 1998, Facies patterns and conodont biogeography in Arctic Alaska and the Canadian Arctic Islands: Evidence against juxtaposition of these areas during early Paleozoic time [abs.]: Celle, Germany, III International Conference on Arctic Margins Abstracts, p. 50.

Dutro, J.T., Jr., and Patton, W.W., Jr., 1982, New Paleozoic formations in the northern Kuskokwim Mountains, west-central Alaska, *in* Stratigraphic Notes, 1980–1982: U.S. Geological Survey Bulletin 1529-H, p. H13–H22.

Fortey, R.A., Harper, D.A.T., Ingham, J.K., Owen, A.W., and Rushton, A.W.A., 1995, A revision of Ordovician series and stages from the historical type area: Geological Magazine, v. 132, no. 1, p. 15–30.

Gilbert, W.G., and Bundtzen, T.K., 1984, Stratigraphic relationship between Dillinger and Mystic terranes, western Alaska Range, Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 16, no. 5, p. 286.

Grantz, Arthur, 1966, Strike-slip faults in Alaska: U.S. Geological Survey Open-File Report 267, 82 p.

Jaeger, Hermann, 1975, Die Graptolithenführung im Silur/Devon des Cellon-Profils (Karnische Alpen): Carinthia II, p. 111–126.

Jeppsson, Lennart, 1972, Some Silurian conodont apparatuses and possible conodont dimorphism: Geologica et Palaeontologica, no. 6, p. 51–69.

Jones, D.L., Silberling, N.J., Berg, H.C., and Plafker, George, 1981, Map showing tectonostratigraphic terranes in Alaska, columnar sections, and summary description of terranes: U.S. Geological Survey Open-File Report 81-792, 20 p., 2 sheets, scale 1:2,500,000.

Kleffner, M.A., 1995, A conodont- and graptolite-based Silurian chronostratigraphy, *in* Mann, K.O., and Lane, H.R., eds., Graphic Correlation: SEPM Society for Sedimentary Geology Special Publication No. 53, p. 159–176.

Measures, E.A., Rohr, D.M., and Blodgett, R.B., 1992, Depositional environments and some aspects of the fauna of Middle Ordovician rocks of the Telsitna Formation, northern Kuskokwim Mountains, Alaska, *in* Bradley, D.C., and Dusel-Bacon, Cynthia, eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1991: U.S. Geological Survey Bulletin 2041, p. 186–201.

Miller, M.L., and Bundtzen, T.K., 1988, Right-lateral offset solution for the Iditarod-Nixon Fork fault, western Alaska: U.S. Geological Survey Circular 1016, p. 99–103.

Nowlan, G.S., McCracken, A.D., and Chatterton, B.D.E., 1988, Conodonts from Ordovician-Silurian boundary strata, Whittaker Formation, Mackenzie Mountains, Northwest Territories: Geological Survey of Canada Bulletin 373, 99 p.

Oliver, W.A., Jr., Merriam, C.W., and Churkin, Michael, Jr., 1975, Ordovician, Silurian, and Devonian corals of Alaska: U.S. Geological Survey Professional Paper 823-B, p. 13–44.

Patton, W.W., Jr., Box, S.E., Moll-Stalcup, E.J., and Miller, T.P., 1994, Geology of west-central Alaska, *in* Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colo., Geological Society of America, The Geology of North America, v. G-1, p. 241–269.

Patton, W.W., Jr., Moll, E.J., Dutro, J.T., Jr., Silberman, M.L., and Chapman, R.M., 1980, Preliminary geologic map of the Medfra quadrangle, Alaska: U.S. Geological Survey Open-File Report 80-811A, scale 1:250,000.

Patton, W.W., Jr., Moll, E.J., and King, H.D., 1984, The Alaskan Mineral Resources Assessment Program: Guide to information contained in the folio of geologic and mineral-resource maps of the Medfra quadrangle, Alaska: U.S. Geological Survey Circular 928, 11 p.

Savage, N.M., Rohr, D.M., and Blodgett, R.B., 1995, Late Silurian conodonts from the Medfra B-4 quadrangle, west-central Alaska [abs.]: Geological Society of America Abstracts with Programs, v. 27, no. 5, p. 76–77.

Scholle, P.A., Bebout, D.G., and Moore, C.H., 1983, Carbonate depositional environments: American Association of Petroleum Geologists Memoir 33, 708 p.

Silberling, N.J., Jones, D.L., Monger, J.W.H., Coney, P.J., Berg, H.C., and Plafker, George, 1994, Lithotectonic terrane map of Alaska and adjacent parts of Canada, *in* Plafker, George, and Berg, H.C., eds., The Geology of Alaska: Boulder, Colo., Geological Society of America, The Geology of North America, v. G-1, plate 3, 1 sheet, scale 1:2,500,000.

Tipnis, R.S., 1979, Fused clusters of *Ptiloncodus simplex* Harris: An Ordovician phosphatic microfossil, *in* Current Research, Part C: Geological Survey of Canada Paper 79-1C, p. 51–54.

Weber, F.R., Wheeler, K.L., Rinehart, C.D., Chapman, R.M., and Blodgett, R.B., 1992, Geologic map of the Livengood quadrangle, Alaska: U.S. Geological Survey Open-File Report 92-562, 20 p., scale 1:250,000.

Wilson, F.H., Dover, J.H., Bradley, D.C., Weber, F.R., Bundtzen, T.K., and Haeussler, P.J., 1998, Geologic map of central (Interior) Alaska: U.S. Geological Survey Open-File Report 98-133, 3 sheets, scale 1:500,000, 63 p.

Wilson, J.L., 1975, Carbonate facies in geologic history: New York, Springer-Verlag, 471 p.

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