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Paleozoic Strata of the Dyckman Mountain Area, Northeastern Medfra Quadrangle, Alaska

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Abstract

Paleozoic rocks in the Dyckman Mountain area (northeastern Medfra quadrangle; Farewell terrane) include both shallow- and deep-water lithologies deposited on and adjacent to a carbonate platform. Shallow-water strata, which were recognized by earlier workers but not previously studied in detail, consist of algal-laminated micrite and skeletal-peloidal wackestone, packstone, and lesser grainstone. These rocks are, at least in part, of Early and (or) Middle Devonian age but locally could be as old as Silurian; they accumulated in shallow subtidal to intertidal settings with periodically restricted water circulation. Deep-water facies, reported here for the first time, are thin, locally graded beds of micrite and calcisiltite and subordinate thick to massive beds of lime grainstone and conglomerate. Conodonts indicate an age of Silurian to Middle Devonian; the most tightly dated intervals are early Late Silurian (early to middle Ludlow). These strata formed as hemipelagic deposits, turbidites, and debris flows derived from shallow-water lithologies of the Nixon Fork subterrane. Rocks in the Dyckman Mountain area are part of a broader facies belt that is transitional between the Nixon Fork carbonate platform to the west and deeper water, basinal lithologies (Minchumina "terrane") to the east. Transitional facies patterns are complex because of Paleozoic shifts in the position of the platform margin, Mesozoic shortening, and Late Cretaceous-Tertiary disruption by strike-slip faulting.

Introduction

Lower and middle Paleozoic strata crop out across much of the eastern half of the Medfra quadrangle in central Alaska. A well-exposed section that consists largely of shallow-water facies is flanked on the east by more poorly exposed, roughly coeval deeper water deposits; these two successions, separated by a strand of the Iditarod–Nixon Fork fault, were included in the Nixon Fork and Minchumina terranes, respectively, by Patton and others (1994) and Silberling and others (1994) (fig. 1). Rocks of both these successions, as well as correlative strata to the south and southwest, were called Farewell terrane by Decker and others (1994) and were interpreted to have formed along a single continental margin.

The Nixon Fork terrane in the Medfra quadrangle includes about 5,500 m of Ordovician through Devonian, chiefly platform carbonate rocks. Four formations are recognized (Dutro and Patton, 1982). Shallow-water strata make up the Novi Mountain Formation (Lower Ordovician), most of the Telsitna Formation (Ordovician), and the Whirlwind Creek Formation (Upper Silurian and Devonian); deeper water facies occur in the uppermost part of the Telsitna and throughout the Paradise Fork Formation (Silurian and Lower Devonian) (Dumoulin and others, 1999).

Patton and others (1994) subdivided their Minchumina terrane into two subterranes. The East Fork subterrane is confined to the Medfra quadrangle and comprises the Upper Cambrian through Lower Devonian East Fork Hills Formation (Dutro and Patton, 1982; Dumoulin and others, 1999), which is a sequence of thin-bedded, fine-grained, commonly silty and (or) dolomitic limestone. The Telida subterrane to the northeast encompasses sparse, discontinuous exposures of unnamed Precambrian(?) and Paleozoic argillite, chert, phyllite, sandstone, and limestone. Eastern exposures of the Telida have compositional ties to terranes in the Livengood quadrangle (northeast of area shown in fig. 1) and contain much less carbonate than exposures to the west; petrographic data thus suggest that the Telida subterrane as presently defined is an artificial construct made up of two distinct sequences of disparate provenance (Dumoulin and others, 1999).

We agree with Decker and others (1994) that lower Paleozoic strata throughout their Farewell terrane probably formed along the same continental margin, but we find their terminology for subdivisions of the Farewell awkward and inadequate for the Medfra area. In this paper, we follow the usage of Bundtzen and others (1997) and Blodgett (1998); we refer to chiefly shallow-water, Ordovician through Devonian rocks in the Nixon Fork terrane of Patton and others (1994) as "Nixon Fork subterrane" and use "Dillinger subterrane" for lower Paleozoic deep-water facies in the McGrath and Lime Hills quadrangles to the south and the Mt. McKinley and Healy quadrangles to the southeast (fig. 1). Rocks not easily assigned to either of these subterranes, such as strata in the Minchumina terrane of Patton and others (1994), are referred to by formation name or map-unit name, as appropriate.

In the northeastern part of the Medfra quadrangle, the boundary between the Nixon Fork subterrane and coeval

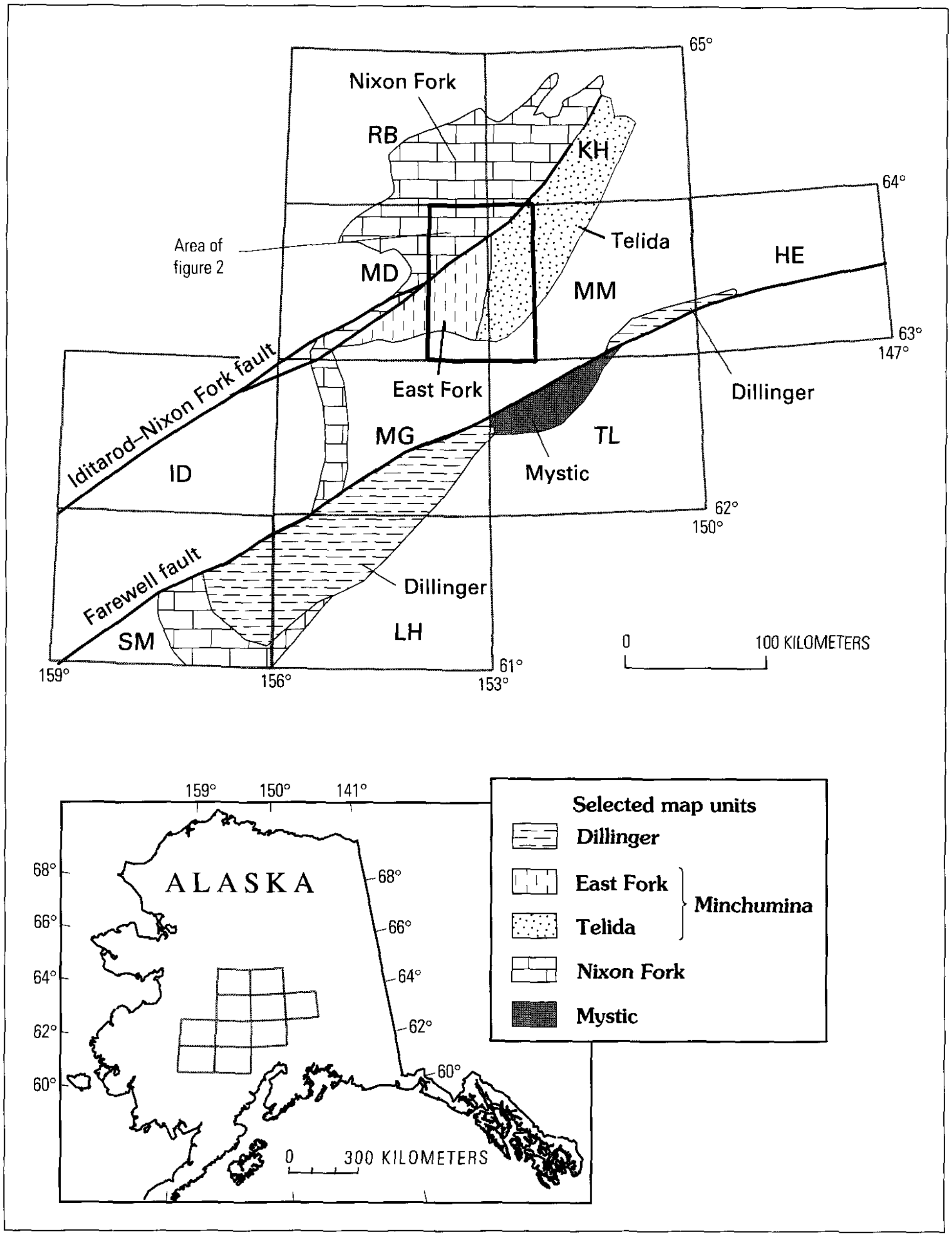

Figure 1. *Location of quadrangles and selected tectonostratigraphic terranes and subterranes* mentioned in text. Dillinger, Nixon Fork, and Mystic are considered (Bundtzen and others, 1997) subterranes of Farewell terrane (Decker and others, 1994); East Fork and Telida are subterranes of Minchumina terrane (Patton and others, 1994). All or part of Minchumina "terrane" is included in Farewell terrane by some authors; *see text for discussion. 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); Dillinger north of lat 63°N. and Mystic from Wilson and others (1998). Quadrangles: HE, Healy; ID, Iditarod; KH, Kantishna River; LH, Lime Hills; MD, Medfra; MG, McGrath; MM, Mt. McKinley; RB, Ruby; SM, Sleetmute; TL, Talkeetna.

deep-water facies is complex. Deep-water strata (Ordovician chert and argillite unit, part of the Minchumina terrane of Patton and others, 1994) are exposed between neritic deposits of the Novi Mountain and Telsitna Formations to the west and unnamed shallow-water carbonate rocks in the Dyckman Mountain area (herein called Dyckman Mountain unit) to the east (fig. 2). The Dyckman Mountain strata were originally mapped as *Whirlwind Creek Formation (Patton and others,* 1980) but were later included in the Minchumina terrane (Patton and others, 1984, 1994) and interpreted as a Middle and Late Devonian carbonate platform built out over older deep-water facies (W.W. Patton, written commun., 1998).

In this paper, we present new lithologic and fossil data demonstrating that carbonate rocks of the Dyckman Mountain unit formed in both deep- and shallow-water settings and are probably of Silurian and Devonian age. These strata provide additional evidence that Paleozoic rocks of the Nixon Fork subterrane, and much if not all of the Minchumina terrane, formed along a single continental margin that was later deformed and dismembered by folding and strike-slip faulting.

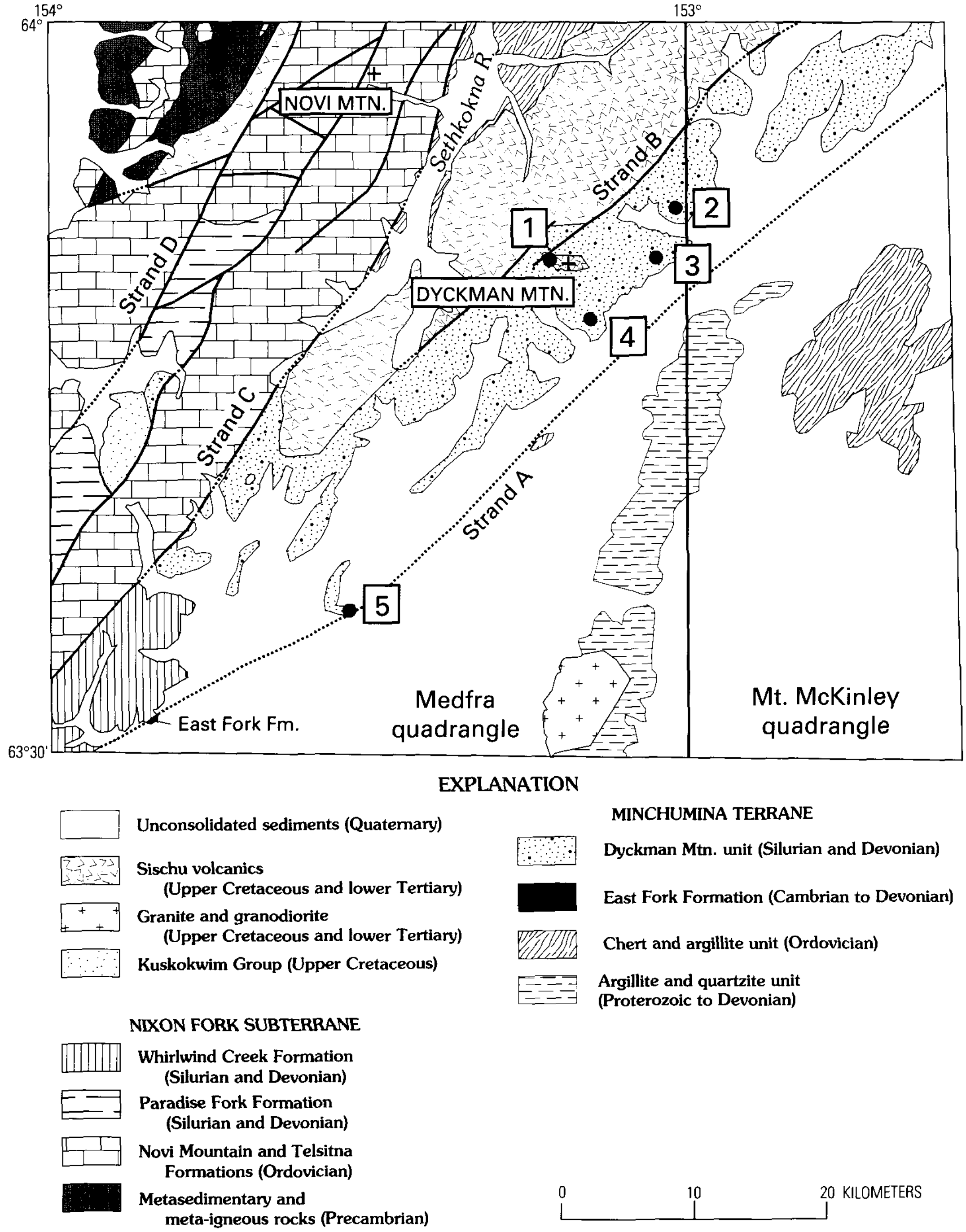

Figure 2. Location of lithologic and fossil collections from study area; geologic mapping modified from Patton and others (1980) and Béla Csejtey, Jr. (unpub. data, 1993, as compiled in Wilson and others, 1998). Grouping of units in the explanation is modified from Patton and others (1994). Strands A, B, C, and D refer to splays of the Iditarod–Nixon Fork fault system mentioned in text. Novi Mountain and Telsitna Formations as shown include outcrops of Whirlwind Creek Formation too small to show at scale of map. Ordovician chert and argillite unit in this area includes abundant fine-grained limestone and dolostone.

Silurian-Devonian Strata in the Dyckman Mountain Area

Paleozoic carbonate rocks in the Dyckman Mountain area were mapped and briefly mentioned by Eakin (1918), Patton and others (1980), and Dutro and Patton (1982) but have not otherwise been previously described. Lithologic and fossil data from adjacent areas in the eastern Medfra quadrangle are reported by Patton and others (1980), Dutro and Patton (1982), and Dumoulin and others (1999). Much of the Dyckman Mountain area is covered—exposures are confined largely to a few unvegetated ridge-tops. We examined strata at five localities (fig. 2) and summarize the Paleozoic stratigraphy of the area in figure 3 (column 3, "rocks of Dyckman Mtn. area").

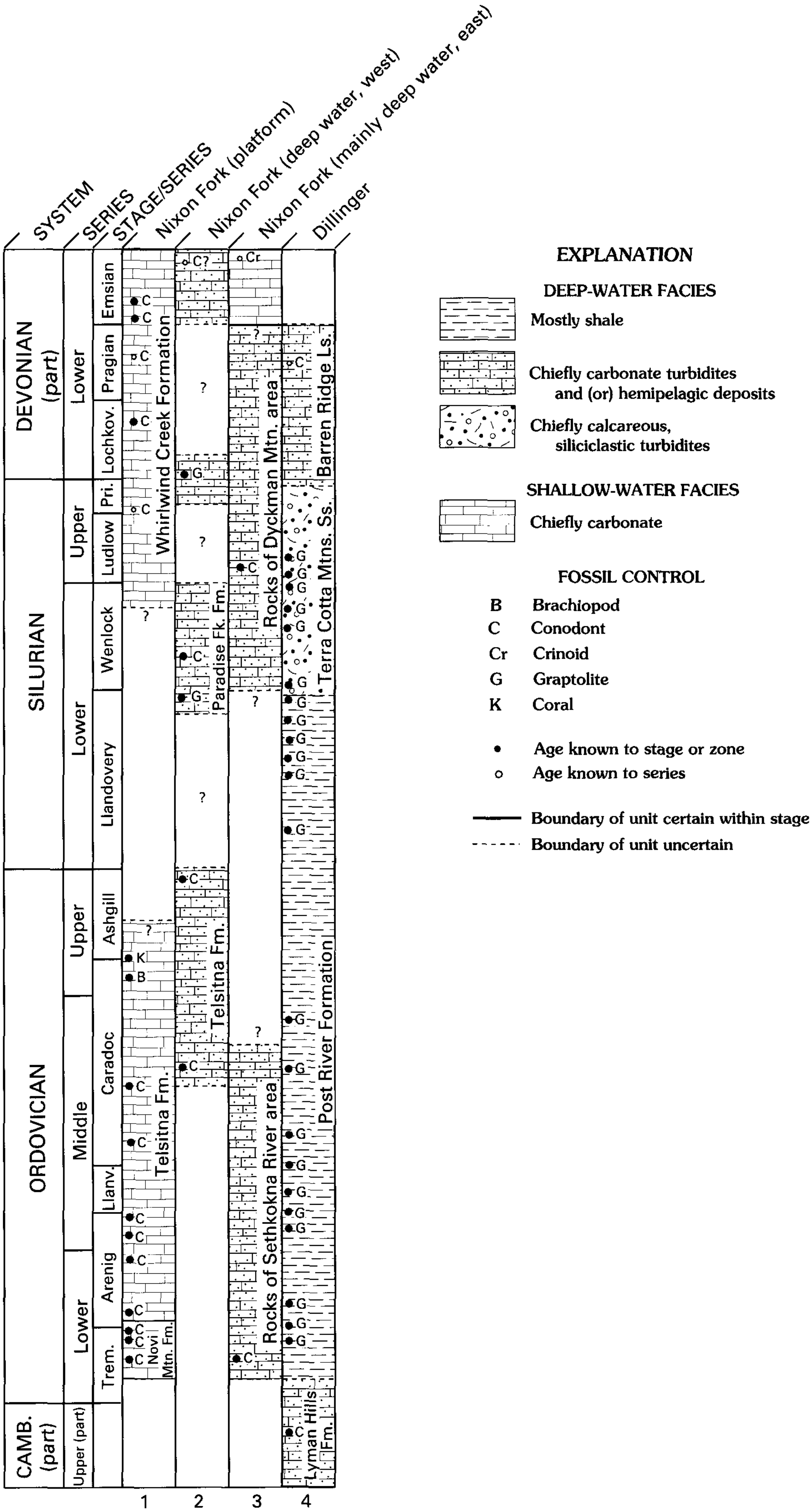

Figure 3. Correlation, lithologies, fossil control, and depositional environments of uppermost Cambrian to Lower Devonian rocks in selected areas of central Alaska. Only fossil groups that most narrowly restrict age of collection or unit are listed. Column 1 is a composite of all shallow-water strata west of strand C of the Iditarod–Nixon Fork fault; column 2 is a similar composite of deep-water strata between strands C and D; column 3 shows strata (chiefly deep-water) east of strand C. See figure 2 for location of fault strands. Data sources: columns 1 and 2, Dutro and Patton (1982); Dumoulin and others (1999); A.G. Harris and J.E. Repetski, unpub. data. Column 3, Dumoulin and others (1999); this paper. Column 4, Bundtzen and others (1994); Churkin and Carter (1996). The former Llandeilo Series is now considered a stage of the Llanvirn Series (Fortey and others, 1995).

Microlithofacies were established through field observations and study of 39 thin sections; age and biofacies determinations are based on six conodont collections (table 1) and several megafossil assemblages. Interpretations of depositional environments follow models in Wilson (1975) and Scholle and others (1983).

Shallow-Water Facies

Lithologies

Shallow-water facies occur at localities 1, 3, 5 and possibly 2 (fig. 2); they are best exposed at locality 3, 6.5 km east of Dyckman Mountain, where at least 180 m of light-gray-weathering, dark-gray limestone crops out discontinuously along the western half of a southwest-trending ridge (98AD409; table 1). Most of the lower part of the section is finely laminated micrite (fig. 4*A*) with rare calcispheres, gastropods, ostracodes, and coralline fragments. Darker laminae, 1.5 cm to <200 μm thick, are rich in peloids and (or) dolomite rhombs; some laminae are crinkly and form mounds ≤ 1 cm high as well as millimeter-thick coatings on skeletal grains (figs. 4*C*, 4*D*). Cycles, 15–25 cm thick, dominate the upper part of the section and consist of lime micrite and peloidal packstone and grainstone that

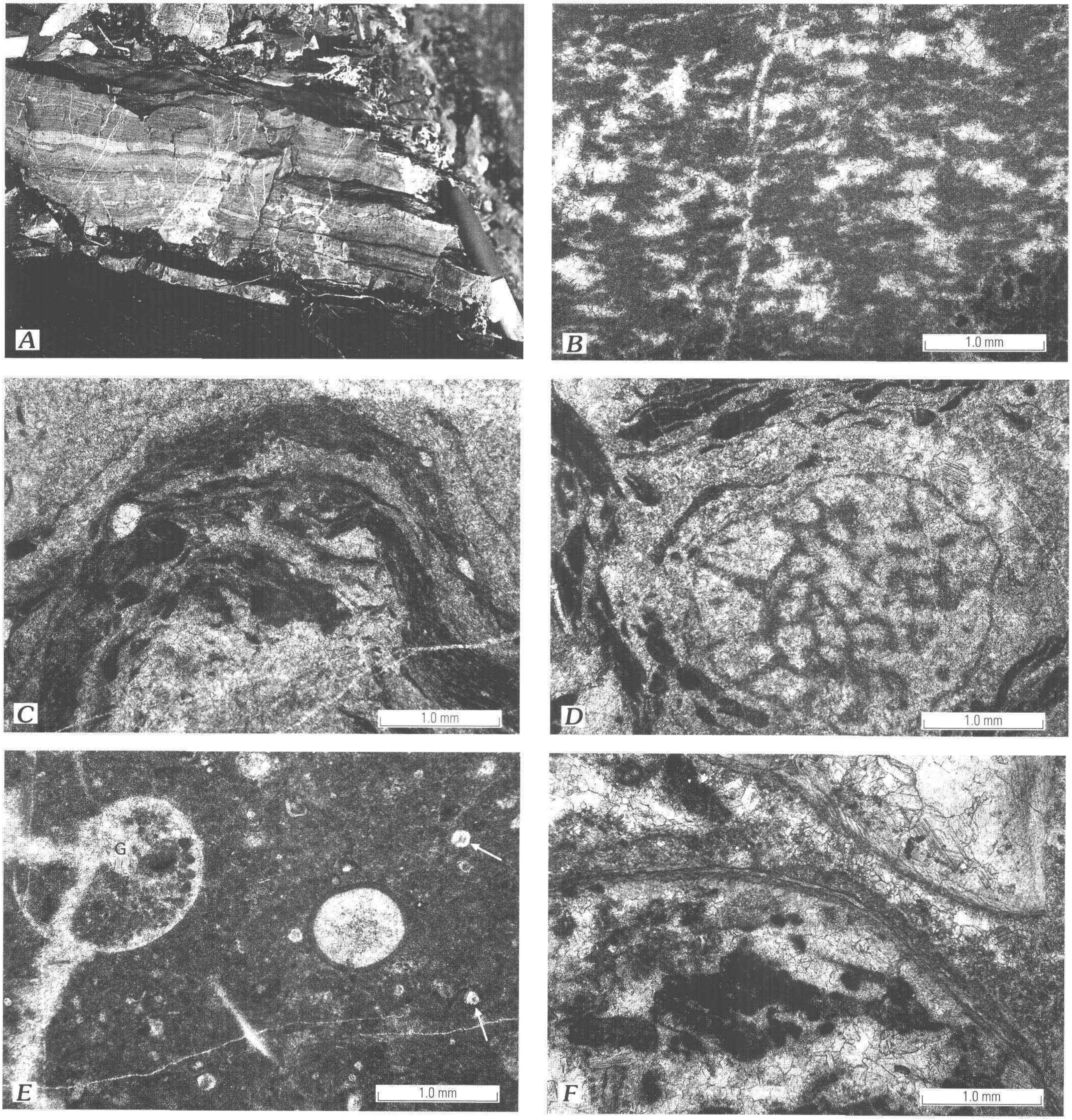

Figure 4. Sedimentary features of shallow-water facies, Dyckman Mountain area (fig. 2, loc. 3). *A-D*, Outcrop view (*A*) and photomicrographs of finely laminated micrite; note light-colored, spar-filled fenestrae in *B*. Crinkly, probable algal laminae form millimeter-scale mounds in *C* and coat coralline material in *D*. *E*, Skeletal-peloid wackestone with gastropod (G) and calcispheres (arrows). *F*, Brachiopod-peloid grainstone.

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

Letters in field number refer to collector: AD, J.A. Dumoulin. Abbreviations: CAI, color alteration index; indet., indeterminate]

Locality no., (Facies)	Quadrangle latitude/ longitude	Conodont fauna and CAI (Field no.; USGS Colln. no.)	Age	Biofacies	Remarks
1 (Shallow-water)	Medfra D-1 63°50'30" 153°12'40"	BARREN (98AD405A)			Sample near top of 10-m-thick section. Medium-dark-gray, light-gray-weathering, fetid, peloidal-skeletal packstone with crinoids, coral pieces, brachiopods, and ostracodes; beds 10 cm thick. 11 kg of rock was processed.
2 (Deep-water)	Medfra D-1 63°52'40" 153°00'50"	2 *Panderodus unicostatus* (Branson and Mehl) 1 indet. bar or blade fragment CAI=3.5 (98AD423B; 12615-SD)	Silurian-Middle Devonian	Indeterminate (too few conodonts).	Sample of 30-cm-thick bed of pebbly limestone conglomerate, clasts (0.5-5 mm in diameter) are gray-, yellow- and red-weathering micrite, calcisiltite, and peloidal grainstone; interbedded with thinner bedded, medium-gray, red-weathering micrite and calcisiltite. 8.9 kg of rock was processed.
	Medfra D-1 63°52'45" 153°00'50"	BARREN (98AD424C)			About 120 m stratigraphically below 98AD423; sample from 0.5-m-thick, finely parallel laminated bed several meters above base of 4- to 5-m-thick outcrop. Sampled bed is dark-gray, medium-dark-gray-weathering dolomitic micrite; beds here mostly 2-10 cm thick. 11.5 kg of rock was processed.
3 (Shallow-water)	Medfra D-1 (63°50'24" 153°03'08")	7 *Panderodus unicostatus* (Branson and Mehl) (fig. 5D) 6 mostly incomplete Pa elements *Ozarkodina*? n. sp. (figs. 5A-C) CAI=4 (97AD40B; 12596-SD)	Silurian-Middle Devonian	Indeterminate (too few conodonts). Probably middle to shallow shelf depositional setting.	Indistinct, 20-cm-thick beds of gray skeletal-peloidal packstone/grainstone with brachiopods, corals, and crinoids. Corals and brachiopods collected near this location identified as Middle Devonian in Eakin (1918). 9.9 kg of rock processed.
	Medfra D-1 63°50'12" 153°04'00"	BARREN (98AD409B)			Sample from 25-cm bed, 1 m below top of 20-m section and about 60 m stratigraphically lower than 98AD409Z; stratigraphic level probably close to that of 97AD40. Sample is dark-gray, light-gray-weathering, fetid gastropod-peloid wackestone that grades up into coral-peloid wackestone. 9.9 kg of rock was processed.
	Medfra D-1 63°50'19.5" 153°03'45"	4 *Panderodus unicostatus* (Branson and Mehl) fragments CAI=5 (98AD409Z; 12608-SD)	Silurian-Middle Devonian	Indeterminate (too few conodonts); the panderodids are small and probably represent a postmortem winnow.	Sample from 30-cm-thick bed of sparse skeletal wackestone with calcispheres, gastropods, and ostracodes. 9.2 kg of rock was processed.

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

Letters in field number refer to collector: AD, J.A. Dumoulin. Abbreviations: CAI, color alteration index; indet., indeterminate]

4 (Deep-water)	Medfra D-1 63°48'00" 153°09'05"	1 *Panderodus unicostatus* (Branson and Mehl) 1 M *Pedavis* sp. indet. (figs. 5E, F) *Pelekysgnathus* sp. indet. 1 P and 4 coniform elements (figs. 5H-K) UNASSIGNED ELEMENTS: 1 Pb, 2 Sb (2 morphotypes), and 1 coniform 3 indet. bar, blade, and platform fragments REDEPOSITED CONODONTS: 1 belodinid of Middle-Late Ordovician morphotype (fig. 5G) CAI=3.5 (98AD415C; 12612-SD)	early Late Silurian (early-middle Ludlow)	Indeterminate (too few conodonts; faunule includes a redeposited conodont).	Lithologically similar (and stratigraphically equivalent?) to 98AD423B (loc. 2). Six-m-thick debris flow, overlain by 2 m of well-bedded micrite. Sample from debris flow, 2.5 m above base. Flow is clast-supported conglomerate, with clasts of dark-gray micrite and calcisiltite as much as 12 cm in diameter. Some clasts have fine parallel laminae; some contain skeletal fragments, peloids, and (or) coated grains. Sample from 30-cm-thick interval with clasts mostly <1 cm. Upper age limit of sample constrained by stratigraphic position. 10.0 kg of rock was processed.
		All conodonts are chiefly small and incomplete coniform elements. 1 M icriodontid element (fig. 5P) 2 *Panderodus unicostatus* (Branson and Mehl) UNASSIGNED ELEMENTS: 2 coniform (2 morphotypes; figs. 5N, O) and 2 M elements of Silurian-Middle Devonian morphotypes 8 indet. mostly coniform fragments CAI=4-4.5 (98AD415E; 12613-SD)	early Late Silurian (early-middle Ludlow)	Indeterminate (too few generically identifiable conodonts). The conodonts are small and broken which suggests a postmortem distal winnow into an off-shelf depositional setting.	Sample from 30-cm-thick interval of laminated micrite and calcisiltite, just above debris flow sampled in 98AD415C; medium dark gray, light gray weathering, in beds 1-20 cm thick with 1- to 2-cm-thick, recessive (shaly?) interlayers. Upper age limit of sample constrained by stratigraphic position. 13.9 kg of rock was processed.
	Medfra D-2 63°48'10" 153°09'19"	All conodonts are robust, relatively large fragments. 3 Pa fragments *Kockelella* sp. indet. of middle Wenlock-middle Ludlow morphotype (fig. 5L) 1 Pa fragment *Ozarkodina*? sp. indet. of Ludlow-Lochkovian morphotype (fig. 5M); this fragment resembles *Oz. crispa* (Walliser) 22 indet. bar, blade, and platform fragments CAI=5 (98AD417C; 12614-SD)	early Late Silurian (no younger than middle Ludlow; likely middle Ludlow). Kleffner (1995), on the basis of graphic correlation, shows the lowest *Oz. crispa* appearing immediately after the extinction of the youngest kockelellid. The collection could represent a level near the base of the *Oz. crispa* Subzone of the *Oz. remscheidensis* Zone (middle Ludfordian).	Indeterminate (too few generically identifiable conodonts).	About 90 m stratigraphically higher than 98AD415; sample from 10-cm-thick bed of lime clast grainstone that is interbedded with limestone conglomerate; clasts (mostly 0.5-2 mm in diameter) of micrite, calcisiltite, skeletal wackestone, and peloidal packstone and grainstone. Lower age limit of sample restricted to Ludlow by stratigraphic position. 10.8 kg of rock was processed.
5 (Shallow-water)	Medfra C-2 (63°35'57" 153°31'09")	BARREN (97AD26A)	late Early-early Middle Devonian (Emsian-Eifelian) on the basis of two-hole crinoid columnals.		Mapped by Patton and others (1980) as East Fork Hills Formation but lithologically unlike this unit. Massive, medium-gray, peloid-skeletal wackestone/packstone containing sparse crinoid ossicles (some with two holes) and coral fragments. 9.6 kg of rock processed.

grade upward into gastropod-peloid wackestone (fig. 4*E*) and then into coralline-peloid wackestone and packstone. Other bioclasts in these beds are calcispheres, calcareous spicules, ostracodes, algae(?), and rare crinoid ossicles and brachiopod fragments.

Massive outcrops of medium- to light-gray-weathering, medium- to dark-gray limestone form the topographically highest part of the ridge at locality 3 (97AD40; table 1), about 0.5 km northeast of the rocks just described. The stratigraphic level of these beds is probably close to that of the western sequence (98AD409), but cannot be precisely determined due to structural complexity and poor exposure between the two sections. Laminated micrite and peloidal mudstone to packstone, much like rocks described above, contain locally abundant, spar-filled horizontal fenestrae as well as rare ostracodes, calcispheres, and algae (fig. 4*B*). This lithology forms intervals about 20 cm thick intercalated with indistinct beds, 20 to 50 cm thick, of skeletal-peloidal packstone and grainstone; bioclasts are mostly coral and stromatoporoid fragments, brachiopods, and crinoid ossicles (fig. 4*F*).

About 5 to 10 m of section on the west side of Dyckman Mountain (fig. 2, loc. 1) is quite similar to strata described above from the east side of locality 3 (97AD40). Skeletal-peloidal wackestone with gastropods, ostracodes, calcispheres, and crinoid ossicles grades upward into packstone containing brachiopod and favositid coral fragments and rare quartz silt. Peloids are of two types in these strata (and in the sections described above). Some are rounded to slightly ovoid and generally ≤100 µm in diameter; others are more irregular in size and shape and may exceed 200 µm in size. The former predominate in muddier layers and likely formed as fecal pellets; the latter occur mostly in skeletal-rich intervals and are probably micritized bioclasts.

Light-gray-weathering, dark-gray limestone along the top of the ridge at locality 2 most likely also formed in a shallow-water setting. Strata here are 3- to 5-cm-thick beds of peloidal grainstone with rare bioclasts.

Shallow-water limestone is also exposed about 30 km southwest of Dyckman Mountain at Little Hog Butte (fig. 2, loc. 5). These rocks were mapped as East Fork Hills Formation by Patton and others (1980) but are lithologically unlike that unit, which consists chiefly of thin-bedded, gray to grayish-orange, locally silty and dolomitic limestone (Dutro and Patton, 1982; Dumoulin and others, 1999). Strata at locality 5, in contrast, are massive, medium-gray, slightly recrystallized beds of peloidal-skeletal wackestone and packstone. Peloids are large (200 µm–2 mm) and irregular in shape, and are probably micritized skeletal grains. Recognizable bioclasts are mainly two- and lesser four-hole crinoid ossicles and rare coral fragments.

Age

Conodont and other fossil data suggest an Early and (or) Middle Devonian age for shallow-water strata in the Dyckman Mountain area, although some parts of the section could be as old as Early Silurian (table 1). Three samples taken for conodonts from localities 1, 3, and 5 (fig. 2) were barren; another sample from locality 3 yielded only long- ranging elements of *Panderodus unicostatus*. A third sample from locality 3 also contained *P. unicostatus* as well as elements of a distinct new species of *Ozarkodina*? (figs. 5*A*–5*C*). Corals and brachiopods from locality 3 were considered in Eakin (1918) to be of Middle Devonian age; the coral *Cladopora* sp. of Silurian-Devonian age was identified in a sample from this locality by W.A. Oliver, Jr., (oral commun., 1999). Two- and four-hole crinoid columnals in the rocks at locality 5 restrict their age to late Early or early Middle Devonian (Emsian or Eifelian).

Depositional Environment

Sedimentary features and faunal assemblages indicate that the rocks described above were deposited in a shallow-marine setting with locally restricted circulation. Crinkly (probably algal) laminae, fenestral fabric, and the abundance of peloids all suggest a shallow subtidal to intertidal setting. Fossils tolerant of high and (or) variable salinity, such as gastropods, calcispheres, and ostracodes, predominate in these strata and imply deposition in inner-shelf or platform environments. The scarcity and low diversity of conodonts in our large samples (9–11 kg; table 1) confirm a shallow-water, partly restricted environment. Local coral-rich beds, however, indicate that some parts of the succession formed in more open, middle- to inner-shelf settings with normal-marine salinity.

Deep-Water Facies

Lithologies

Deep-water strata were examined at localities 2 and 4 (fig. 2). More than 210 m of section is discontinuously exposed at locality 4, and at least 120 m of similar rock occurs beneath probable shallow-water facies at locality 2. In both areas, meter- to decameter-thick intervals of thin-bedded, fine-grained limestone (fig. 6*A*) are intercalated with subordinate thicker to massive beds of pebbly lime grainstone and limestone conglomerate (figs. 6*B*–6*D*).

Fine-grained limestone intervals are dark gray but weather to light or medium gray or locally (particularly at loc. 2) to distinctive pale shades of yellow, orange, and red. Beds are <1 to 10 cm thick and commonly finely laminated; laminae reflect small variations in size (graded couplets; fig. 6*A*) and (or) organic content and are generally subtler, more closely spaced, and less irregular than those in the shallow-water facies. Some intervals have recessive shaly partings, and Eakin (1918, p. 26) reported subordinate interbeds of dark "slate." Limestone lithologies range from mudstone (grains ≤ 4 µm) to calcisiltite (grains chiefly 8–20 µm, rarely to 150 µm); a few mudstone layers are partly dolomitized. Rare small peloids and bioclasts occur locally; possible calcitized radiolarians were noted in one sample.

Coarser grained strata are found sporadically throughout the section at locality 4 and in the middle part of the section at locality 2. Most beds are 10 to 30 cm thick, but a massive layer at least 6 m thick occurs about 90 m below the top of the section at locality 4 (figs. 6*B*, 6*C*). All beds examined were clast supported; in some samples, clasts are outlined by stylolites and packing has been enhanced by pressure solution. Clasts are

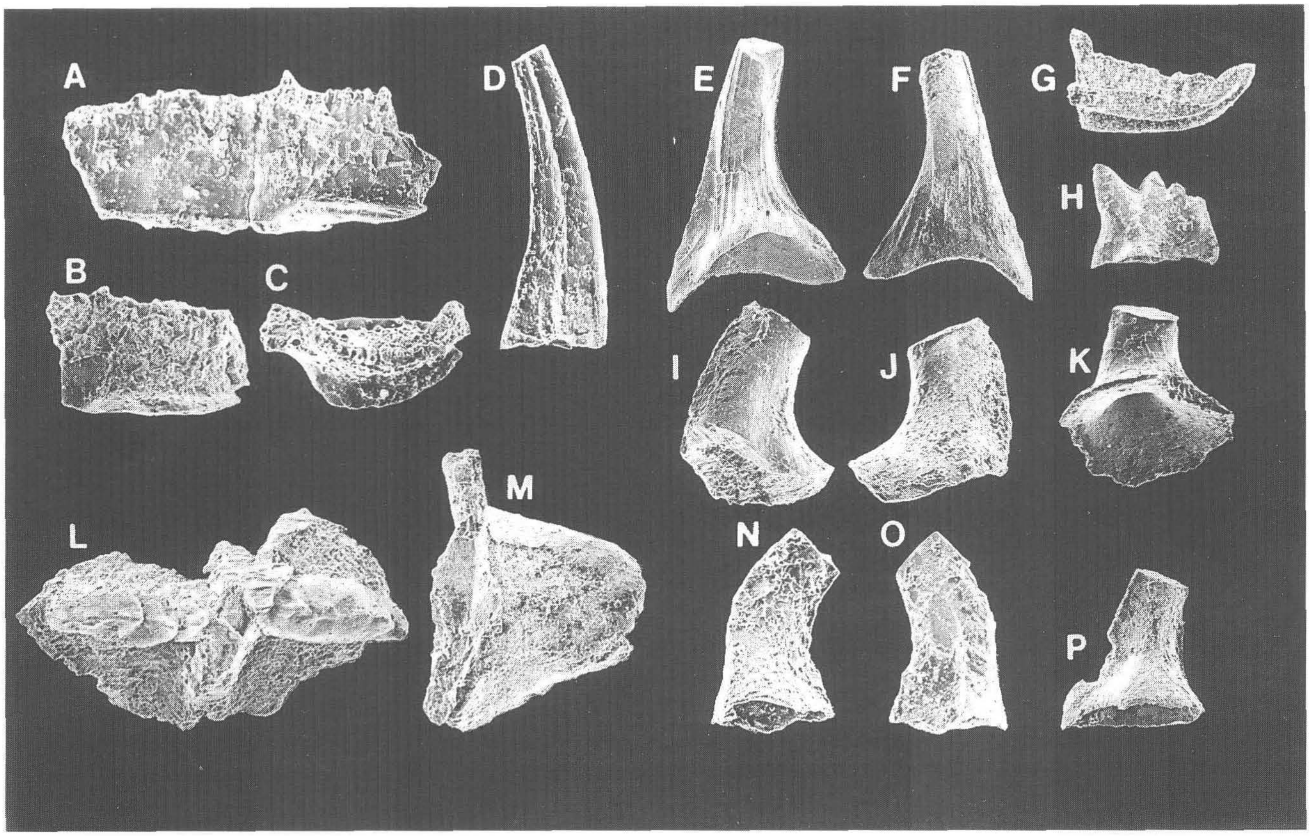

Figure 5. Conodonts from Paleozoic rocks in the Dyckman Mountain area, northeastern Medfra quadrangle, central Alaska (scanning electron micrographs of carbon-coated specimens; illustrated specimens are reposited in the U.S. National Museum, USNM, Washington, D.C.). See table 1 for lithologic description of sample and analysis and age assignment of faunule and figure 2 for geographic and geologic position.

A-D, Silurian-Middle Devonian, USGS colln. 12596-SD (fig. 2, loc. 3).

A-C, *Ozarkodina*? n. sp., outer lateral and upper views of two Pa elements, x100, USNM 50155-56. Pa elements are characterized by many fine short denticles that are relatively uniform, fused throughout most of their length, and restricted to the upper one-fourth of a comparatively high blade. All our specimens are incomplete; the largest (A), has at least 25 denticles and lacks a distinct cusp. The expanded basal cavity lies in the posterior half of the element.

D, *Panderodus unicostatus* (Branson and Mehl), outer lateral view, x75, USNM 501157.

E-K, early Late Silurian, USGS colln. 12612-SD (fig. 2, loc. 4).

E, F, *Pedavis* sp. indet., M element, inner and outer lateral views, x50, USNM 501158.

G, Redeposited Middle-Late Ordovician belodinid, lateral view, x60, USNM 501159.

H-K, *Pelekysgnathus* sp. indet.; P (lateral view), Sc (outer and inner lateral views), and Sa? (posterior view) elements, x60, USNM 501160-62.

L, M, early-middle Ludlow, USGS colln. 12614-SD (fig. 2, loc. 4), x50.

L, *Kockelella* sp. indet. of middle Wenlock-middle Ludlow morphotype, posterior fragment of Pa element, upper view, USNM 501163.

M, *Ozarkodina*? sp. indet. of early Late Silurian morphotype, posterior fragment of Pa element, upper view, USNM 501164. This specimen resembles the middle-late Ludlow index *Oz. crispa* (Walliser).

N-P, early Late Silurian-Early Devonian, USGS colln. 12613-SD (fig. 2, loc. 4).

N, O, Unassigned coniform Sb? element, inner and outer lateral views, X150, USNM 501165.

P, *Icriodontid*? M element, inner lateral view, x60, USNM 501166

mostly dark gray in a lighter gray matrix but some clasts weather yellow or red. Maximum clast size is generally about 4 cm and reaches 12 cm in some beds; average clast size ranges from 500 µm to 1 cm. The largest clasts are generally elongate. Clasts may be finely laminated or graded and are rounded to irregular in form; these shapes suggest that most clasts were only partly lithified when deposited. Clasts are chiefly lime mudstone (micrite), calcisiltite, and peloidal packstone and grainstone (fig. 6*D*), but fragments of ooid grainstone, skeletal wackestone, and coarse skeletal debris were also observed. Bioclasts include gastropods, brachiopods, and possible algae. Matrix is generally micrite or calcareous silt; calcite cement occurs locally. Both clasts and matrix contain virtually no siliciclastic material.

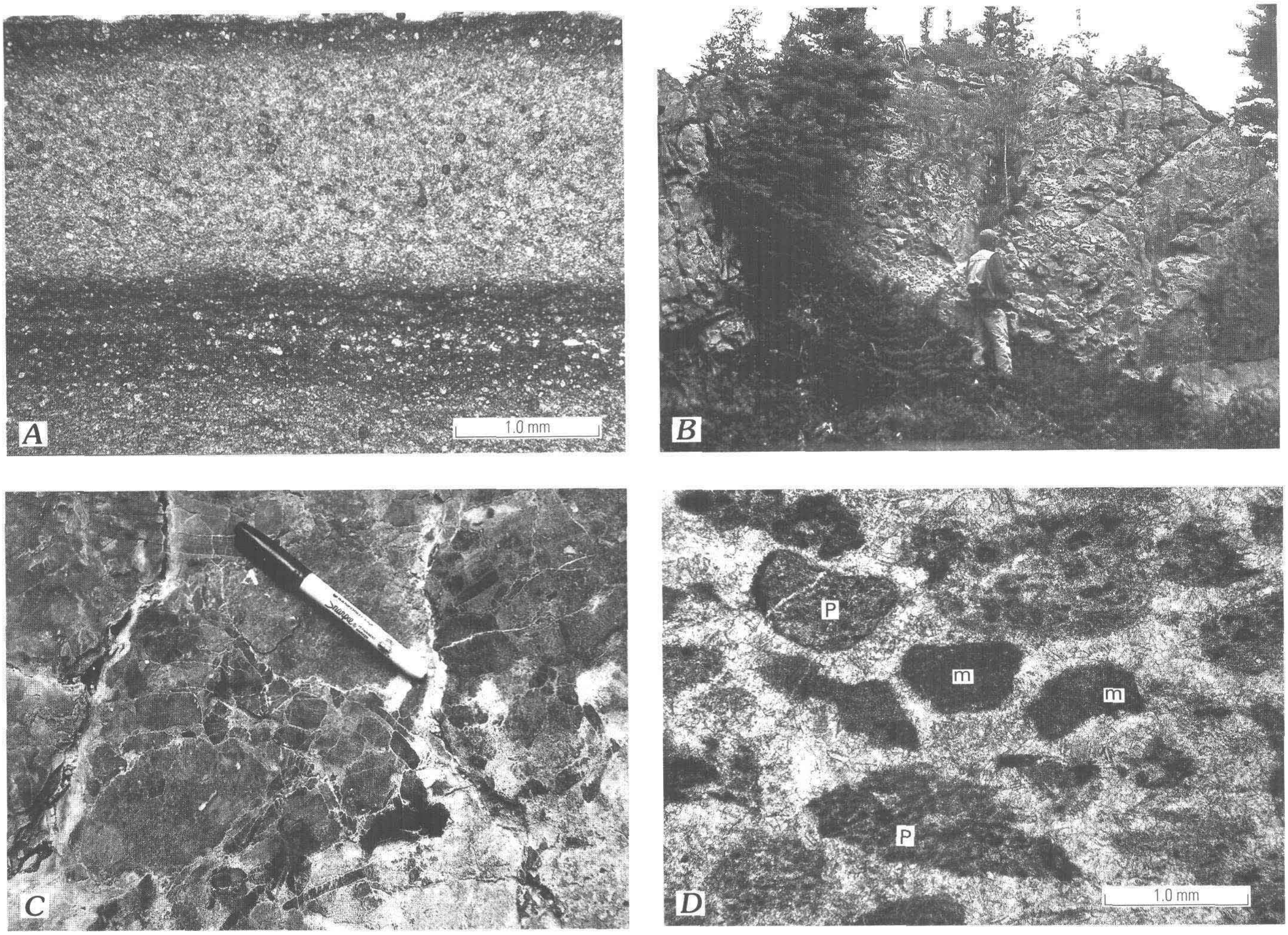

Figure 6. Sedimentary features of deep-water facies, Dyckman Mountain area (fig. 2, loc. 4) in outcrop (*B, C*) and photomicrographs (*A, D*). A, Graded couplets of calcisiltite (light) and dolomitic lime mudstone (dark). *B-D*, Carbonate clast debris flow; clasts chiefly micrite (m) and peloidal grainstone (P).

Age

Conodont faunas indicate that deep-water facies in the Dyckman Mountain area are Silurian to Middle Devonian, most probably Silurian; they contain redeposited forms as old as Middle or Late Ordovician (table 1; fig. 5*G*). A single collection from locality 2 (fig. 2) yielded only a few specimens of the same long-ranging panderodid recovered from the shallow-water facies, but three assemblages from locality 4 are more biostratigraphically useful. The most diagnostic collection (98AD417C), from redeposited lime grainstone in the uppermost part of the section, is of Silurian (early-middle Ludlow, possibly middle Ludlow) age. Conodonts in this sample are typical of shallow-water settings and could be either older forms reworked into younger deposits or penecontemporaneous forms hydraulically transported into a deeper water environment. Several lines of evidence, however, imply that the shallow-water source facies and the deeper water depositional facies for these conodonts were essentially coeval. As noted above, most carbonate clasts were relatively unlithified when deposited, indicating that clast transport took place soon after initial sedimentation of the clast material. In addition, the other collections from locality 4, including one from a fine-grained interval of "background" sediment (discussed below), are compatible with a Ludlow age. Taken together, these data suggest that deep-water strata at locality 4 accumulated largely during early Late Silurian time.

Depositional Environment

Deep-water strata in the Dyckman Mountain area originated as hemipelagic deposits, fine-grained distal turbidites, and subordinate coarser debris flows derived from a carbonate platform and deposited in a slope and (or) basinal setting. Laminae in fine-grained intervals (micrite and calcisiltite) may have had several origins. Some laminae may be varves formed through cyclic changes in productivity and (or) detrital influx; graded couplets are more likely distal turbidites. Laminated micrite at locality 2 (fig. 2) is deformed by minor disharmonic folds of probable slump origin; such folds suggest deposition in a slope environment.

We interpret coarser intervals of lime grainstone and conglomerate as debris flows made of shallow- and deep-water carbonate clasts. Abundant fragments of micrite and calcisiltite are identical to, and probably derived from, the fine-grained hemipelagic interbeds, but clasts rich in peloids, coated grains (including ooids), and bioclasts such as gastropods and algae must have originated in a shallow-water shelf or platform setting. Conodonts and sedimentary textures suggest that shallow-water clasts were derived from beds equivalent in age and facies to the Novi Mountain, Telsitna, and Whirlwind Creek Formations in the Nixon Fork subterrane. Middle and (or) Late Ordovician belodinid conodonts, like that redeposited in sample 98AD415C (table 1; fig. 2, loc. 4), occur in the Telsitna, and Silurian ozarkidinids (98AD417C) are common in parts of the Whirlwind Creek. Ooid grainstone is abundant in the Novi Mountain (Dutro and Patton, 1982) and also reported from the Telsitna (Measures and others, 1992); peloidal packstone and grainstone are found throughout the Nixon Fork subterrane but are particularly abundant in the Telsitna.

Structure

The Dyckman Mountain area lies between two strands (A and B) of the Iditarod–Nixon Fork fault system (fig. 2), which underwent 88–94 km of dextral displacement during the Late Cretaceous and Tertiary (Miller and Bundtzen, 1988, 1992). Strand A, which has a strong topographic expression, separates the Dyckman rocks of the present study from deep-water strata that Patton and others (1994) assigned to the Minchumina terrane. Strand B is not as strongly expressed topographically. Across it, Dyckman rocks are juxtaposed against the Upper Cretaceous and lower Tertiary Sischu volcanics. For lack of piercing points, there is no direct evidence for the amount of displacement on either strand (Dumoulin and others, 1999). Based on documented offsets elsewhere (Miller and Bundtzen, 1988), both strands are inferred to have undergone a few to a few tens of kilometers of dextral horizontal displacement; strand B, in addition, has a vertical component of displacement, northwest side down.

Paleozoic rocks of the Dyckman Mountain area have been folded, presumably in Mesozoic time, about northeast-trending axes. Folds are open to tight, with subhorizontal axes and steep axial surfaces. The folding is likely related to regional shortening that affects all Paleozoic rocks of the Farewell terrane, regardless of proximity to strike-slip faults. It is unlikely that any significant shortening in the Dyckman Mountain area is related to transpression between strands of the Iditarod fault system because the Sischu volcanics, which depositionally overlie the Dyckman unit, are essentially undeformed (Eakin, 1918). Owing to the poor exposure, difficult access, and the still poorly defined internal stratigraphy, it is not yet possible to trace folds —or stratigraphic horizons—at the scale of 1:63,360 in the Dyckman Mountain area. Were such detailed mapping available, a valley-and-ridge map pattern like that documented for the Dillinger subterrane in the McGrath quadrangle (Bundtzen and others, 1997) might also be expected here.

Although folded and faulted, Paleozoic rocks in the Dyckman Mountain area lack penetrative fabrics. Conodonts in these strata have color alteration indices of 3.5 to 5, indicating that the host rocks reached temperatures of at least 180°–300°C (Epstein and others, 1977). Limestone textures in most thin sections show no evidence of recrystallization.

Resistant bodies of limestone breccia occur at localities 2 and 3 (fig. 2). The full extent and attitude of these bodies could not be determined because of limited exposures, but they are at least several meters across in outcrop. At locality 3, randomly oriented blocks of laminated limestone up to a few meters in length float in a matrix of fine-grained calcite. A similar breccia at locality 2 is pervaded by multiple generations of calcite veins, some with crystals ≥2 cm across, and is juxtaposed against bedded carbonate rocks along an east-west-striking dextral fault. Together, these features suggest a tectonic rather than sedimentary origin for the breccia bodies. Structurally controlled breccias that cut carbonate rocks of the Nixon Fork subterrane near Reef Ridge (20 km southwest of the area of figure 2) contain zinc-(lead-cadmium) mineralization (Schmidt, 1997). We took several samples for geochemical analyses from the Dyckman breccias, but none showed any evidence of mineralization.

Correlation

Available stratigraphic and faunal data suggest that deep-water facies are largely older than, and grade upward into, shallow-water facies in the Dyckman Mountain area (fig. 3). Some shallow-water strata could be slightly older than, and (or) coeval with, deeper water rocks. As noted above, much of the Dyckman area is covered; vegetated slopes are probably underlain chiefly by fine-grained limestone and shale. Siliciclastic strata equivalent to the Ordovician chert and argillite unit, exposed to the north along the Sethkokna River (fig. 2), may also underlie carbonate rocks northeast of Dyckman Mountain (Eakin, 1918).

Faunal and sedimentologic data suggest correlations between Paleozoic strata in the Dyckman area and coeval rocks in both the Nixon Fork and Dillinger subterranes. Shallow-water Dyckman facies are similar in many respects to the Whirlwind Creek Formation, exposed to the southwest in the Nixon Fork subterrane. The Whirlwind Creek (Upper Silurian and Devonian) is characterized by cycles of algal laminite that grade up into pelloidal and then fossiliferous limestone; notable fossils are ostracodes, gastropods, brachiopods, stromatoporoids, and corals (Dutro and Patton, 1982). Unlike Dyckman-area rocks, the Whirlwind Creek includes abundant dolostone; dolomite breccias are locally common and host zinc and lead-zinc mineral occurrences in the Reef Ridge area (Schmidt, 1997).

Shallow-water rocks of the Dyckman Mountain area also resemble the Cheeneetnuk Limestone, which crops out in the central part of the Nixon Fork subterrane (southwestern McGrath quadrangle) (Blodgett and Gilbert, 1983; Decker and others, 1994). The upper part of the Cheeneetnuk is Middle Devonian (early Eifelian); the lower part is undated but may be of Early Devonian age. The unit accumulated in a deepening-upward depositional regime; shallow subtidal to intertidal facies grade up into open-marine deposits. Like shallow-water strata in the Dyckman area, the Cheeneetnuk contains intervals of algal laminite as well as fossiliferous beds rich in corals, brachiopods, and crinoids. The Cheeneetnuk also includes dolomitic horizons, however, and the fauna in its upper third is considerably more diverse than that observed in Dyckman-area rocks.

Deep-water strata near Dyckman Mountain are lithologically most similar to parts of the Dillinger subterrane exposed to the southeast and south (fig. 1). In the Mt. McKinley and Healy quadrangles, map unit DOs (Ordovician to

Devonian metasedimentary sequence of Csejtey and others, 1992) consists, in part, of thin-bedded to massive calcareous turbidites and debris flows interbedded with micritic intervals (these rocks make up subunit C of Dumoulin, Bradley, and Harris, 1998). Carbonate conglomerate in subunit C, like that in the Dyckman Mountain area, forms beds at least 5 m thick and contains clasts, chiefly of micrite (lime mudstone), that are as much as 12 cm long; siliciclastic material is rare or absent in most sections. Conodonts from this subunit are late Early Silurian (Wenlock). Similar calcareous turbidites and limestone conglomerate also occur in the Dillinger subterrane in the southeastern McGrath and northwestern Lime Hills quadrangles (Bundtzen and others, 1988, 1994); these strata (Barren Ridge Limestone of Churkin and Carter, 1996) are Late Silurian (Ludlow) to Early Devonian in age.

Finer grained deep-water strata in the Dyckman Mountain area also resemble the Paradise Fork Formation in the Nixon Fork subterrane. The Paradise Fork consists of fissile to laminated micrite and calcisiltite interbedded with shale and subordinate grainstone rich in micritic clasts; it is mostly of middle Early Silurian (late Llandovery to early Wenlock) age but is locally as young as Early Devonian (Dumoulin and others, 1999). Silurian kockelellid conodonts similar to those in Dyckman sample 98AD417C (table 1; loc 4, fig. 2; fig. 5*L*) also occur in the Paradise Fork.

Discussion

Our new data from the Dyckman Mountain area shed light on the relation between shallow-water facies of the Nixon Fork subterrane and coeval deep-water strata ("Minchumina terrane") and on the nature of the shelf-to-basin transition near the northern end of the Nixon Fork carbonate platform.

In the northeastern part of the Medfra quadrangle, the boundary between the Nixon Fork and Minchumina "terranes" proved difficult to define (figs. 1, 2). It was originally drawn along strand A of the Iditarod–Nixon Fork fault (Patton and others, 1980) but was later shifted west to follow strand C (Patton and others, 1984, 1994). Shallow-water "Nixon Fork" facies are not recognized east of strand A and deep-water "Minchumina" rocks do not occur west of strand D, but between these strands, a complex alternation of deep- and shallow-water strata exists (fig. 2). Deep-water facies (Paradise Fork Formation) interfinger with shallow-water deposits between strands C and D; deep-water facies of the Dyckman Mountain area underlie (and might also interfinger with) shallow-water strata between strands A and B.

Facies patterns throughout the Farewell terrane have been disrupted by Late Cretaceous and Tertiary strike-slip faulting. Restoration of a total of 90 km of dextral map-separation along strands A, B, C, and D of the Iditarod–Nixon Fork fault and 150 km of dextral map-separation along the Farewell fault produces a horseshoe-shaped basin ringed by shallow-water facies on three sides (fig. 9 of Dumoulin and others, 1999). In this reconstruction, which distinguished only "primarily shallow water" and "primarily deep water" successions, a fault slice of deep-water strata (between strands B and C) remains isolated from the broader tract of basinal rocks to the east.

A more realistic reconstruction recognizes an intermediate facies belt transitional between deep- and shallow-water strata (fig. 7) Such transitional facies include interfingering platform and off-platform deposits as well as off-platform strata that are clearly linked to the adjacent platform margin. Using this approach, all of the Nixon Fork subterrane exposed east of strand D could be considered "transitional." Intercalated shallow- and deep-water strata are best documented between fault strands C and D. Here, deeper water facies of Middle and Late Ordovician age interfinger with roughly coeval shallow-water strata in the upper part of the Telsitna Formation, and Silurian and Early Devonian deep-water deposits of the Paradise Fork adjoin age-equivalent neritic sequences of the Whirlwind Creek Formation (Dumoulin and others, 1999). Intercalated platform and off-platform strata characterize much of the Farewell terrane basin margin to the south, as documented in sections at Lone Mountain and White Mountain in the McGrath quadrangle (Decker and others, 1994; T. Bundtzen, written commun., 1997).

Even where intercalation of platform and off-platform facies is not evident, deep-water strata in the northeastern Medfra quadrangle can be tied to contemporaneous neritic deposits. Faunal assemblages and redeposited clast lithologies suggest that deep-water strata east of Iditarod fault strand A were derived from shallow-water facies of the Nixon Fork subterrane. Conodonts from calcareous turbidites in the Ordovician chert and argillite unit (between strands B and C) match those from the lower part of the Novi Mountain Formation species for species (Dumoulin and others, 1999). And, as noted above, clast textures and specific conodonts found in Silurian debris flows of the Dyckman Mountain area indicate derivation from Ordovician and Silurian Nixon Fork subterrane rocks.

Patton and others (1994, p. 247) suggested that "the absence of a transitional facies between the fault-bounded blocks" of the Nixon Fork and Minchumina terranes argues against their interpretation as parts of a single coherent terrane. We propose that a "transitional facies" as defined above marks the northern edge of the Nixon Fork carbonate platform and documents shifts in the position, and perhaps the nature, of the platform margin through time. This margin appears to have backstepped from east to west (present-day coordinates) between Early Ordovician and Early Silurian time, and then prograded east again later in the Silurian. Changes from chiefly fine grained off-platform deposits (such as those in the Paradise Fork Formation) to coarser grained strata, like those in the Dyckman Mountain area, may reflect both local and more widespread factors ranging from steepness of the platform margin to eustatic shifts.

We agree with Patton and others (1994), however, that transitions from shallow- to deep-water strata along certain parts of the northern Nixon Fork margin are relatively abrupt and are best explained by faulting. For example, less than 10 km separates Ordovician shallow-water facies at Novi Mountain from coeval deep-water rocks along the Sethkokna River. In addition, compositional differences between western and eastern exposures of the Minchumina terrane suggest that it consists of two or more roughly coeval sequences of disparate origin (Dumoulin and others, 1999). Only the eastern parts of this terrane (the East Fork subterrane and western exposures of the Telida

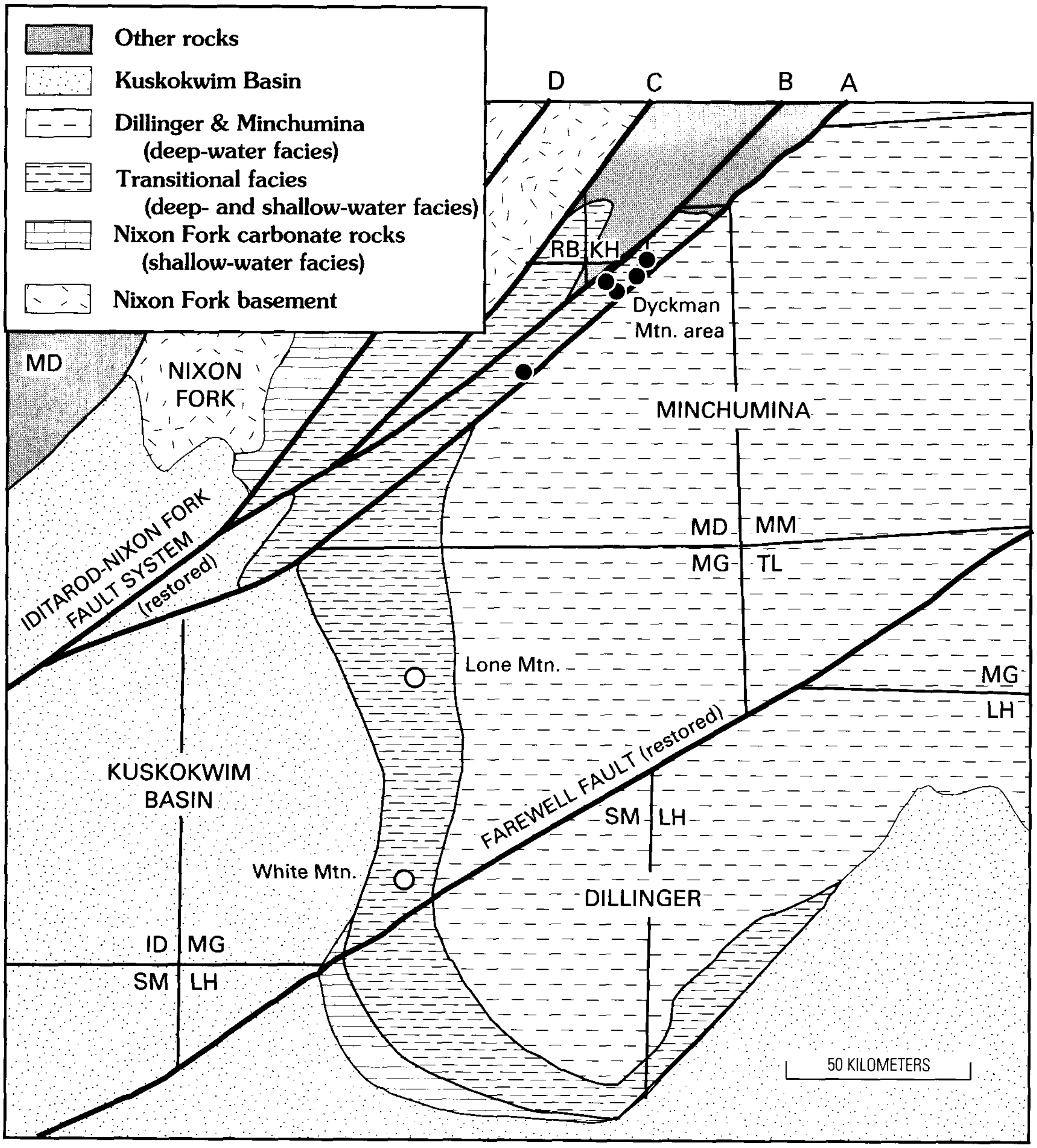

Figure 7. Palinspastic map of study area. Letters A, B, C, and D refer to strands of the Iditarod-Nixon Fork fault system mentioned in text. Restoration of 90 and 150 km of dextral strike-slip on the Iditarod and Farewell faults, respectively, aligns the deep-water Dillinger and Minchumina terranes in a position east of the Nixon Fork carbonate platform. Black dots are locations plotted in figure 2. Fine lines are quadrangle boundaries; quadrangle abbreviations as in figure 1.

subterrane) are rich in carbonate and can be confidently interpreted as derived from the Nixon Fork carbonate platform. Eastern exposures of the Telida 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 ultimate origin of Paleozoic rocks in central Alaska remains contentious. Some authors have suggested that the Farewell terrane is a displaced fragment of the North American (Laurentian) continental margin (Decker and others, 1994), whereas others have interpreted it as a sequence rifted away from the Siberian craton (Blodgett, 1998). Biogeographic affinities of Paleozoic faunas can help to constrain the paleogeographic position of rocks in central Alaska, but the faunas from the Dyckman Mountain area are not particularly useful for such analyses. Megafossils in the shallow-water strata have not been studied in sufficient detail to allow their biogeographic characterization. Worldwide, deep-water conodont faunas are relatively cosmopolitan, as are most normal-marine shallow-water conodont faunas of Silurian and Devonian age.

The sparse conodont collections from the Dyckman Mountain area conform to these trends and provide only general information on the paleogeographic affinities of the faunules. These poorly productive, low-diversity collections contain chiefly broken, specifically and biostratigraphically nondiagnostic conodonts. Specimens that are specifically identifiable are long-ranging cosmopolites (for example, *Panderodus unicostatus*) or new species (figs. 5A–5C). Ordovician conodont faunas from the Medfra quadrangle, in contrast, contain a notable component of provincial forms; these forms include elements typical of both Siberian and Laurentian biotic provinces (Dumoulin, Bradley, Harris, and Repetski, 1998). This distinctive combination of Siberian and Laurentian faunal affinities also characterizes lower Paleozoic strata in northern Alaska (Dumoulin and Harris, 1994).

Conodont collections from the Dyckman Mountain area do constrain the general paleobiogeographic setting of this part of the Farewell terrane. The occurrence of Late Silurian and Devonian icriodontids and pedavids as well as a redeposited Ordovician belodinid indicates that, during the Middle Ordovician to Middle Devonian, the Dyckman Mountain area most likely lay in a tropical to subtropical paleogeographic setting.

Conclusions

Paleozoic rocks in the Dyckman Mountain area, previously mapped as the Whirlwind Creek Formation (Patton and others, 1980) and thought to be exclusively shallow-water facies, also include deep-water lithologies. Shallow-water strata are Devonian and perhaps in part Silurian and formed in shallow subtidal to intertidal, locally restricted settings; deep-water rocks are Silurian and perhaps in part Devonian and represent hemipelagic deposits, turbidites, and debris flows. Conodonts and clast lithologies indicate that the deep-water strata were derived from beds equivalent in age and facies to the Novi Mountain, Telsitna, and Whirlwind Creek Formations in the Nixon Fork subterrane to the west.

Rocks in the Dyckman Mountain area are part of a broader facies belt, disrupted by folding and strike-slip faulting, that is transitional between the Nixon Fork carbonate platform to the west and exclusively deeper water deposits (western part of the Minchumina terrane) to the east. In this belt, shallow- and deep-water lithologies interfinger, and faunal and petrologic evidence ties deep-water strata to specific units of the platform sequence. Complex facies patterns in these transitional strata reflect not only later structural disturbance but progradation and backstepping of the platform margin through time. The transitional facies belt provides evidence that, as to the south in the McGrath quadrangle, lower Paleozoic shallow- and deep-water strata in the northeastern Medfra quadrangle formed along the same continental margin and should be considered part of the Farewell terrane.

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