Depositional Framework and Regional Correlation of Pre-Carboniferous Metacarbonate Rocks of the Snowden Mountain Area, Central Brooks Range, Northern Alaska

By J.A. Dumoulin and Anita G. Harris

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METRIC CONVERSION FACTORS

For readers who wish to convert from the metric system of units to the inch-pound system, the conversion factors are listed below.

Multiply	By	To obtain
	Length	
micrometer (μm)	0.0039	inch
millimeter (mm)	0.039	inch
centimeter (cm)	0.394	inch
meter (m)	3.281	foot
kilometer (km)	0.621	mile

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ABSTRACT

A succession of chiefly metacarbonate rocks in the Snowden Mountain area of the central Brooks Range includes strata of Cambrian (and older?) to Devonian age, structurally intercalated with dominantly siliciclastic rocks of Devonian age. Both carbonate and siliciclastic rocks are deformed and metamorphosed to greenschist facies, but locally preserved primary textures and environmentally diagnostic conodont assemblages allow interpretation of depositional environments. Rocks of the Snowden Mountain area are the first pre-Carboniferous metacarbonate succession from the central Brooks Range for which detailed sedimentologic and biofacies data are available.

Massive metacarbonate rocks at Dillon Mountain may be Cambrian and (or) older in age, contain coated grains and stromatolites, and formed in a peritidal environment. Phyllite and lesser sandy metalimestone (Snowden Mountain unit) yield early Middle Cambrian trilobites with Siberian biogeographic affinities and were deposited on an outer shelf or slope. Carbonaceous phyllite, metachert, and metalimestone (Snowden Creek unit) produce cosmopolitan, cool-water conodonts of Middle Ordovician (late Arenigian to early Caradocian?) age. These strata accumulated chiefly in a slope to basinal setting, but the vertical sequence indicates a shallowing-upward depositional regime. Middle Ordovician rocks are succeeded by Upper Ordovician and Silurian dolostone and metalimestone (Mathews River unit) that contain conodonts of Edenian and Maysvillian, Richmondian, Llandoverian and early Wenlockian, and Wenlockian and Ludlovian ages. Late Ordovician conodonts include Siberian and North American faunal elements; Silurian conodonts are chiefly cosmopolitan. The Mathews River unit is characterized by shallowing-upward peritidal cycles and was deposited in a range of warm, shallow-water environments; it is locally overlain by Lower and (or) Middle Devonian (Emsian and (or) Eifelian) metalimestone bearing two-hole crinoid columnals. Thrust slices of metacarbonate rocks in the Wiehl Mountain area, the Snowden Mountain massif, and the Table Mountain area retain some primary features similar to those of the Mathews River unit but are less well dated and may be of Ordovician to Devonian age.

The dominantly metacarbonate succession is structurally juxtaposed with metasiliciclastic rocks of the Beaucoup Formation, Nutirwik Creek unit, and Hunt Fork Shale. These units contain layers and lenses of metalimestone that yield latest Middle and early Late Devonian (latest Givetian and Frasnian) conodonts. Thicker limy layers formed as biohermal buildups and ooid or bioclastic shoals; thinner limy layers are tempestites or turbidites derived from shelf or platform carbonate deposits.

Metasedimentary rocks of the Snowden Mountain area have some faunal and lithologic similarities to coeval strata in the Baird Mountains (western Brooks Range), the Shublik and Sadlerochit Mountains (eastern Brooks Range), and the York Mountains (Seward Peninsula). The chiefly metacarbonate succession correlates particularly well with Ordovician and Silurian strata in the eastern Baird Mountains; Devonian siliciclastic units correspond to Middle and Upper Devonian rocks in the Baird Mountains. Available biogeographic and lithologic data from northern Alaska are best explained by postulating that the pre-Carboniferous carbonate successions accumulated on a single continental margin or platform that had faunal exchange with both Siberia and North America, rather than on a series of discrete platforms juxtaposed by later tectonic events.

ACKNOWLEDGMENTS

We thank our colleagues on the Brooks Range segment of the Trans-Alaska Crustal Transect program for logistical support and useful geologic discussions, particularly Alison

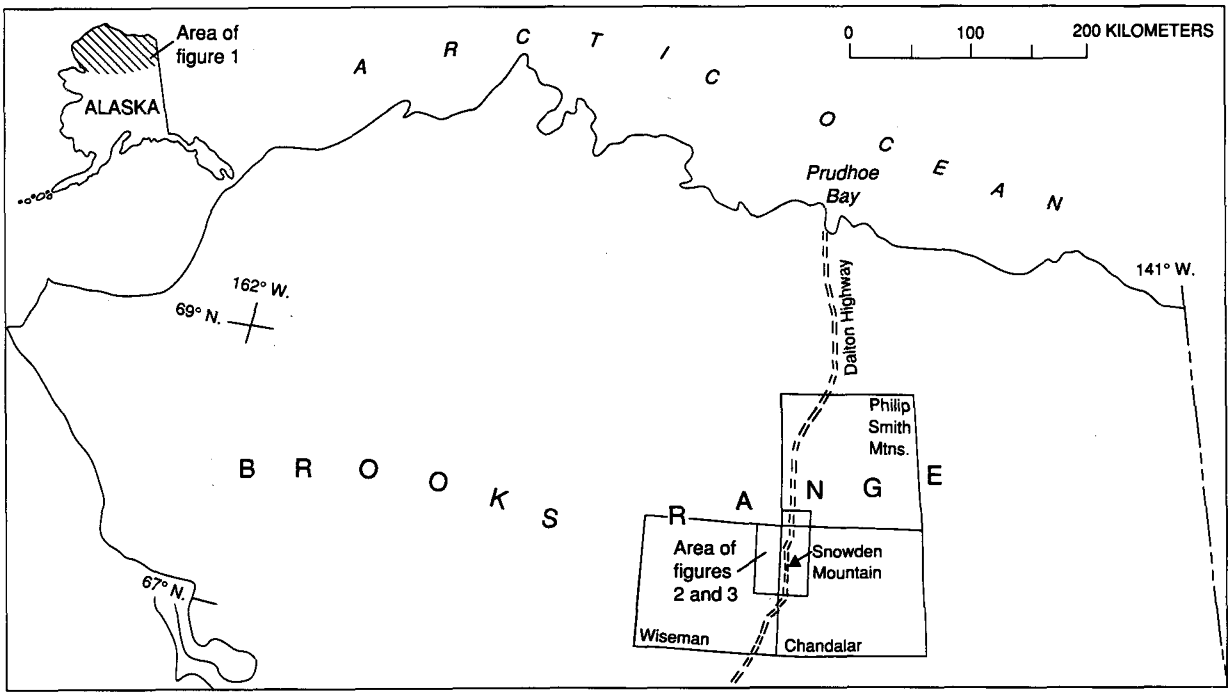


Figure 1. Location of Snowden Mountain study area in Chandalar, Philip Smith Mountains, and Wiseman quadrangles (1:250,000), northern Alaska.

B. Till. We appreciate the careful technical reviews provided by Godfrey S. Nowlan, Geological Survey of Canada, and James G. Clough, Division of Geological & Geophysical Surveys, State of Alaska.

INTRODUCTION

This paper describes pre-Carboniferous metacarbonate rocks that crop out along the Dalton Highway through the central Brooks Range (fig. 1). In this area, bedrock consists largely of intercalated thrust sheets of calcareous and siliceous metasedimentary rocks. Our study concentrates on a succession of chiefly carbonate rocks, which are Cambrian (and older?) to Devonian in age, and on subordinate limy layers within three Devonian siliciclastic units.

The focus of this study is the Snowden Mountain area, about 300 km south of Prudhoe Bay. The area investigated in detail extends from south of Sukakpak Mountain north to Atigun Pass and includes parts of the Chandalar, Philip Smith Mountains, and Wiseman 1:250,000-scale quadrangles (figs. 1–3).

The pre-Carboniferous stratigraphy of northern Alaska is only beginning to be unraveled. Bedrock geology is dominated by a Jurassic to Cretaceous orogenic belt, which extends more than 1,000 km from the Seward Peninsula through the Brooks Range. Outcrops of pre-Carboniferous metacarbonate rocks occur throughout this belt, but their origin and tectonic significance are uncertain. Did these rocks once constitute a single carbonate platform, like that formed by the chiefly Carboniferous Lisburne Group, which has since been tectonically dismembered? Or are they parts of several discrete platforms, derived from disparate continental margins, that have been juxtaposed by later tectonic events?

Rocks of the Snowden Mountain area are the first pre-Carboniferous carbonate succession from the central Brooks Range for which detailed sedimentologic and biofacies data are available, and these data permit comparison with better known lower and middle Paleozoic rocks in the western and eastern Brooks Range and Seward Peninsula. Detailed lithologic and faunal similarities between strata in these areas suggest that, like the Lisburne Group, older carbonate rocks display relative stratigraphic continuity across northern Alaska.

GEOLOGIC SETTING

During the Jurassic to Cretaceous Brooks Range orogeny, rocks of the central Brooks Range were complexly folded, thrust faulted, and underwent syntectonic regional metamorphism; contrasting structural levels are now exposed from south to north, the direction of tectonic transport (Moore and others, 1991). Several schemes have been proposed by various authors to describe these contrasting levels; bedrock has been divided into belts, terranes and subterranes, and domains and allochthons. These diverse approaches all recognize the existence of distinct linear zones within the orogen that are characterized by rocks of contrasting metamorphic grade and structural style.

All of the metacarbonate succession and most of the siliciclastic rocks described in this paper occur within a region variously designated as the central belt (Till and others, 1988; Till and Moore, 1991), the Hammond subterrane of the Arctic Alaska terrane (Moore and others, in press), or the Skajit allochthon (Oldow and others, 1987). Central belt rocks are markedly less deformed and metamorphosed than the pelitic and calcareous rocks of the schist belt (Coldfoot subterrane) to the south; schist belt rocks are penetratively deformed and have undergone high-pressure metamorphism (Till and Moore, 1991). However, central belt rocks are more deformed and metamorphosed than rocks of the Endicott Mountains allochthon (Endicott Mountains subterrane) to the north, and the stratigraphy of central belt rocks is less well understood (Oldow and others, 1987).

The precise location and nature of boundaries between the schist belt, central belt, and Endicott Mountains allochthon are controversial (Oldow and others, 1991; Moore and others, 1991; Till and Moore, 1991), and the northernmost thrust sheets of Devonian siliciclastic rocks discussed in this paper are considered part of the Endicott Mountains allochthon by some authors. These rocks are included here because their lithofacies, conodont faunas, and levels of thermal alteration are similar to those of Devonian siliciclastic rocks within the central belt. All the rocks described in this report have been dismembered by thrust faults and metamorphosed to greenschist facies; they contain conodonts that have color alteration indices (CAIs) of 5 or higher, indicating that the host rocks reached at least 300°C (Epstein and others, 1977). However, microfossils, megafossils, and primary sedimentary textures are locally well preserved; these features allow reconstruction of original stratigraphic relationships and depositional environments and provide a basis for regional correlation.

PREVIOUS WORK

The geology of much of the central Brooks Range is still relatively poorly known, and pre-Carboniferous carbonate rocks in this area have received little attention. Reconnaissance geologic mapping and resource assessment of this part of the Brooks Range was initiated by Mertie (1925, 1929); later, more detailed geologic maps of the Chandalar, Wiseman, and Philip Smith Mountains quadrangles were published by Brosgé and Reiser (1964, 1971), Brosgé and others (1979), and Dillon and others (1986, 1988). Oldow and others (1987) presented a generalized geologic map of the central Brooks Range as well as balanced cross sections along two north-south transects, one of which bisects the Snowden Mountain area. All of these maps include brief lithologic descriptions of the metacarbonate rocks described in this report.

Brosgé and others (1962) described the general Paleozoic sequence in the eastern half of the Brooks Range and assigned most metacarbonate rocks in the Snowden Mountain area to the Skajit Limestone of Middle(?) and Late Devonian age. Palmer and others (1984) first recognized rocks of early Paleozoic (Cambrian) age in the Snowden Mountain area, and Dillon and others (1987a, 1988) documented the occurrence of rocks of Ordovician and Silurian(?) age in this region. The latter two reports summarize lithologic and age data that were available from the Snowden Mountain area prior to 1986 but contain little specific biostratigraphic or sedimentologic information. The present study combines detailed petrologic data, results of more than 60 productive conodont collections made during the 1989 and 1990 field seasons, and a reassessment of all previous fossil collections available from the study area in order to characterize the sedimentology, stratigraphy, and regional relationships of pre-Carboniferous metacarbonate rocks in the Snowden Mountain region.

STRATIGRAPHIC NOMENCLATURE

Previous workers assigned most metacarbonate rocks in the Snowden Mountain area to the loosely defined Skajit Limestone and considered these rocks to be of Devonian age on the basis of rare, poorly preserved megafossils (Brosgé and others, 1962). Metasedimentary, chiefly siliciclastic rocks (for example, units Dsg, Dl, Dls, and Ds of Brosgé and Reiser, 1964)[1] spatially associated with these massive carbonate bodies were thought to stratigraphically overlie the Skajit Limestone and were also interpreted as Devonian in age. Later publications (Brosgé and others, 1979, and Dillon and others, 1988) referred some fine-grained metaclastic rocks in the Wiseman and Philip Smith Mountains quadrangles to the Upper Devonian Hunt Fork Shale. Dutro and others (1979) proposed a new Upper Devonian stratigraphic unit, the Beaucoup Formation, to encompass intercalated clastic and carbonate rocks in the Philip Smith Mountains, Chandalar, and Arctic quadrangles; this unit was considered to unconformably overlie the Skajit Limestone and conformably underlie the Hunt Fork Shale. Rocks previously assigned to unnamed units, such as units Dl, Dls, and Ds of Brosgé and Reiser (1964) in the Chandalar quadrangle, were reassigned, in part, to the Beaucoup Formation.

In the middle 1980's, conodont and megafossil collections made by field parties of the Alaska State Division of Geological & Geophysical Surveys in the Wiseman and

[1]Dsg, Devonian siltstone and grit; Dl, Devonian limestone; Dls, Devonian calcareous and noncalcareous phyllite, grit, and silty limestone; Ds, Devonian slate.

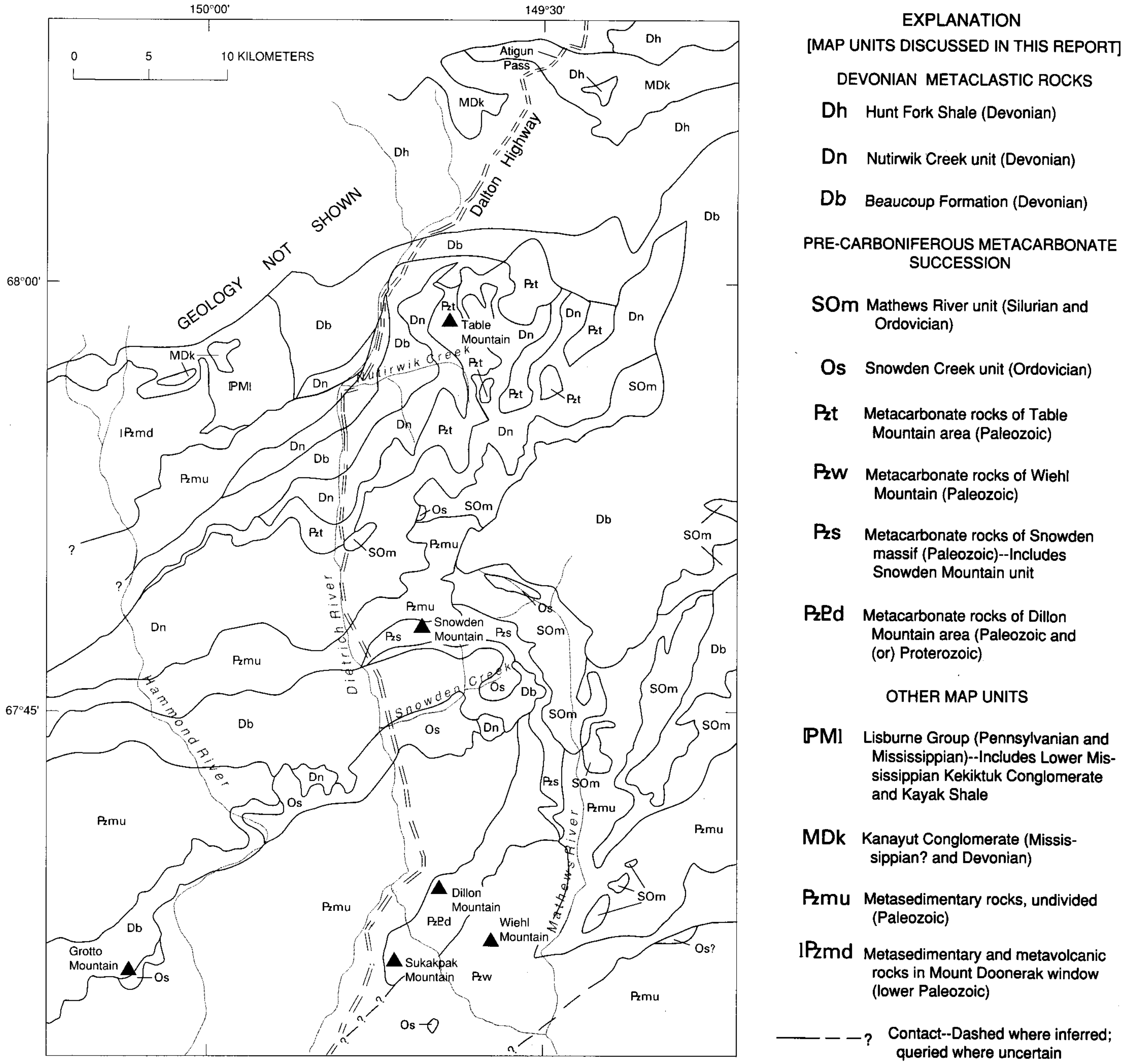


Figure 2. Generalized distribution of geologic units in the Snowden Mountain area, based on preliminary compilations (1992) by personnel of the Trans-Alaska Crustal Transect Program; a geologic map of this area was not available for our use. Most contacts of geologic units are thrust faults, and many units are internally imbricated. Map units may include areas underlain by rocks of other units too small to show at the scale of this map.

Chandalar quadrangles revealed that at least some of the massive carbonate bodies included in the Skajit Limestone, and some of the associated metaclastic rocks assigned to the Beaucoup Formation or to unnamed Devonian map units by previous workers, are of Silurian and older age. Dillon and others (1987a, 1988) proposed a new stratigraphy to encompass these findings. They defined a sequence of unnamed lower Paleozoic map units, including several units of Cambrian(?) and Cambrian(?) to Ordovician(?) age, two Middle Ordovician units (Om, Obpm),[2] and an Upper Ordovician and Silurian unit (unit SOm[2]; designated as unit

[2]Om, Ordovician marble; Obpm, Ordovician black phyllite and metalimestone; SOm, Ordovician to Silurian marble.

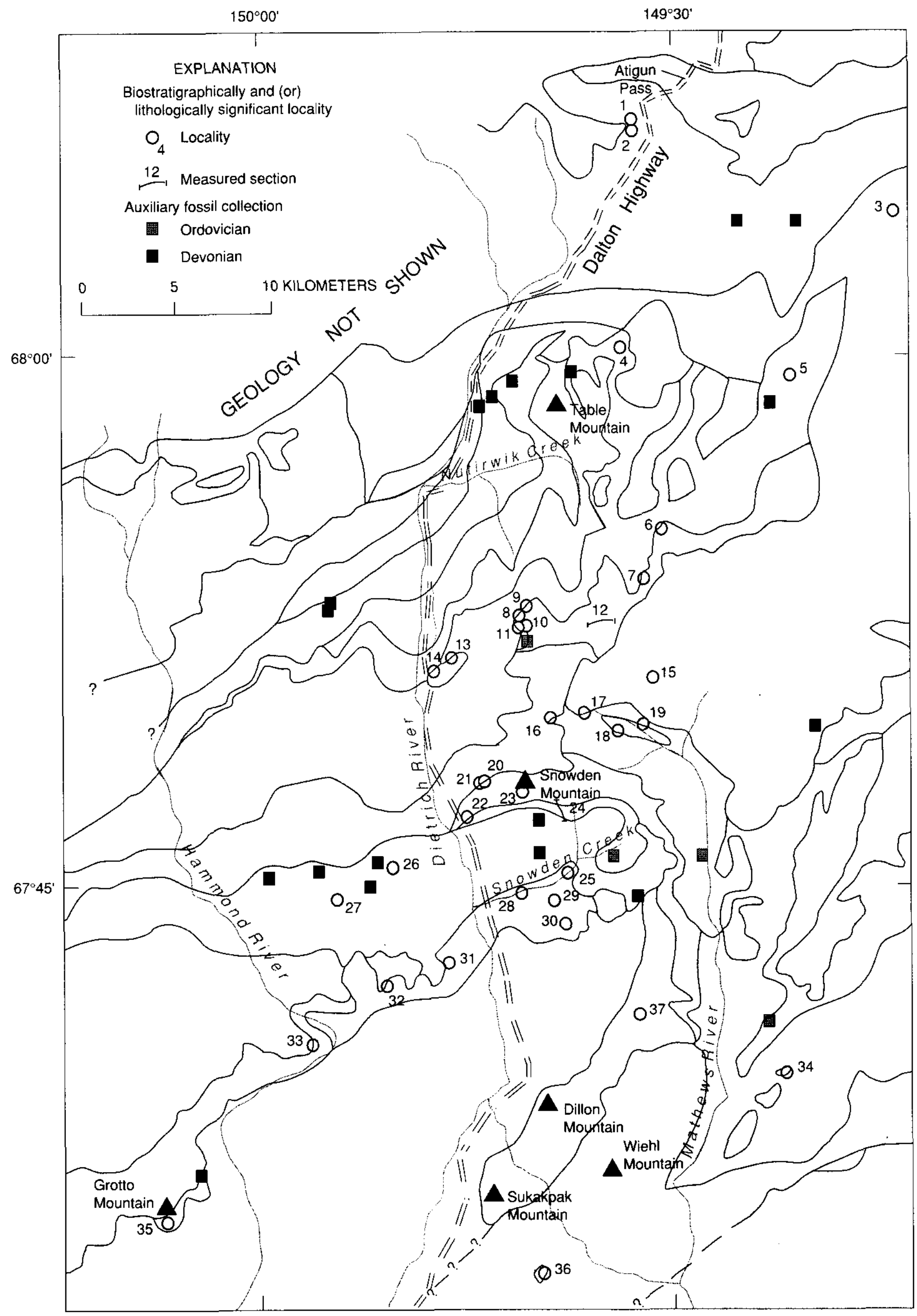


Figure 3. Geographic names and location of measured sections and lithologic and fossil collections in the Snowden Mountain area. See figure 2 for distribution and identification of geologic units; see appendix 1 for geographic coordinates and key faunal components and lithologies for numbered localities.

OSm by Dillon and others, 1987a, 1988). These workers retained the Skajit Limestone, Beaucoup Formation, and Hunt Fork Shale, considered all three units to be of Devonian age, but restricted their geographic extent within the northern Wiseman-Chandalar area. In addition, they proposed a series of new Devonian units, such as the rocks of Whiteface Mountain, which were distinguished on the basis of different proportions of metasedimentary versus metavolcanic rocks.

Our work indicates that most of the massive carbonate rocks previously assigned to the Skajit Limestone in the Snowden Mountain region are of pre-Devonian age. However, at least some massive carbonate rocks in this area are Devonian in age, and other strata are Silurian or Devonian. Reliable lithologic criteria that allow discrimination of pre-Devonian from Devonian carbonate rocks have not yet been established. Contacts between the massive carbonate rocks and the associated metaclastic rocks are generally faults, but, locally, contacts appear to be gradational and stratigraphic. The various Devonian metaclastic rock units, as presently defined, are also difficult to discriminate in the field (for example, Hunt Fork Shale versus Beaucoup Formation). Our present state of knowledge is sufficient to indicate problems with previously established stratigraphic nomenclature but is not yet adequate to support the definition of a series of new formal unit names. Hence, in this paper, established stratigraphic names are used where they are consistent with our new lithologic and faunal data. Elsewhere, map-unit designations or informal names employed during recent mapping are used, and the relationship of these names to the older stratigraphic nomenclature is indicated.

METHODS

The metacarbonate rocks described in this report were observed and sampled in a series of traverses and partial measured sections east and west of the Dalton Highway; locations of measured sections and key lithologic and fossil collections are shown in figure 3 and described in appendix 1.

Petrographic descriptions are based on field studies of lithology and sedimentary structures as well as on examination of about 50 polished slabs and 400 thin sections. Sections were measured using Jacob's staff, Brunton compass, and tape; identification of calcite and dolomite was made on selected samples using the Alizarin Red-S and potassium ferricyanide staining technique of Dickson (1966). Carbonate rocks in which original texture is not obscured by metamorphism, deformation, or diagenesis are classified following Dunham (1962); when descriptive modifiers are employed, they are listed in order of increasing abundance. Metalimestone is used to indicate rocks that are partially recrystallized but retain some relict primary textures; marble is used to describe rocks that are totally recrystallized. Biostratigraphy relies largely on conodont faunas from our measured sections and spot samples, but data from previous megafossil collections (particularly corals and trilobites) are included where appropriate. Interpretations of depositional environments are based on depositional models for carbonate rocks outlined in Wilson (1975); the environmental implications of conodont assemblages (for example, Sweet and Bergström, 1971; Clark, 1984) are also used to constrain our interpretations.

METACARBONATE SUCCESSION—CAMBRIAN (AND OLDER?) TO MIDDLE DEVONIAN METASEDIMENTARY ROCKS

Bedrock in the Snowden Mountain area consists mostly of large masses of metacarbonate rocks associated with subordinate thinner intervals of carbonaceous phyllite (fig. 4). Deformation and metamorphism have obscured the original depositional patterns of these rocks, but compilation of a number of partial, but overlapping, measured sections allows reconstruction of a generalized stratigraphy (figs. 5, 6). The oldest dated strata are of early Middle Cambrian age; these rocks are fault bounded, and their stratigraphic relationship to the other units discussed here is uncertain. Rocks of Late Cambrian and Early Ordovician age have not been recognized in the Snowden Mountain area, but Middle Ordovician strata are widely distributed and comprise a variety of carbonaceous, chiefly fine-grained lithofacies laid down in a shallowing-upward depositional regime. These rocks are structurally intercalated with, and locally grade up into, massive metacarbonate rocks. Many exposures of this lithology are of Late Ordovician and Silurian age, but some are Devonian, and other metacarbonate masses in the study area may be of Cambrian or older age. The reconstructed stratigraphic column shown in figure 6 is undoubtedly incomplete; it does not include lithologic units in the Snowden Mountain area (such as units Pzmu and lPzmd in fig. 2) that are of unknown or uncertain age. However, it portrays our present understanding of the relative stratigraphic position, age range, and minimum thickness of well-dated lithologic units known to be pre-Late Devonian in age in the Snowden Mountain area. A more speculative column including units of less well constrained age is presented and discussed below (see "Summary of the Metacarbonate Succession in the Snowden Mountain Area," p. 26).

CAMBRIAN ROCKS

The oldest well-dated rocks in the study area are a thin interval of phyllite and subordinate metalimestone, about 3 km in lateral extent, that discontinuously underlies massive marble on the north side of Snowden Mountain (fig. 3, loc. 20). These rocks constitute unit Ꞓl (Cambrian marble) of Dillon and others (1988) and are here referred to as the Snowden Mountain unit. Ten to twenty meters of continuous section are relatively well exposed directly below the massive marble along a small north-facing ridge; additional phyllitic strata discontinuously exposed on the steep northern side of this ridge also belong to this unit but are inaccessible and were not examined during the course of this study. The entire phyllite and metalimestone interval is no more than a few hundred meters thick.

Figure 4. Massive metacarbonate rocks chiefly of the Mathews River unit, Chandalar D–6 quadrangle.

The Snowden Mountain unit overlies a thick section of metasedimentary rocks, including calcschist and metaconglomerate; the nature of the contact between these units is uncertain but was thought to be a normal stratigraphic contact by Dillon and others (1988) (see further discussion below). The upper contact of the Snowden Mountain unit has been interpreted as an unconformity (Dillon and others, 1987a, 1988), but where observed during the course of this study it appears to have undergone at least some faulting. The basal meter of strata directly overlying the phyllite and metalimestone interval consists of dominantly clast-supported, calcareous conglomerate (fig. 7*A*), which grades upward into massive, cliff-forming gray marble. Clasts are 1 mm to 15 cm in diameter, subrounded to angular, and generally well aligned. Most clasts consist of medium-gray, finely crystalline marble; rare pebbles and cobbles of tan, fine-grained, dolostone(?) and white, coarse-crystalline marble also occur. This conglomeratic layer could represent a basal lag developed along an unconformity surface, but it (and the immediately overlying gray marble) is locally strongly sheared, brecciated, and iron stained, thus indicating at least some deformation along the upper contact of the Snowden Mountain unit.

LITHOLOGIES

The dominant lithology in the Snowden Mountain unit is noncalcareous, gray to silver phyllite. Thin layers and lenses of slightly recrystallized, sandy metalimestone make up 5 to 10 percent of the section and are thicker and more abundant in the upper part of the section. The top 2 m of strata are orange-weathering, dark-gray, bioclastic wackestone to packstone, with phyllitic partings and layers spaced 4 to 10 cm apart. The wacke-packstone consists of locally abundant whole and fragmentary trilobites and phosphatic brachiopods, as well as echinoderm and other fossil debris, peloids, and a few to 10 percent angular, fine sand- to silt-sized quartz grains in a matrix of lime mud; thin seams of dolomite euhedra occur locally (fig. 7*B*).

AGE AND BIOFACIES

Limy layers in the uppermost part of the Snowden Mountain unit contain trilobites of early Middle Cambrian age, including many specimens of *Kounamkites* cf. *K. frequens* Chernysheva, less common specimens of *Chon-*

dranomocare cf. *C. speciosum* M. Romanenko, and fragments of indeterminate olenellids (Palmer and others, 1984; Dillon and others, 1988) (fig. 8). The fauna has strong Siberian biogeographic affinities and is typical of open-shelf facies (Palmer and others, 1984).

DISTRIBUTION

Dillon and others (1987a, p. 337) suggested that strata "thought to be stratigraphically below and on strike with those at the trilobite locality" within the Chandalar D–6 quadrangle are also of Cambrian age. These rocks consist of units Ꞓcq, Ꞓcs, and parts of OꞒc, OꞒvc, and OꞒvp (Dillon and others, 1988)[3] and include interlayered tan- to orange-weathering, calcareous schist and quartzite, sandstone and granule conglomerate, sandy marble, and gray, green, and purple phyllite. Dillon and Reifenstuhl (in press) extended this stratigraphy south of the Snowden Mountain area on the basis of lithologic correlation and considered additional, widely distributed strata in the Chandalar C–5 and C–6 quadrangles to be of Cambrian age. Thus far, no fossils have been found in any of these rocks to confirm a Cambrian age; 10 samples taken for microfossils from these units are barren, and a single productive sample from the Chandalar C–6 quadrangle contains a conodont fragment of post-Cambrian age. In addition, at least some of the units assigned a Cambrian age by Dillon and others (1988) have strong lithologic similarities to rocks of known Devonian age, and contacts considered to be stratigraphic by Dillon and others (1988) have been reinterpreted as faults by later workers (T.E. Moore, U.S. Geological Survey, written commun., 1991). In this paper, only the Snowden Mountain unit (unit Ꞓl of Dillon and others, 1988) is considered to be of Cambrian age; it has been recognized in only one locality, along the north side of Snowden Mountain (fig. 3, loc. 20).

DEPOSITIONAL ENVIRONMENT

Sedimentary features of the Snowden Mountain unit suggest deposition in an outer shelf or slope setting. The fine grain size and lack of current structures characteristic of most of the section imply deposition in a quiet setting, below fair-weather wave base. Lenses of quartzose lime wackestone and packstone intercalated in the phyllite probably represent storm deposits, and the increased abundance of such lenses in the upper part of the section suggests a shallowing-upward depositional regime. The trilobite-brachiopod-echinoderm fauna contained within the limy lenses is characteristic of normal marine conditions and moderate water depths (Palmer and others, 1984).

[3]Ꞓcq, Cambrian chlorite quartz schist; Ꞓcs, Cambrian calc-schist; OꞒc, Cambrian(?) to Ordovician(?) calcareous clastic rocks; OꞒvc, Cambrian(?) to Ordovician(?) volcanic conglomerate; OꞒvp, Cambrian(?) to Ordovician(?) interlayered volcanic rocks and phyllite.

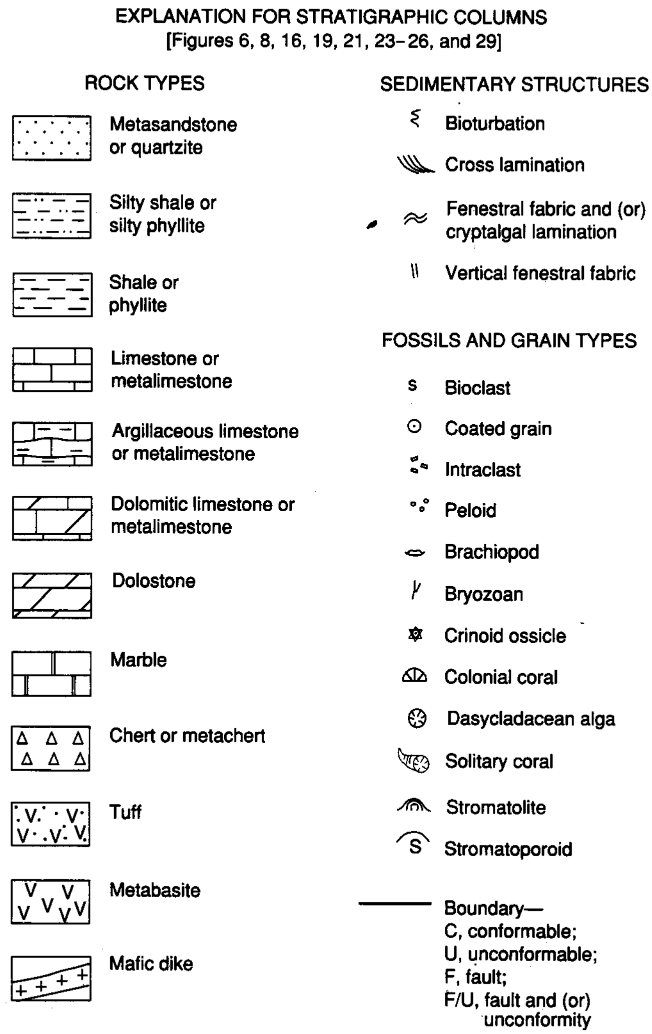


Figure 5. Lithologic and paleontologic symbols used in this report.

MIDDLE ORDOVICIAN ROCKS

Middle Ordovician strata are widely distributed in the Snowden Mountain area and consist primarily of phyllite, metachert, metalimestone, and marble (fig. 6). These rocks were originally included in units Dsk (Skajit Limestone) and Dl (limestone) by Brosgé and Reiser (1964) and were considered by them to be of Devonian age. Dillon and others (1987a, 1988) recognized the presence of Middle Ordovician conodonts in these strata and assigned them to their units Obpm (black carbonaceous phyllite and crinoidal metalimestone) and Om (gray to black crinoidal marble bodies of mappable extent included within unit Obpm).

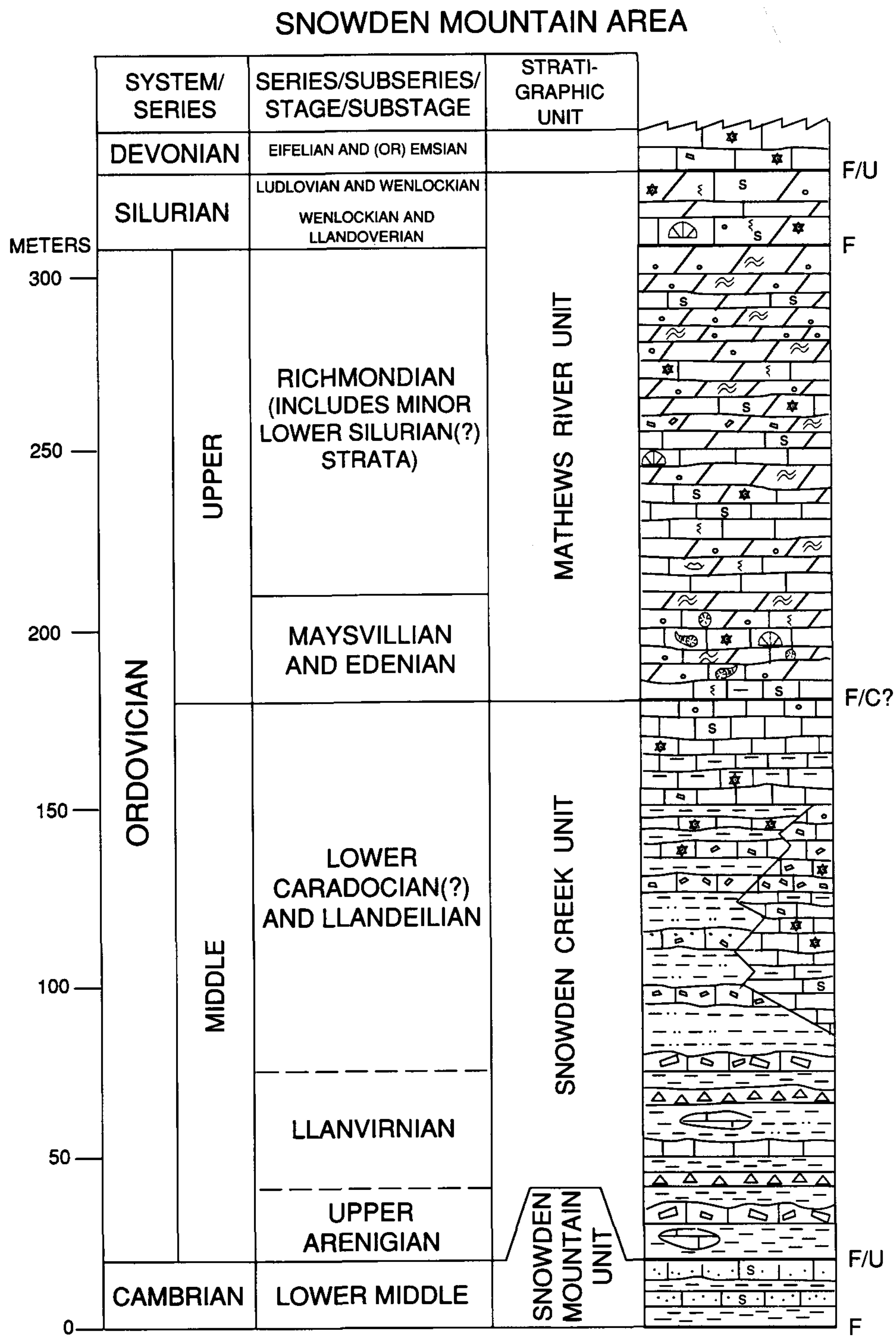


Figure 6. Generalized composite stratigraphic column for metacarbonate succession in the Snowden Mountain area, based on a number of overlapping, partial measured sections with good biostratigraphic control. Thicknesses are minima, particularly for Upper Ordovician and Silurian rocks. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American Midcontinent Province faunas (NAMP). See figure 5 for explanation of symbols.

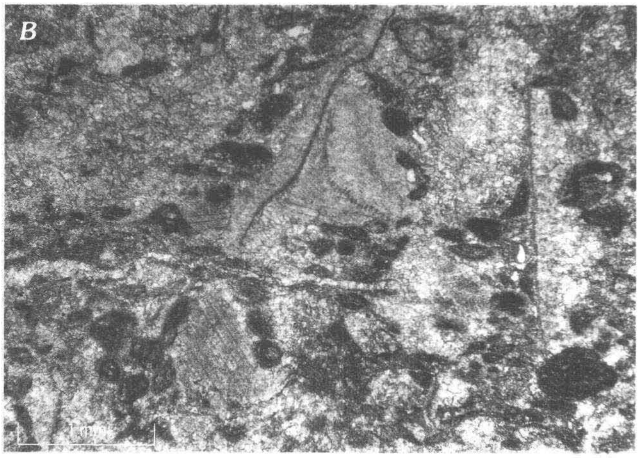


Figure 7. *A*, Carbonate-clast conglomerate directly overlying Snowden Mountain unit; layer could be a lag developed along an unconformity surface or a fault breccia (fig. 3, loc. 20) (pencil, 14 cm long). *B*, Photomicrograph of bioclastic peloidal packstone, Snowden Mountain unit (fig. 3, loc. 20); dark ovoids are peloids, and other grains are bioclasts, including echinoderm and trilobite fragments.

The basic unit concept established by Dillon and others (1987a, 1988) is used here, and these rocks are referred to as the Snowden Creek unit. However, our map distribution of the Snowden Creek unit (fig. 2) differs somewhat from that of unit Obpm (Dillon and others, 1987a, 1988), and the unit as defined here includes a slightly broader array of rock types. In addition, our interpretation of the stratigraphic context of these rocks differs from that of Dillon and others (1987a, 1988). These authors stated that unit Obpm unconformably(?) overlies calcareous metasedimentary rocks, which they believed to be of Cambrian age, and is in turn overlain by "Skajit Limestone of Devonian age" (Dillon and others, 1987a, p. 337). Our studies indicate that the basal contact of most exposures of the Snowden Creek unit is a fault, and a stratigraphic relationship to rocks of definite Cambrian age has not been established. The upper contact of this unit is also generally a fault, but locally (for example, fig. 3, loc. 11) a gradational and apparently conformable contact with Upper Ordovician and Silurian massive metacarbonate rocks of the Mathews River unit is observed.

The Snowden Creek unit is at most a few hundred meters thick. Exposed sections range from about 10 to 100 m thick and are typically strongly folded; some sections may have been structurally thickened. A generalized composite stratigraphy (fig. 6) has been pieced together from a number of overlapping partial measured sections, particularly those at localities 22, 24, 28, 29, and 36 (fig. 3).

LITHOLOGIES

Carbonaceous, fine-grained siliciclastic and calcareous rocks characterize the Snowden Creek unit and are interlayered on a scale of a few centimeters to tens of meters. Calcareous material dominates some sections but makes up less than 5 percent of others (Dillon and others, 1987a) (fig. 9*A*); these differences reflect both temporal and spatial fluctuations in carbonate input. Elongate lenses of light-colored calcite marble (equivalent to unit Om of Dillon and others, 1987a, 1988) occur locally within the Snowden Creek unit.

Siliciclastic lithologies in the Snowden Creek unit include phyllite, metachert, and rare metasandstone. Phyllite-rich intervals are poorly exposed and crop out best in streamcuts such as the headwaters of Snowden Creek (fig. 3, loc. 24). More commonly, phyllite forms subordinate layers a few millimeters to a few meters thick within sections of metachert or metalimestone. Phyllite is black to silvery gray, generally carbonaceous, and locally calcareous; foliation planes are spaced a few millimeters to 3 cm apart.

Reddish-brown- to brown-weathering, gray to black metachert occurs in intervals of 2 to 30 m; it weathers into irregular slabs, 0.5 to 5 cm thick, which may contain millimeter- to centimeter-scale laminations of mica, pyrite, or carbonaceous material. In some outcrops, this small-scale compositional layering is so pronounced that the rocks are rhythmically color-banded (for example, fig. 3, loc. 29). Local lenses, 15 to 30 cm thick, of brown-weathering, black dolostone occur throughout the metachert intervals. Both metachert and dolostone are fine grained; crystal size is 20 to 100 μm in metachert and 20 to 50 μm in dolostone. Both lithologies contain spheroids and ovoids, 50 to 400 μm (mostly 100–200 μm) in diameter, that are probable radiolarian ghosts. In the metachert layers, these ghosts are made of quartz crystals that are slightly coarser than those in the surrounding matrix. Ghosts in the dolomitic lenses consist of crystalline calcite or dolomite; concentrations of carbonaceous material preserve details of the original test in some specimens. Radiolarian ghosts generally are rare (a few percent) and disseminated but reach abundances of 5 to

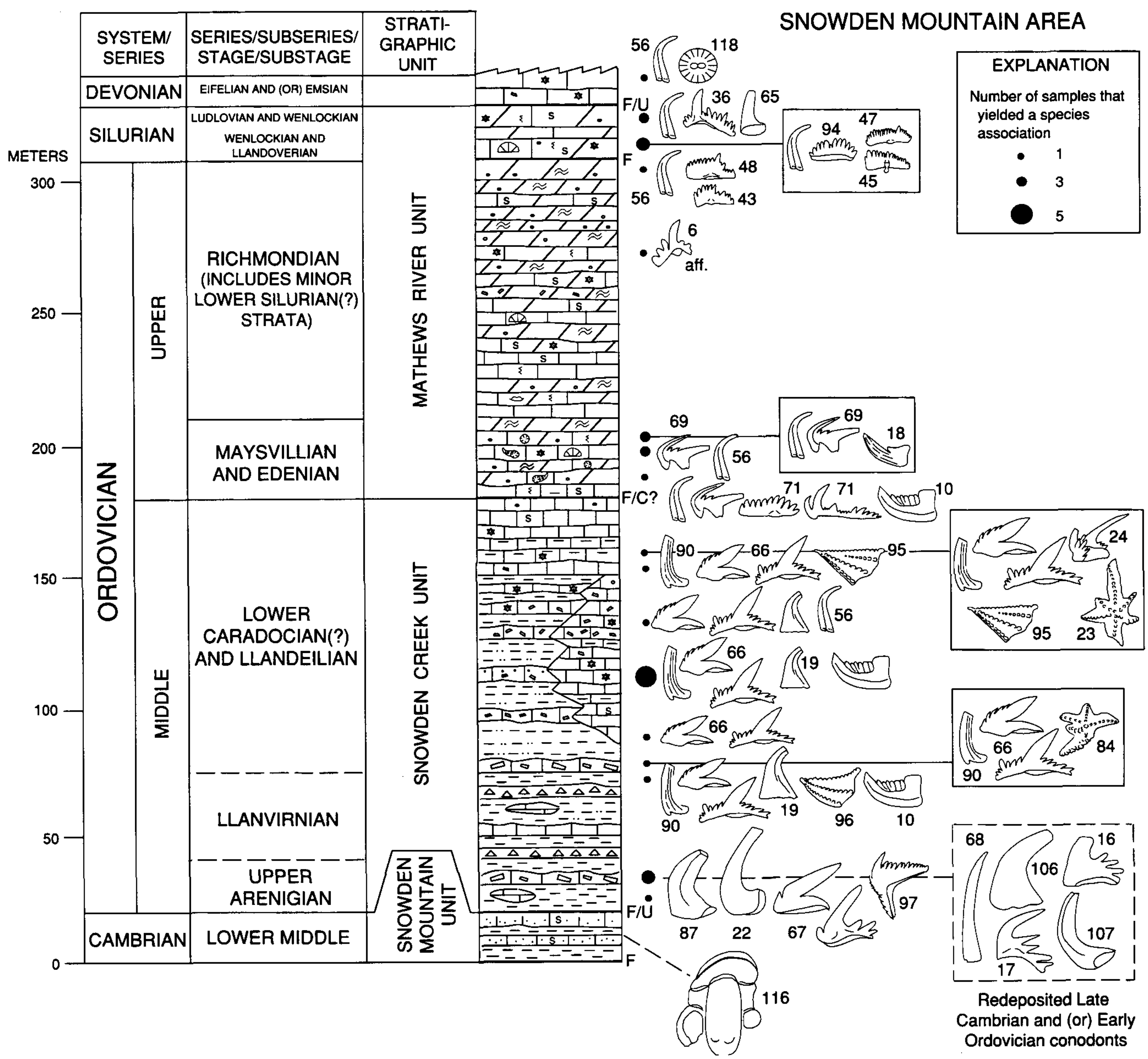
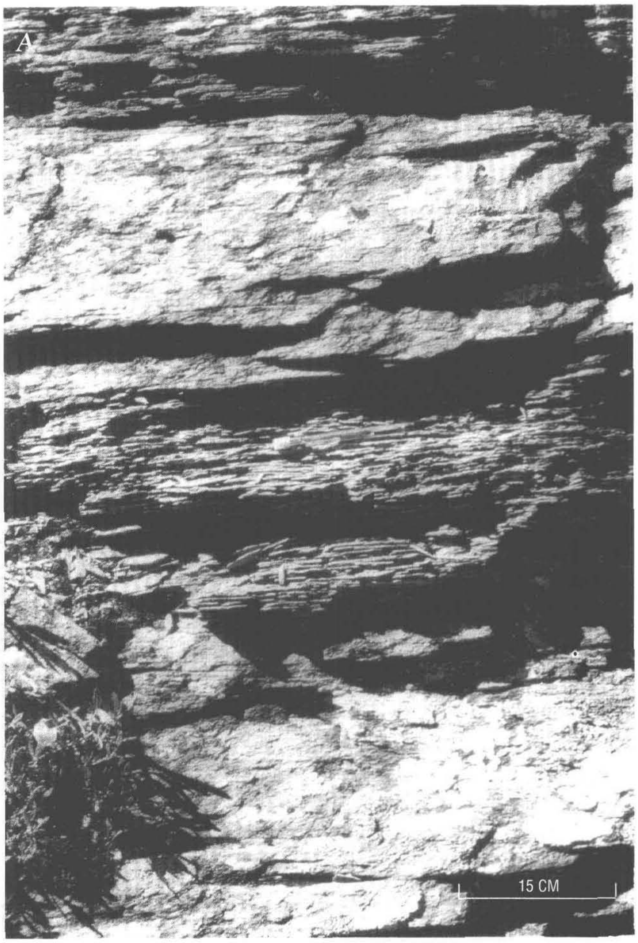


Figure 8. Generalized composite stratigraphic column showing fossil distribution in the metacarbonate succession in the Snowden Mountain area; selected fossils (chiefly conodonts) of biostratigraphic, paleogeographic, and (or) paleoecologic significance are shown at appropriate points adjacent to the lithologic column. Thicknesses are minima, particularly for Upper Ordovician and Silurian rocks. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American Midcontinent Province (NAMP) faunas. See figure 5 and table 1 for explanation of symbols and numerical identification of fossils, respectively.

25 percent in some samples and may be concentrated into irregular laminae. Some metachert layers contain small knots of chloritoid.

Metasandstone is less abundant in the Snowden Creek unit than the finer grained siliciclastic lithologies described above but may form 20 to 30 percent of some outcrops. It occurs intercalated with phyllite in graded, poorly sorted layers, 2 to 25 cm thick, which weather pink, greenish gray, or brownish gray. Most layers are semischistose, and some are slightly calcareous; grain size ranges from very fine to very coarse. Clasts are rounded to subangular and consist of 15 to 30 percent quartz, lesser amounts of plagioclase, and abundant lithic grains in a recrystallized matrix of mica, chlorite, and calcite. Lithic clasts are primarily sedimentary (chert, siltstone, dolostone) and metamorphic (schist, phyllite). Heavy minerals include tourmaline and garnet.



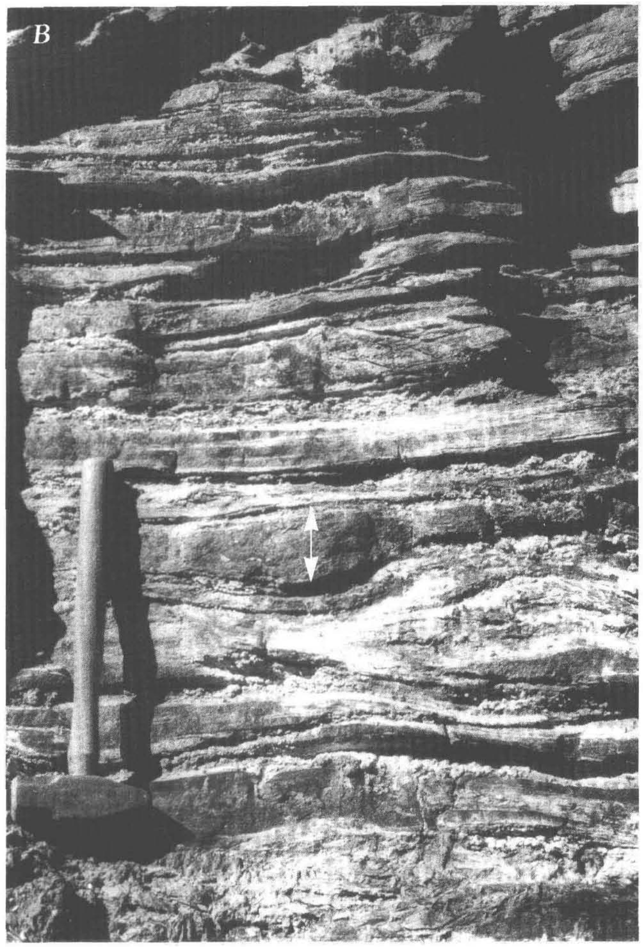
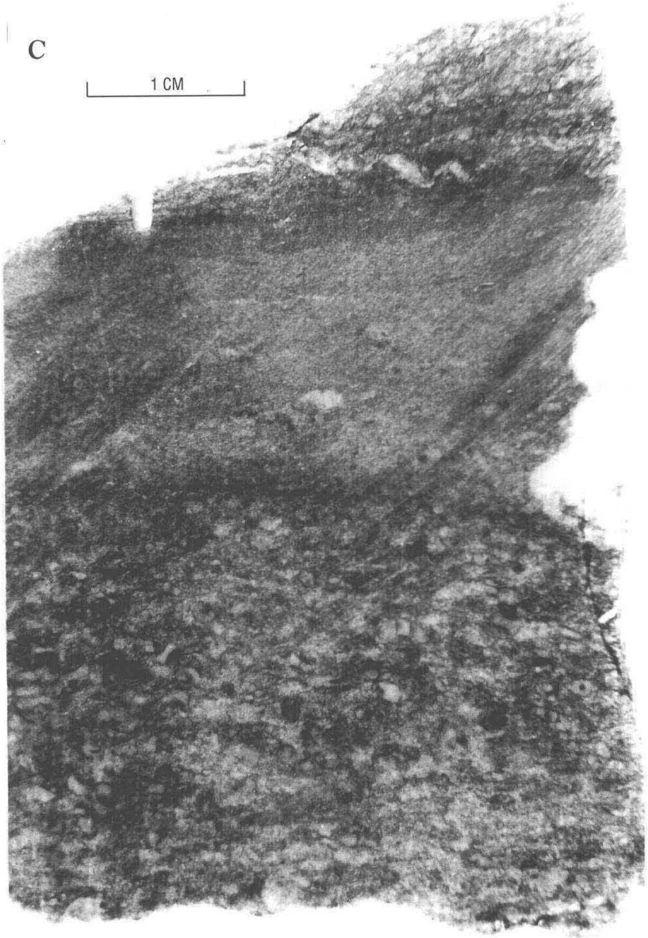


Figure 9. Sedimentary features of the Snowden Creek unit. *A*, Section consisting chiefly of noncalcareous phyllite and lesser metasandstone (fig. 3, loc. 22). *B*, Section consisting chiefly of calcareous turbidites (fig. 3, loc. 28); arrow marks turbidite shown in *C* (hammer, 40 cm long).

Limy layers are found throughout the Snowden Creek unit, but, as noted above, the kind and amount of calcareous material vary strikingly from section to section. The major carbonate rock types are thinly layered, carbonaceous metalimestone and massive, light-colored calcite marble.

Carbonaceous metalimestone is most abundant in the lower part of the Snowden Creek unit. It occurs as continuous sequences, 10 to 100 m thick, that dominate some sections and as subordinate layers, a few millimeters to 1 m thick, in sections made mostly of phyllite and (or) metachert. In both settings it forms couplets, 0.5 to 10 cm thick, defined by a contrast in color, grain size, and (or) noncarbonate components (fig. 9*B–D*). The finer grained upper part of the couplet is dark gray to black, weathers brown or black, and may contain abundant mica and (or) carbonaceous material. The lower part of the couplet is generally thicker, lighter in color, and may contain abundant quartz. Most contacts between the two parts of a single couplet are gradational, whereas those between adjacent couplets are sharp. In the least deformed and recrystallized outcrops of carbonaceous metalimestone, details of original bedform and composition are preserved. Most couplets are even to slightly undulatory, laterally continuous, and parallel laminated; some form lenses, 0.5 to 1. 5 m long, with scoured bases.

The amount of noncarbonate material in the couplets varies greatly from outcrop to outcrop. Some couplets contain few noncarbonate grains and consist mostly of calcareous bioclasts and (or) calcareous lithiclasts and lime mud. At locality 28 (fig. 3), at least 40 m of relatively pure metalimestone overlies several meters of black metachert. Carbonate couplets here consist of skeletal packstone grading up to lime mudstone and are separated by 1 cm or less of calcareous phyllite; bioclasts are almost exclusively echinoderm debris (crinoid columnals) (fig. 9*B–D*). The basal centimeter of a typical 8-cm-thick couplet at this outcrop contains columnals that average 2 mm in diameter, as well as 5 to 10 percent rounded grains of quartz silt and



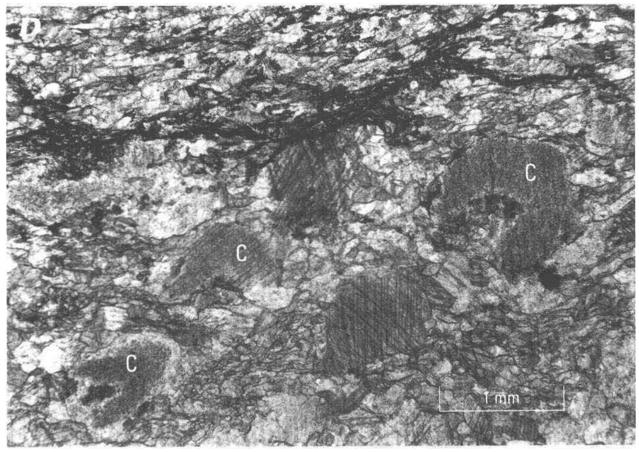


Figure 9.—Continued.
C, Sawed slab of turbidite showing well-developed graded bedding. *D*, Photomicrograph of lower part of turbidite in *C*; rock consists primarily of crinoid ossicles, C, in a matrix of fine-crystalline calcite and minor amounts of quartz silt.

fine sand, in a matrix of fine-crystalline (200 μm) calcite. The upper part of the couplet contains rare columnals that average 0.5 mm in diameter, and less than 1 percent quartz silt, in a matrix of microcrystalline (20–40 μm) calcite. At other outcrops (for example, fig. 3, loc. 19), couplets contain 20 to 30 percent rounded to angular carbonate lithic clasts (fig. 10*A*, *B*) in addition to echinoderm debris. These clasts include lime mudstone, peloidal wackestone and grainstone, bioclastic packstone and grainstone, and fine-grained dolostone with disseminated radiolarian ghosts. The largest clasts are as much as 1.5 cm in diameter but in general are coarse to very coarse sand sized.

Other metalimestone intervals include abundant non-carbonate material. At locality 30 (fig. 3), just 3 km southeast of locality 28, 100 m of quite impure metalimestone overlies 5 m of black metachert. The coarse lower parts of couplets at this site contain 20 to 80 percent quartz, as well as calcite and subordinate white mica. Elsewhere, rounded phosphatic grains and phosphatic skeletal fragments make up as much as 25 percent of the coarse fraction of some metalimestone couplets.

Distinctive, light-colored carbonate bodies (unit Om of Dillon and others, 1987a, 1988) occur locally within the Snowden Creek unit. These bodies are typically elongate lenses, 10 to 100 m thick and a few hundred meters to several kilometers long, which are white to light gray and weather white to beige. Most are massive, fine- to medium-crystalline, calcite marble in which original texture has been obliterated. Locally, however, original fabric can be discerned and consists of peloidal-skeletal packstone or grainstone. These white marble bodies are most common in the upper part of the section.

At several outcrops, carbonaceous metalimestone grades upward through an interval of a few tens of meters into massive white marble. At locality 28 (fig. 3), 2 m of black metachert with minor thin layers of black metalimestone is overlain by about 40 m of metalimestone couplets. At the base of the metalimestone sequence, couplets are dark gray to black, 3 to 5 cm thick, and typically separated by about a centimeter of calcareous phyllite. A few meters higher, couplets are medium gray, 5 to 10 cm thick, and separated by at most a few millimeters of phyllite. In the uppermost part of the sequence, light-gray, flaggy metalimestone grades up into white, sugary, fine crystalline marble. Changes in microtexture occur throughout this sequence as well. The lowest metalimestone layers (those

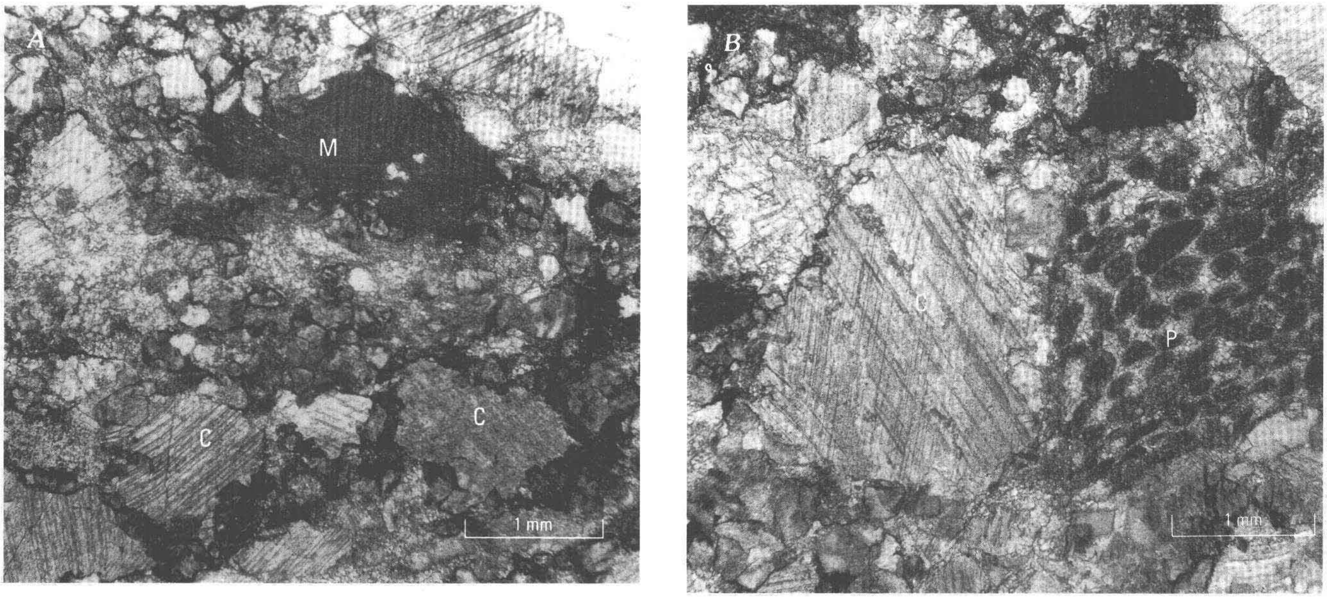


Figure 10. *A* and *B*, Photomicrographs of clasts in calcareous turbidite, Snowden Creek unit (fig. 3, loc. 19). C, crinoid ossicle; M, carbonaceous mudstone clast; P, peloidal grainstone clast.

intercalated with the metachert) are strongly carbonaceous and contain radiolarian ghosts. The metalimestone couplets consist primarily of echinoderm packstone, micrite, and minor detrital quartz and become less carbonaceous and more quartzose upward. The marble consists of 5 percent crinoid columnals in a matrix of anhedral calcite.

AGE AND BIOFACIES

Conodonts have been obtained from 22 samples, which represent 16 localities and several lithologies in the Snowden Creek unit (fig. 3 and app. 1, locs. 18, 19, 22, 24, 25, 28, 30–32, 35, 36), and provide relatively good age control for these strata. Dolostone lenses in metachert, thin metalimestone couplets intercalated with phyllite, and thick sequences of pure and impure metalimestone have all yielded conodonts (fig. 8; table 1; app. 1). Key species, including *Periodon flabellum*, *Tripodus laevis*, *Pygodus serra*, *Py. anserinus*, *Prattognathus rutriformis*, and *Eoplacognathus elongatus* transitional to *Polyplacognathus* sp. (fig. 8; pl. 1, figs. 1, 2, 5, 6, 9–12, 17, 18), indicate an age of late Arenigian to at least Llandeilian and probably to early Caradocian (early to middle Middle Ordovician) for this unit (USGS collns. 10728–CO, 9913–CO, 9911–CO, 10851–CO); the highest beds (USGS colln. 9909–CO) contain *Periodon aculeatus* (pl. 1, fig. 8) and are thus no younger than early Caradocian (middle Middle Ordovician). The most precisely dated parts of the unit represent intervals within the *serra* Zone (USGS colln. 10728–CO) and *Baltoniodus variabilis* Subzone to lowermost *B. gerdae* Subzone of the *Amorphognathus tvaerensis* Zone (USGS colln. 10851–CO) of late Llanvirnian and latest Llandeilian age to earliest Caradocian age, respectively. The oldest beds thus far sampled are very late Arenigian in age (USGS collns. 10826–CO and 10827–CO); these strata also contain redeposited Late Cambrian and (or) Early Ordovician conodonts (fig. 8; pl. 1, figs. 21–24). Conodonts from the Snowden Creek unit are chiefly cosmopolitan, deep- and (or) cool-water species of the protopanderodid-periodontid biofacies.

DISTRIBUTION

The Snowden Creek unit is exposed primarily in several west- to southwest-trending linear outcrop belts. The southernmost belt lies south of Sukakpak and Wiehl Mountains; age control is provided by a single sample (fig. 3, loc. 36). The central belt is the best dated and most studied; it consists of at least three discrete fault slices and can be traced from south of Snowden Mountain west across the Dalton Highway to Grotto Mountain. Two smaller exposures occur north and northeast of Snowden Mountain (fig. 3, locs. 11 and 18–19).

DEPOSITIONAL ENVIRONMENT

Sedimentary features and conodont biofacies of the Snowden Creek unit indicate that deposition took place chiefly in a slope to basinal setting, and the vertical sequence of lithologies suggests a shallowing-upward depositional regime. The carbonaceous siliceous lithology is interpreted as metachert because of its lithologic association and the presence of radiolarian ghosts and fine-scale lami-

Table 1. Names of fossils shown in figures 8, 19, 21, and 24–26.

No.	Conodonts
1	*Ancyrodella gigas*
2a	*Ancyrodella lobata*
2b	*Ancyrodella nodosa*
3	*Ancyrodella* sp. indet.
4	*Ancyrognathus* cf. *A. coeni*
5	*Ancyrognathus* aff. *A. triangularis*
6	*Aphelognathus* aff. *A. divergens*
7	*Aspidognathus* cf. *A.* sp. B of Mannik (1983)
8	*Astropentagnathus irregularis*
9	*Aulacognathus bullatus*
10	*Belodina* sp.
11	*Chosonodina rigbyi*
12	*Clavohamulus densus*
13	*Clavohamulus* n. sp.
14	*Cordylodus angulatus*
15	"*Cordylodus*" *horridus*
16	*Cordylodus intermedius*
17	*Cordylodus proavus*
18	*Culumbodina*? cf. *C. occidentalis*
19	*Dapsilodus*? *similaris*
20	*Diaphorodus delicatus*
21	*Distomodus*? *dubius*
22	*Drepanodus arcuatus*
23	*Eoplacognathus elongatus* transitional to *Polyplacognathus* sp.
24	*Erraticodon balticus*
25	*Fahraeusodus marathonensis*
26	*Fryxellodontus*? n. sp.
27	*Histiodella* n. sp.
28	*Icriodella*? sp. indet.
29	*Icriodus symmetricus*
30	*Icriodus taimyricus*
31	*Icriodus* sp. indet.
32	*Juanognathus variabilis*
33	*Jumudontus gananda*
34	*Klapperina ovalis*
35	*Kockelella amsdeni*
36	*Kockelella* sp. indet.
37	*Macerodus* n. sp.
38	*Mesotaxis falsiovalis*
39	*Oepikodus communis*
40	*Oistodus lecheguillensis*
41	*Oistodus multicorrugatus*
42	*Oneotodus costatus*
43	*Oulodus*? n. sp.
44	*Oulodus* sp.
45	*Ozarkodina* cf. *O. cadiaensis*
46	*Ozarkodina confluens*
47	*Ozarkodina excavata*
48	*Ozarkodina* aff. *O. oldhamensis*
49	*Ozarkodina remscheidensis remscheidensis*
50	*Ozarkodina* n. sp. cf. *O. remscheidensis*
51	*Ozarkodina* n. sp.
52	*Palmatolepis plana*
53	*Palmatolepis proversa*
54	*Palmatolepis* sp. indet.
55	*Paltodus subaequalis*
56	*Panderodus* sp.
57	*Pandorinellina exigua philipi*
58	*Pandorinellina expansa*
59	*Pandorinellina insita*
60	*Paracordylodus gracilis*
61	*Paroistodus originalis*
62	*Paroistodus proteus*
63	*Paroistodus* cf. *P. proteus*
64	*Pelekysgnathus dubius*
65	*Pelekysgnathus* sp. indet.
66	*Periodon aculeatus*
67	*Periodon flabellum*
68	*Phakelodus tenuis*
69	*Phragmodus* n. sp. (= *Ph.* n. sp. of Barnes, 1974)
70	*Plectodina*? *tunguskaensis*
71	*Plectodina*? cf. *Pl.*? *dolboricus*
72	*Plegagnathus*? *repens*
73	*Polonodus* sp.
74	*Polygnathus evidens*
75	*Polygnathus gronbergi*
76	*Polygnathus inversus*
77	*Polygnathus linguiformis*
78	*Polygnathus pacificus*
79	*Polygnathus planarius*
80	*Polygnathus samueli*
81	*Polygnathus webbi*
82	*Polygnathus* of the *Po. xylus* group
83	*Polygnathus* sp. indet.
84	*Prattognathus rutriformis*
85	*Prioniodus elegans*
86	*Proconodontus muelleri*
87	*Protopanderodus graeai*
88	*Protopanderodus insculptus*
89	*Protopanderodus liripipus*
90	*Protopanderodus varicostatus*
91	*Protoprioniodus aranda*
92	*Pseudobelodina adentata*
93	*Pseudobelodina vulgaris vulgaris*
94	*Pterospathodus* aff. *P. cadiaensis*
95	*Pygodus anserinus*
96	*Pygodus serra*
97	*Pygodus* sp. indet.
98	*Rossodus manitouensis*
99	*Rossodus* n. sp.
100	*Rossodus* sp.
101	*Scolopodus bolites*
102	*Scolopodus floweri*
103	*Scolopodus leei*
104	*Spinodus ramosus*
105	*Stereoconus corrugatus*
106	*Teridontus nakamurai*
107	*Variabiloconus bassleri*
108	*Walliserodus australis*
109	*Walliserodus ethingtoni*
	OTHER FOSSILS
110	*Chancelloria* sp. (spongelike forms)
111	Acrotretid brachiopods
112	*Tcherskidium* n. sp. of Blodgett and others (1988) (brachiopod)
113	*Pelagiella* sp. (primitive mollusk)
114	*Homagnostus* sp. (agnostid trilobitomorph)
115	*Hystricurus*? *sainsburyi* (trilobite)
116	*Kounamkites* cf. *K. frequens* (trilobite)
117	*Plethometopus armatus* (trilobite)
118	Two-hole crinoid columnal

nation. Metachert and phyllite dominate the lower part of the unit and indicate a relatively quiet, starved basin setting; the highly carbonaceous nature of these rocks and the lack of an indigenous benthic fauna suggest that the basin was poorly oxygenated. Rare graded metasandstone layers are probable turbidites.

Metalimestone layers occur throughout the Snowden Creek unit but are thicker and more abundant in its upper part. Sedimentologic and faunal evidence demonstrate that most metalimestone layers are also probable turbidites, which were deposited against a "background" accumulation of fine-grained siliceous material (now metachert) and clay (now phyllite). Most calcareous layers are distinctly graded and form partial Bouma (1962) sequences (typically ABDE or BDE); the lack of a well-developed C division is common in carbonate turbidites (Scholle, 1971; Dumoulin, 1992).

Composition of the carbonate turbidites suggests their derivation from a variety of intrabasinal and extrabasinal sources and some changes in provenance with time. Lithic clasts include grains indicative of a deep-water origin, such as black phyllite and dolostone with radiolarian ghosts, and lithologies typical of a shallow-water carbonate-platform source, such as peloidal mudstone and bioclastic grainstone. Some clasts are rounded and irregular; these were probably still soft when deposited and thus derived from contemporaneous, intrabasinal strata. Other clasts are angular and contain calcite veins; these were fully lithified when eroded and infer an extrabasinal origin. Faunal evidence (discussed below) demonstrates that older, extrabasinal rocks have been eroded, reworked, and included in these turbidites. Calcareous extrabasinal sources appear to have been most important in the early history of the Snowden Creek unit; samples from lower in the unit contain more carbonate lithic clasts, whereas those in the upper part of the unit consist mostly of skeletal (echinoderm) debris and contain more quartz.

Paleoenvironmental interpretation of the elongate white marble bodies in the Snowden Creek unit is problematic because most retain little primary texture. Where original fabric can be discerned, it is typical of shallow-water sedimentary environments (peloidal-skeletal packstone or grainstone), and there are no structures, such as graded bedding, indicative of redeposition. Previous studies of metacarbonate rocks in northern Alaska (Dumoulin and Harris, 1987a, 1992) have demonstrated that shallow-water accumulations of skeletal grainstone are particularly susceptible to recrystallization and obliteration of primary texture. The marble bodies are much less carbonaceous than the rest of the Snowden Creek unit, are generally in gradational contact with intervals of darker metalimestone (turbidites), and occur predominantly in the uppermost part of the unit. Most of the marble bodies probably represent carbonate banks or shoals formed in situ on local highs that developed within the basin. Their concentration in the upper part of the unit suggests a shallowing-upward depositional regime. Small, shallow-water carbonate buildups, which pass laterally and vertically into basinal bituminous pelagic sediments, have been described from the Cretaceous of Mexico and the Middle East (Jenkyns, 1980; Wilson, 1975).

Conodont biofacies analysis supports the environmental interpretations outlined above. Conodonts from the Snowden Creek unit represent the protopanderodid-periodontid biofacies, which is characteristic of a cool- and (or) deep-water depositional environment. Assemblages from dolostone lenses in metachert (for example, fig. 3, loc. 31) include complete and well-preserved fragile elements; such elements could not have survived post-mortem transport and were probably deposited by simple settling from within the water column to the basin floor. Most conodonts from the Snowden Creek unit, however, come from carbonate turbidites; these assemblages are hydraulically sorted, and some include elements of anomalous age or biofacies introduced by redeposition. The coarser grained parts of these turbidites yield mostly large, robust protopanderodids (pl. 1, figs. 3, 4), whereas finer grained layers produce more delicate periodontids (pl. 1, figs. 8, 15). Several early Middle Ordovician faunas collected northeast of Snowden Mountain (fig. 3, loc. 18) include reworked conodonts of Late Cambrian and (or) Early Ordovician age, such as *Phakelodus tenuis*, *Cordylodus* spp., *Rossodus manitouensis*, and *"Scolopodus" gracilis* (fig. 8; pl. 1, figs. 21–24). In addition, although conodonts of cool-water biofacies dominate the Snowden Creek unit, some samples include a few forms typical of warmer, shallower water, such as belodinids (fig. 3, loc. 35), plectodinids, and *Prattognathus rutriformis* (fig. 3, loc. 22; pl. 1, fig. 6), that were transported seaward into a deeper water setting. All samples from the elongate marble bodies are barren.

Thus, Middle Ordovician strata in the Snowden Mountain area were deposited primarily in a poorly oxygenated, off-platform setting that received minor fine-grained siliciclastic detritus, as well as pulses of allodapic calcareous material derived from contemporaneous and older carbonate deposits rimming the basin. Carbonate input varied across the basin, but, in general, increased through time. Eventually, water depths shallow enough for in situ accumulation of calcareous shoals were achieved locally.

UPPER ORDOVICIAN AND SILURIAN ROCKS

The carbonaceous Middle Ordovician strata discussed above are structurally intercalated with, and locally grade up into, massive metacarbonate rocks (fig. 11*A*) assigned to the Skajit Limestone by previous workers (for example, Brosgé and Reiser, 1964). Dillon and others (1987a, 1988) reported the presence of Late Ordovician and Silurian(?) microfossils and megafossils from several thrust slices of "Skajit Limestone" north of Snowden Mountain and

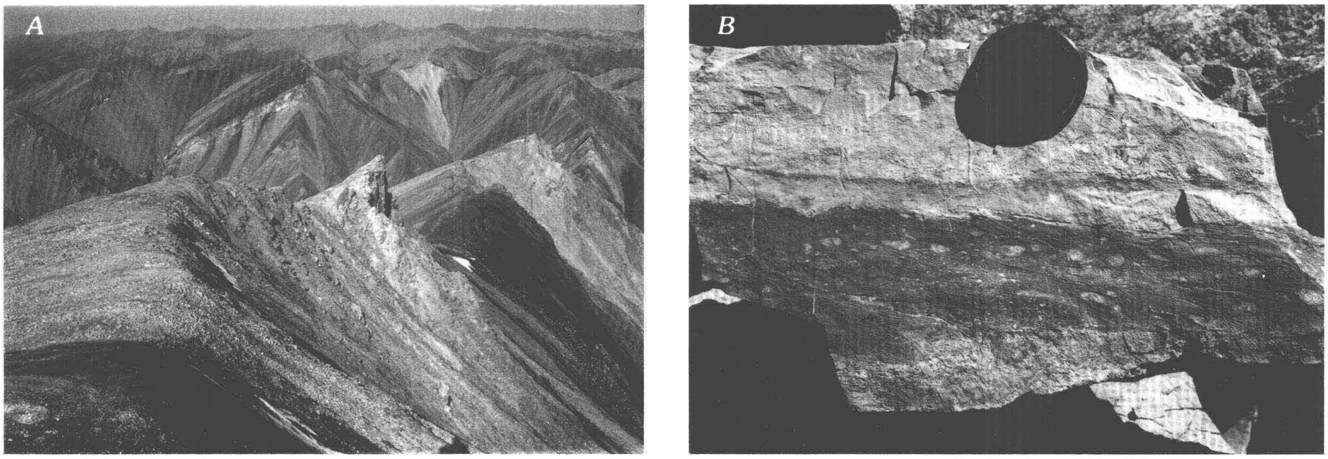


Figure 11. Sedimentary features of the Mathews River unit. *A*, Typical cliff-forming outcrops of massive dolostone and metalimestone located in the Chandalar D–6 quadrangle. *B*, Dark-weathering, fossiliferous, burrowed metalimestone overlain by light-weathering, thinly laminated dolostone (lens cap, 6 cm in diameter) (fig. 3, loc. 12). Bioturbated metalimestone beds produce more conodonts than other lithologies in this unit.

reassigned these rocks to their unit SOm. This unit was described as consisting of "massive gray marble and orange dolomite with local replacement bodies of black chert" (Dillon and others, 1988). Other massive carbonate outcrops in the Snowden Mountain area were still considered to represent the Skajit Limestone of Devonian age, however, which was described by Dillon and others (1988) as consisting mostly of "massive gray marble and dolomite," and subordinate carbonate conglomerate and minor pelitic, quartzose, and volcanic layers. Thus, discrimination of these two units on lithologic grounds is difficult.

Our studies confirm the Late Ordovician and Silurian age of unit SOm but also identify Late Ordovician and Silurian fossils in strata both north and south of Snowden Mountain that had been referred to the Skajit Limestone (Dsk) by Dillon and others (1987a, 1988). In addition, our collections produced fossils of definite and possible Devonian age from some occurrences of the Skajit Limestone (as mapped by Dillon and others, 1988). Various lines of evidence (discussed below) suggest that other outcrops of the Skajit Limestone may be pre-Late Ordovician in age. Massive carbonate bodies in the Snowden Mountain area probably represent dismembered pieces of a long-lived carbonate platform; individual thrust slices differ in age and the degree to which primary fabric has been preserved. In this paper, distinctive dolomitic metacarbonate rocks north and south of Snowden Mountain, including unit SOm and parts of unit Dsk of Dillon and others (1987a, 1988), are referred to as the Mathews River unit. All rocks assigned to this unit have yielded some fossils of Late Ordovician and (or) Silurian age. Massive metacarbonate rocks in which the distinctive lithologic features of the Mathews River unit have not been found are shown in figure 2 as PzЄd, Pzs, Pzw, or Pzt. Some of these strata may be facies equivalents of the Mathews River unit or parts of the Mathews River unit that have lost their distinctive lithologic features through metamorphism and (or) deformation. Other strata may be older or younger than the Mathews River unit. These rocks are discussed below as "Metacarbonate Rocks of Uncertain Age."

Most sections of the Mathews River unit are fault bounded as well as internally faulted and folded. A composite of several partial measured sections (fig. 3, locs. 6, 12, and 16) shows the unit to be at least 150 m thick. Stratigraphic relationships with other units may be discerned in the northern outcrop belt. At locality 11 (fig. 3), rocks of the Mathews River unit gradationally and apparently conformably overlie rocks of the Snowden Creek unit. At locality 6 (fig. 3), a thin layer of Devonian carbonate rocks overlies the Mathews River unit; the contact appears to be an unconformity but could be a fault. Carbonate rocks lithologically similar to these Devonian strata, but which have not yet been dated, overlie the Mathews River unit at several other localities.

LITHOLOGIES

Massive cliffs of orange and gray dolostone and metalimestone and lesser amounts of marble make up the Mathews River unit (fig. 11*A*). Some dolostone forms irregular masses that crosscut bedding, but most occurs as even, laterally continuous beds, which alternate with darker weathering metalimestone to produce the decimeter- to meter-scale color-banding characteristic of this unit (fig. 11*B*). Black chert constitutes 1 to 10 percent of some outcrops; it replaces skeletal material and forms irregular bands and stringers a few centimeters thick. Much of this unit is notably fetid, particularly those sections dominated by dolostone. Where original textures are best preserved, the Mathews River unit consists of four main lithologies, interbedded on a scale of a few centimeters to tens of meters. These lithologies are bioturbated metalimestone, parallel-laminated metalimestone, fossiliferous dolostone, and algal-laminated dolostone.

The first lithology is gray- to brown-weathering, medium-gray to black, locally dolomitic metalimestone, which forms slightly undulatory to nodular beds, 2 to 50 cm (mostly 5–15 cm) thick, separated by orange-weathering argillaceous partings (fig. 12*A*). Most beds show megascopic and microscopic evidence of bioturbation, ranging from an irregularly mottled fabric to a network of discrete burrows (fig. 12*B*). Mottled fabric typically consists of irregular ovoids and cylinders, one to a few centimeters across, in a darker matrix. Discrete burrows are light colored, a few millimeters in diameter, and subvertical; most have a *Chondrites*- or *Trichichnus*-like form. Both mottles and burrows are less dolomitic, less carbonaceous, and coarser grained than the surrounding material. Within a single bed, mottled fabric generally grades upward into an array of discrete burrows, which in turn decrease upward in size and abundance.

Bioturbated metalimestone is mostly skeletal wackestone and lesser packstone and mudstone, which may alternate on a scale of centimeters or decimeters. Matrix consists of micrite, locally slightly recrystallized (crystals 2–14 μm). Skeletal material constitutes 15 to 25 percent of most samples but reaches 60 to 80 percent and shows overly close packing in some millimeter- to centimeter-thick layers. Fossils in wackestone and mudstone intervals are mostly whole skeletons; shells are articulated and many are coated with and (or) partially replaced by pyrite. Bioclasts in packstone layers are commonly 3 mm or less in diameter, broken, abraded, and (or) disarticulated. Shelter porosity, filled with sparry calcite cement, and biogenic geopetal fabric (fig. 12*C*) are locally well developed in this lithology.

A relatively diverse fauna characterizes the bioturbated metalimestone intervals. Corals are locally abundant and include *Catenipora* sp. aff. *C. rubra* (T.E. Bolton, Geological Survey of Canada, written commun., 1992) (fig. 12*D*), halysitids, favositids (fig. 12*E*, *F*), and syringoporids (R.B. Blodgett and W.A. Oliver, Jr., U.S. Geological Survey, written commun., 1991). Most corals occur as isolated specimens, and biohermal concentrations were not observed. Other fossils include echinoderm debris, brachiopods (including pentamerids), mollusks, and bryozoans.

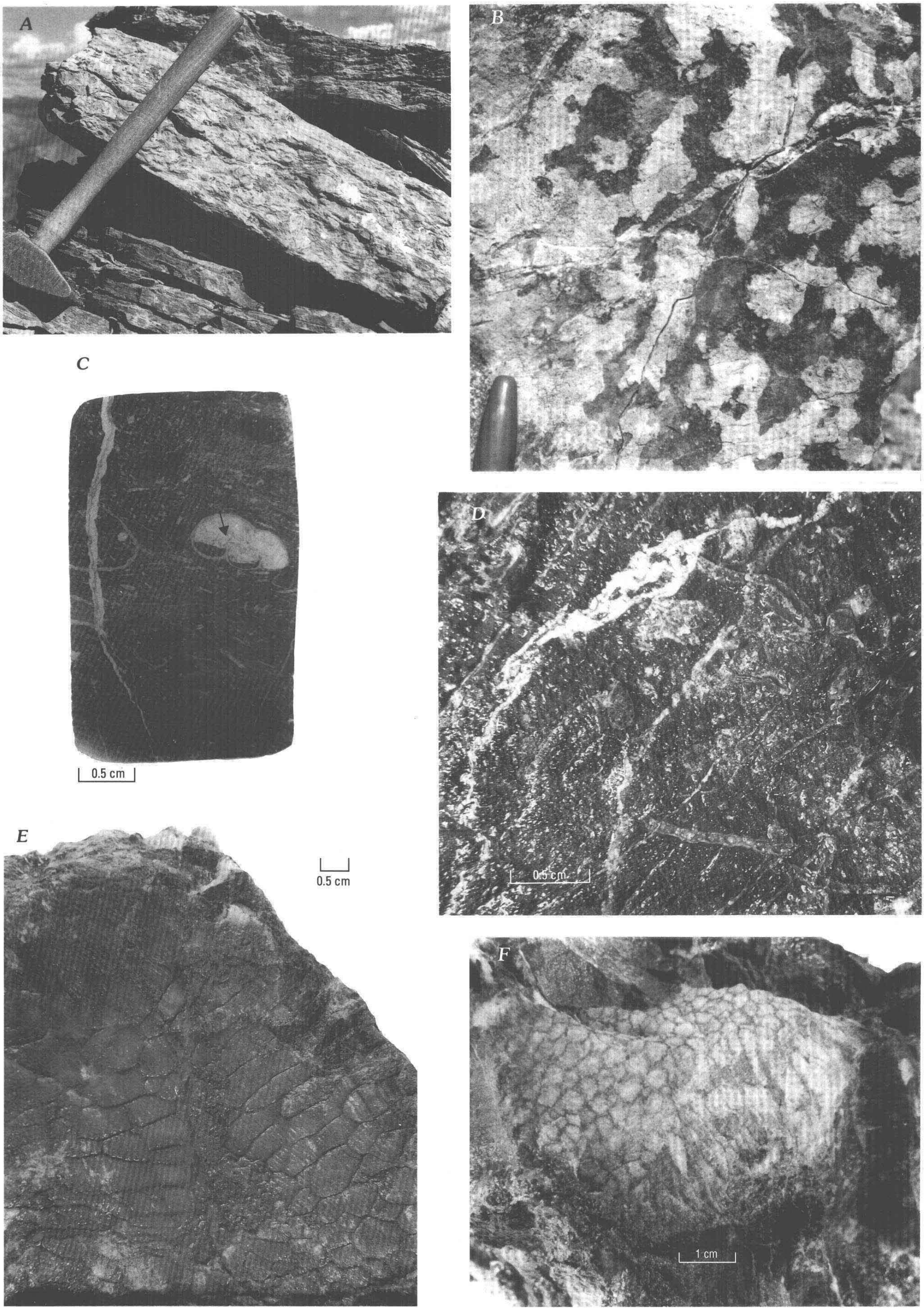
A second distinctive lithology is tan- to gray-weathering, gray metalimestone in even, parallel-laminated beds 2 to 5 cm thick; it forms subordinate intervals as much as 30 cm thick within intervals of bioturbated metalimestone. These beds consist of packstone and grainstone made up of silt- to fine-sand-sized skeletal material, peloids, and a few percent detrital quartz. Bioclasts are mostly broken, abraded, and not specifically identifiable. Laminae are made of concentrations of peloids alternating with bioclasts; peloidal layers are generally somewhat dolomitic.

Orange- to light-brown-weathering, dark-gray to black, locally calcitic dolostone in even, massive beds 20 cm to 3 m (typically 50 cm to 1 m) thick constitutes the third lithology. Most samples consist largely of euhedral to subhedral dolomite crystals 40 to 100 μm in size. Relict microtextures indicate that these rocks were sparsely bioclastic lime wackestone and mudstone prior to dolomitization (fig. 13*A*); a few to 20 percent silt- to sand-sized bioclasts are disseminated in the fine-grained matrix. In some samples, skeletal material has not been dolomitized; elsewhere, bioclast outlines are preserved as concentrations of organic material that crosscut dolomite crystal boundaries. Identifiable skeletal material in these beds consists mostly of ostracodes, including *Leperditia* sp. (Dillon and others, 1988), gastropods, dasycladacean algae (fig. 13*B*), and rare halysitid coral fragments. Locally, bioclasts have been bored or partly to completely micritized. A few to 10 percent disseminated peloids and oncoids occur in some samples. Peloids are ellipsoidal and average 0.2 mm in diameter; oncoids are oval, irregularly laminated, range from 0.5 to 2.0 mm in size, and are commonly partially pyritized.

The fourth lithology is beige-, pink-, orange-, or tan-weathering, light- to medium-gray, dolostone to dolomitic limestone; it forms even to slightly irregular beds 2 cm to 2 m (mostly 10–40 cm) thick. Many samples are finely laminated (fig. 13*C*) and contain fenestral fabric. Laminae are 0.2 to 1.0 mm thick, crinkled and irregular, form small-scale hummocks with as much as 0.5 cm of relief, and are interpreted as cryptalgal in origin. Fenestrae vary from horizontal, laminar forms to more irregular shapes; most are 2 to 3 mm in diameter. Sheet cracks, 0.5 to 2 mm by 1 to 2 cm, occur locally. Both fenestrae and sheet cracks are filled with relatively coarse, sparry calcite or dolomite.

Most of this lithology consists of finely crystalline (25–80 μm) dolomite, but some intervals are undolomitized or partially dolomitized and display excellently preserved original microtexture. Fenestrae in these rocks are surrounded by lime mud or fine-grained peloids; the peloids have locally coalesced into a flocculent, clotty mass (structure grumeleuse) in which individual grain outlines are difficult to discern (for example, Bathurst, 1976). The peloids are made of fine-grained calcite (crystals 2–20 μm),

Figure 12. Sedimentary features and megafossils of the ▶ Mathews River unit. *A*, Nodular-bedded, bioturbated metalimestone overlying parallel-laminated metalimestone (fig. 3, loc. 10) (hammer, 40 cm long). *B*, Mottled fabric produced by bioturbation (fig. 3, loc. 12) (pen tip, 3 cm long). *C*, Shelter porosity in bioclastic wackestone (fig. 3, loc. 6); gastropod shell (arrow) is filled with a thin layer of lime mudstone (dark) overlain by sparry calcite cement (light). *D–F*, Slabs of colonial corals in bioturbated metalimestone: *D*, *Catenipora* sp. aff. *C. rubra* (primitive halysitid coral) (fig. 3, loc. 6); *E* and *F*, Favositoid corals (fig. 3, locs. 12 and 16, respectively).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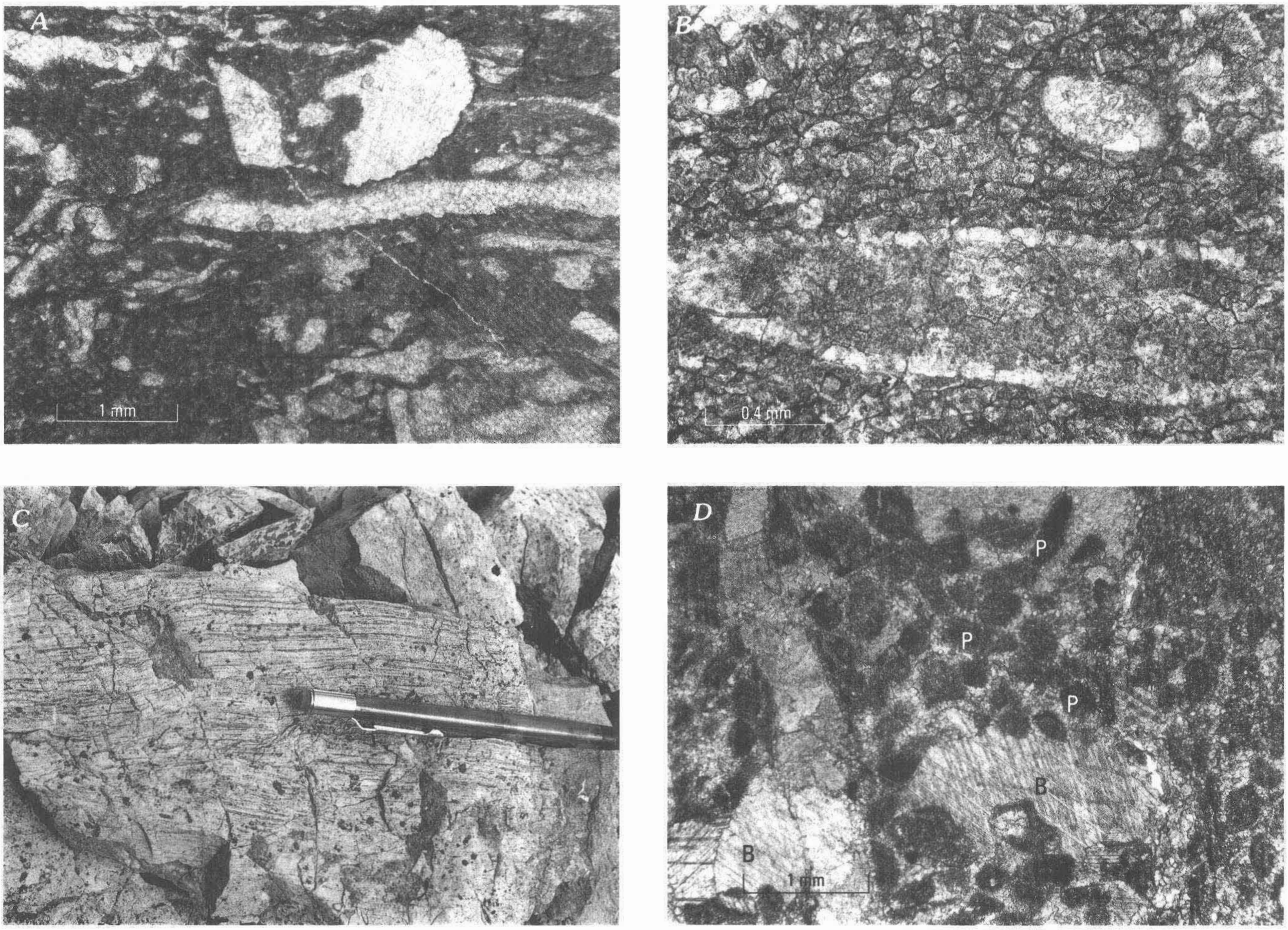


Figure 13. Fossils and sedimentary features of the Mathews River unit. *A*, Photomicrograph of typical texture of fossiliferous dolostone; bioclasts float in matrix of peloidal carbonate mud (fig. 3, loc. 12). *B*, Photomicrograph of dasycladacean algae in fossiliferous dolostone (fig. 3, loc. 13). *C*, Cryptalgal lamination in dolostone (fig. 3, loc. 8) (entire pencil, 14 cm long). *D*, Photomicrograph of peloidal, P, grainstone containing subordinate bioclasts, B (fig. 3, loc. 34).

have maximum diameters of 100 to 160 μm, and are uniformly ellipsoidal.

Laminae in this lithology are produced by alternations of lime micrite and fine-crystalline dolomite or by subtle variations in dolomite color or crystal size. Some samples contain a few percent disseminated bioclastic debris. In addition, relatively coarse grained peloidal and (or) bioclastic grainstone and packstone form local layers a few millimeters to several centimeters thick. Peloids in these layers are irregular to oval and are 0.1 to 0.8 mm in diameter (fig. 13*D*). Recognizable bioclasts include ostracodes and dasycladacean algae.

AGE AND BIOFACIES

The age of the Mathews River unit is constrained largely by conodonts, obtained from 26 samples at 17 localities (fig. 3; app. 1, locs. 6, 8–10, 12, 13, 16, 17, 34); 5 coral faunas from 4 localities provide additional age control. All four lithologies described above yield conodonts, but burrowed metalimestone is the most productive rock type. Conodont collections from all parts of this unit are dominated by the long-ranging genus *Panderodus*, which merely indicates a Middle Ordovician through Middle Devonian age. It is the sole constituent of five samples but elsewhere occurs with species that allow more precise age assignments. The oldest conodont samples (fig. 3, locs. 6, 8–10, 13; app. 1) contain *Phragmodus* n. sp. (fig. 8; pl. 2, figs. 20–24; =*Phragmodus* n. sp. of Barnes, 1974) and fewer *Plectodina*? cf. *P.*? *dolboricus* and are of Edenian to Maysvillian (early Late Ordovician) age. Two samples yield slightly younger faunas. One collection (fig. 3, loc. 12) consists exclusively of abundant, broken specimens of *Aphelognathus* aff. *A. divergens* and is Richmondian in age (fig. 8; pl. 2, fig. 16). A sample of peloidal dolostone (fig. 3, loc. 9) yielded *Ozarkodina* aff. *O. oldhamensis* and oulodontids (fig. 8; pl. 2, figs. 7–14) and is of very latest

Ordovician to Early Silurian age. The youngest conodont collections are Silurian in age; both Llandoverian to early Wenlockian (fig. 8; pl. 2, figs. 1–4) (fig. 3, locs. 16, 17) and Wenlockian to Ludlovian (pl. 2, figs. 5, 6) (USGS collns. 12069–SD, 12070–SD) faunas were found. Silurian samples contain rare pterospathodids, icriodellid fragments, oulodids, and ozarkodinids (including *O. excavata* and *O.* cf. *O. cadiaensis*), as well as ramiform and coniform elements of *Kockelella* and *Pelekysgnathus*, respectively (pl. 2, figs. 1–6). Coral collections from the Mathews River unit include *Catenipora* sp. aff. *C. rubra* of probable early Late Ordovician age (T.E. Bolton, written commun., 1992), *Tetradium*(?) sp. and halysitids of Late(?) Ordovician age, and *Mesofavosites*? sp. of probable Late Ordovician or Silurian age (Dillon and others, 1988).

Conodonts from the Mathews River unit represent warm, shallow-water biofacies. Late Ordovician collections are dominated by provincial forms, but Edenian to Maysvillian faunas have slightly different biogeographic affinities than Richmondian faunas. Edenian to Maysvillian collections consist mostly of Siberian-northern North American province elements (*Phragmodus* n. sp. and *Plectodina*? cf. *P.*? *dolboricus*). The single Richmondian sample is a monospecific collection of a western North American form, *Aphelognathus* aff. *A. divergens*.

DISTRIBUTION

The Mathews River unit crops out in several thrust sheets north, east, and southeast of Snowden Mountain. These sheets are intercalated with Devonian siliciclastic rocks, and, in the south, with metasedimentary rocks of uncertain age (fig. 2).

Conodont collections demonstrate that some sections of the Mathews River unit have been tectonically thickened, and other sections contain fault slices of younger units. At locality 9 (fig. 3), peloidal dolostone of latest Ordovician or Early Silurian age underlies crinoidal marble of early Late Ordovician age; sedimentologic criteria indicate that these strata are not overturned. At locality 12 (fig. 3), peloidal and algal-laminated dolostone of Richmondian age underlies at least 20 m of Frasnian metalimestone (Nutirwik Creek unit), which in turn underlies metalimestone and dolostone of Middle and Late Ordovician age.

DEPOSITIONAL ENVIRONMENT

The Mathews River unit was deposited in normal marine to slightly restricted, moderate to very shallow water environments. Sedimentologic and faunal evidence indicate that the major lithologies described above formed in specific settings on the middle to inner shelf. Bioturbated metalimestone and parallel-laminated metalimestone were deposited in open-marine conditions at moderate to shallow water depths. Fossiliferous dolostone accumulated in a somewhat restricted, shallower water environment. Algal-laminated dolostone formed in the most restricted and shallowest water setting.

Bioturbated metalimestone and subordinate beds of parallel-laminated metalimestone formed primarily below fair-weather wave base. These lithologies have features such as variable bed thickness, nodular bed form, abundant carbonate mud, and argillaceous partings that are characteristic (Wilson and Jordan, 1983) of middle shelf deposits. They contain a stenohaline macrofauna of corals, bryozoans, echinoderms, and brachiopods, indicating that open circulation and normal marine salinity prevailed during deposition. Bioturbated metalimestone is mostly "whole fossils wackestone" (usage of Wilson, 1975); the lime mud matrix and intact, unabraded skeletal material in these beds indicate deposition in relatively quiet water lacking "currents of removal" (Dunham, 1962). Mud-poor beds of bioclastic packstone and parallel-laminated metalimestone (containing broken and abraded skeletal debris, peloids, and quartz) most likely accumulated during storms and (or) in local shoals.

Fossiliferous dolostone formed in a shallower, more restricted environment than the rocks just described, probably on the inner shelf. The abundance of lime mud (now dolomitized) indicates a quiet depositional setting like that inferred for the bioturbated metalimestone, but the macrofauna includes few forms characteristic of normal marine conditions and is dominated by biota tolerant of restricted circulation (Wilson, 1975) such as ostracodes, gastropods, and dasycladacean algae. Some bioclasts are micritized, a process that most commonly occurs in the photic zone as a result of boring by endolithic algae (Bathurst, 1976). Local occurrence of oncoids and peloids in this lithology further supports the interpretation of a shallow-water, somewhat hypersaline depositional setting. Oncoids are biogenic encrustations, typically formed on soft substrates in moderate-energy environments (Wilson, 1975; Flügel, 1982). Oncoids disseminated in a micritic matrix, as well as pelleted mudstone and wackestone, typically occur in protected, somewhat restricted environments such as marine shelf lagoons (Wilson, 1975).

Sedimentary structures and fauna of the algal-laminated mudstone lithology indicate deposition in shallow subtidal to supratidal environments on the inner shelf (Wilson, 1975; Shinn, 1983; James, 1984). The association of algal mats, fenestral fabric, and sheet cracks is best developed and most commonly preserved in intertidal to supratidal settings (James, 1984). Modern and ancient shallow subtidal sediments consist largely of gray (reduced) pelleted muds that have been thoroughly bioturbated and lack primary sedimentary structures; storms introduce such sediments onto tidal flats, where they form layers a few millimeters to several centimeters thick that alternate with algal laminite (Shinn, 1983). Most peloids in the Mathews River unit are similar in size and shape to modern fecal pellets, but some grains are larger and (or) quite irregular and may be skeletal particles that are completely micritized (Bathurst, 1976). The sparse biota of the algal-laminated dolostone is consistent with deposition in an inner shelf setting. Megafossils are limited to ostracodes and algae, forms that are tolerant of restricted circulation and shallow water depths (Wilson, 1975).

Interpretations of the depositional environments of the Mathews River unit suggested by conodont biofacies agree with those outlined above that are based on sedimentary features. Collections from bioturbated metalimestone and fossiliferous dolostone contain variably abundant *Panderodus* associated with *Phragmodus* n. sp., *Plectodina*? cf. *P.*? *dolboricus*, and belodinids in Ordovician strata and with pterospathodids, icriodellid fragments, oulodids, ozarkodinids, and ramiform and coniform elements of *Kockelella* and *Pelekysgnathus* in Silurian strata. These assemblages indicate deposition in warm, relatively shallow water settings. Samples of clast-rich skeletal packstone and parallel-laminated metalimestone also produce *Phragmodus* n. sp. but consist chiefly of abraded, incomplete conodont fragments typical of high-energy depositional environments. Algal-laminated dolostone yields monospecific faunas of *Panderodus* sp. or *Aphelognathus* aff. *A. divergens* that are characteristic of warm, shallow-water, intermittently restricted environments.

Sedimentologic and paleontologic evidence indicates that fossiliferous dolostone and algal-laminated dolostone were deposited in shallow to very shallow water with locally restricted circulation, and this depositional setting probably accounts for the pervasive dolomitization of these lithologies. Dolomite in the algal-laminated lithology may be detrital and (or) authigenic; both types of dolomite are common on modern tidal flats (Shinn, 1983). Subtidal sediments in the Mathews River unit may have been dolomitized by reflux of Mg-rich surficial brines produced in nearby supratidal environments; this mechanism has been invoked by many authors to explain dolomitization of a variety of modern and ancient sediments.

The four major lithologies described and interpreted above occur throughout the Mathews River unit, but there is some spatial and temporal variation in their abundance. For example, bioturbated metalimestone is most abundant in the lower Upper Ordovician part of the unit, whereas fossiliferous dolostone and algal-laminated dolostone predominate in uppermost Ordovician and Silurian strata. Sedimentary features and conodont biofacies suggest that the shallowest, most restricted conditions prevailed during Richmondian time.

The Mathews River unit also contains small-scale lithologic cycles in both Ordovician and Silurian strata. A typical cycle is 50 cm to 5 m thick and consists of 20 cm to a few meters of burrowed, fossiliferous metalimestone overlain by a similar thickness of massive, sparsely fossiliferous dolomitic wackestone. The wackestone grades up into a thinner interval of algal-laminated, peloidal dolostone with fenestral fabric, which is in turn overlain by another bed of fossiliferous metalimestone. The cycles appear to have formed under shallowing-upward (regressive) conditions because transitions from bioturbated metalimestone to dolomitic wackestone, and from dolomitic wackestone to cryptalgal dolostone, are generally gradational, whereas those from cryptalgal dolostone to fossiliferous metalimestone are commonly abrupt.

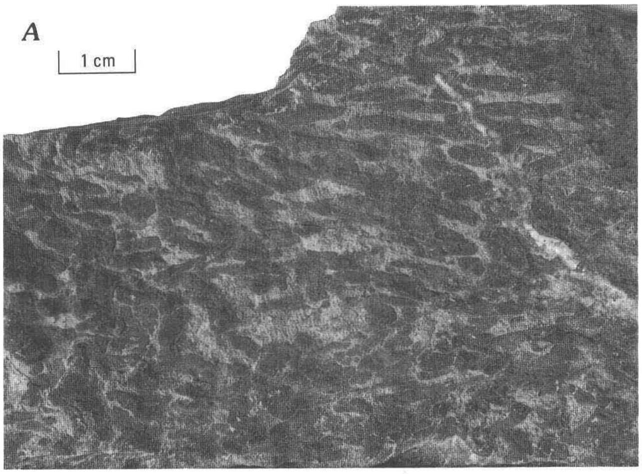
LOWER AND (OR) MIDDLE DEVONIAN ROCKS

Rocks of confirmed Early or Middle Devonian age are rare in the study area, but Emsian and (or) Eifelian marble and metalimestone crop out 4.5 km east of Nutirwik Creek (fig. 3, loc. 6). At this locality, a small lens, 10 to 15 m thick, of Lower and (or) Middle Devonian strata unconformably overlies, or is faulted above, carbonate rocks of the Mathews River unit. These Devonian rocks are strongly deformed, lineated, and flattened, but relict sedimentary textures are locally preserved.

Devonian rocks at locality 6 consist of yellow-weathering, cliff-forming marble with layers 50 cm to 2 m thick of dark-gray to black metalimestone and rare pink- to orange-weathering, medium-gray dolostone. Relict textures preserved in metalimestone include peloidal-bioclastic packstone and wackestone; bioclasts are chiefly crinoid columnals and coral debris. The most distinctive relict texture occurs near the base of the section and consists of packstone rich in aligned sticklike forms that do not branch and are probably amphiporid stromatoporoids (fig. 14). Individual sticks are 1 to 4 mm in diameter, as much as 3 cm in length, and contain an internal network of 0.2-mm pores; details of original wall structure have been destroyed by recrystallization. Similar packstone, rich in sticklike forms and crinoids, structurally (and stratigraphically?) overlies the Mathews River unit at several other sites (fig. 3, locs. 7, 8, and 14) and may be correlative with packstone at locality 6. Fossils and sedimentary structures in all these strata indicate a shallow-water depositional environment.

Two-hole crinoid columnals in the rocks at locality 6 restrict their age to the Emsian and (or) Eifelian (late Early and (or) early Middle Devonian) (R.B. Blodgett, oral commun., 1990). These rocks are more likely of Emsian than Eifelian age. Our experience in northern Alaska indicates that two-hole crinoid columnals most often occur in rocks of Emsian age and are unlikely to occur in rocks younger than early Eifelian in age. Conodonts from locality 6 (USGS colln. 12064–SD) merely indicate a Silurian through Middle Devonian age. Samples taken for conodonts from the other localities noted above yielded only *Panderodus* sp. (Middle Ordovician to Middle Devonian) or were barren.

A



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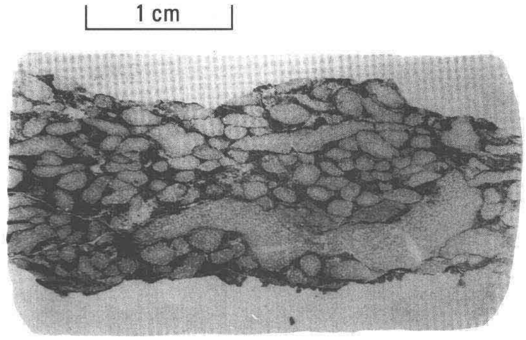


Figure 14. Aligned sticklike organic forms (probable amphiporid stromatoporoids) in Emsian or Eifelian metalimestone (fig. 3, loc. 6). *A*, Slab. *B*, View of thin section in reflected light.

METACARBONATE ROCKS OF UNCERTAIN AGE

Massive metacarbonate rocks that lack the lithologic characteristics of the Mathews River unit crop out throughout the study area; they occur in fault slices in the vicinity, from south to north, of Wiehl, Dillon, Snowden, and Table Mountains (Pzw, PzPd, Pzs, and Pzt, fig. 2). These rocks are undated or contain fossils indicative of a relatively broad age range; some may be correlative with the Mathews River unit, but others may be older or younger. Some of these rocks possess distinctive sedimentary features, but most have retained little primary fabric. Lithologic and age information for these rocks is summarized by geographic area below.

WIEHL MOUNTAIN AREA

Metacarbonate rocks at Wiehl Mountain are lithologically similar to the Mathews River unit and yield fossils permissive, but not diagnostic, of correlation with the Mathews River unit. But the Wiehl Mountain area metacarbonate rocks are locally intercalated with noncarbonate lithologies not seen in the Mathews River unit and so are discussed separately here.

Metacarbonate rocks make up the main massif of Wiehl Mountain and continue east at least 10 km. They are in thrust contact with calcschist to the east, other metacarbonate rocks to the northwest, and the Snowden Creek unit and other metasedimentary rocks to the south. Marble is the major lithology; it is white to dark gray, white to orange to gray weathering, fine to medium crystalline and forms prominent cliffs. Local color lamination on a millimeter to centimeter scale reflects variation in purity and crystal size; darker laminae contain more mica and carbonaceous material and are finer grained. Layers of pink- to orange-weathering, light- to dark-gray dolostone a few centimeters to several meters thick form recessive zones or saddles.

Relict sedimentary textures are preserved in some metalimestone and dolostone layers. Lime packstone and wackestone containing peloids and (or) bioclasts occur at several localities on the west and north sides of Wiehl Mountain; identifiable skeletal debris in these rocks consists of echinoderm and brachiopod fragments. Color mottling, probably produced by bioturbation, characterizes some dolostones. Other dolomitic layers preserve cryptalgal lamination and fenestral fabric. These sedimentary structures are like those found in the Mathews River unit and indicate a shallow subtidal to peritidal depositional environment.

Several types of metaigneous rocks are intercalated with the massive metacarbonate rocks at Wiehl Mountain. Brosgé and Reiser (1964) noted four elongate bodies of albite-epidote-chlorite-muscovite schist (Dgs) on the east side of the mountain. Dillon and others (1987b) reported bimodal volcanic rocks in this area; their "Llama Creek" sequence includes felsic flows, tuffs, and breccias, as well as mafic greenschists. These authors obtained a U–Pb isotopic age of 396 Ma (middle Early Devonian, based on Bally and Palmer, 1989; Harland and others, 1990) from a felsic flow on Wiehl Mountain and suggested that mafic and felsic rocks in this region are coeval.

We observed both felsic and mafic metavolcanic rocks intercalated with the metacarbonate rocks at Wiehl Mountain (fig. 15*A*). Rubble of gray metarhyolite, containing phenocrysts of potassium feldspar and plagioclase, was found at one locality. Elsewhere, reddish-brown to green altered tuff forms centimeter- to meter-thick layers in marble; these layers consist mostly of fine-grained, felty masses of mica, clay, and carbonate that retain relict shard textures. Larger bodies (to 40 m thick) of green to greenish-gray, andesitic to basaltic metavolcanic rocks are locally schistose but elsewhere preserve diabasic textures and chilled margins.

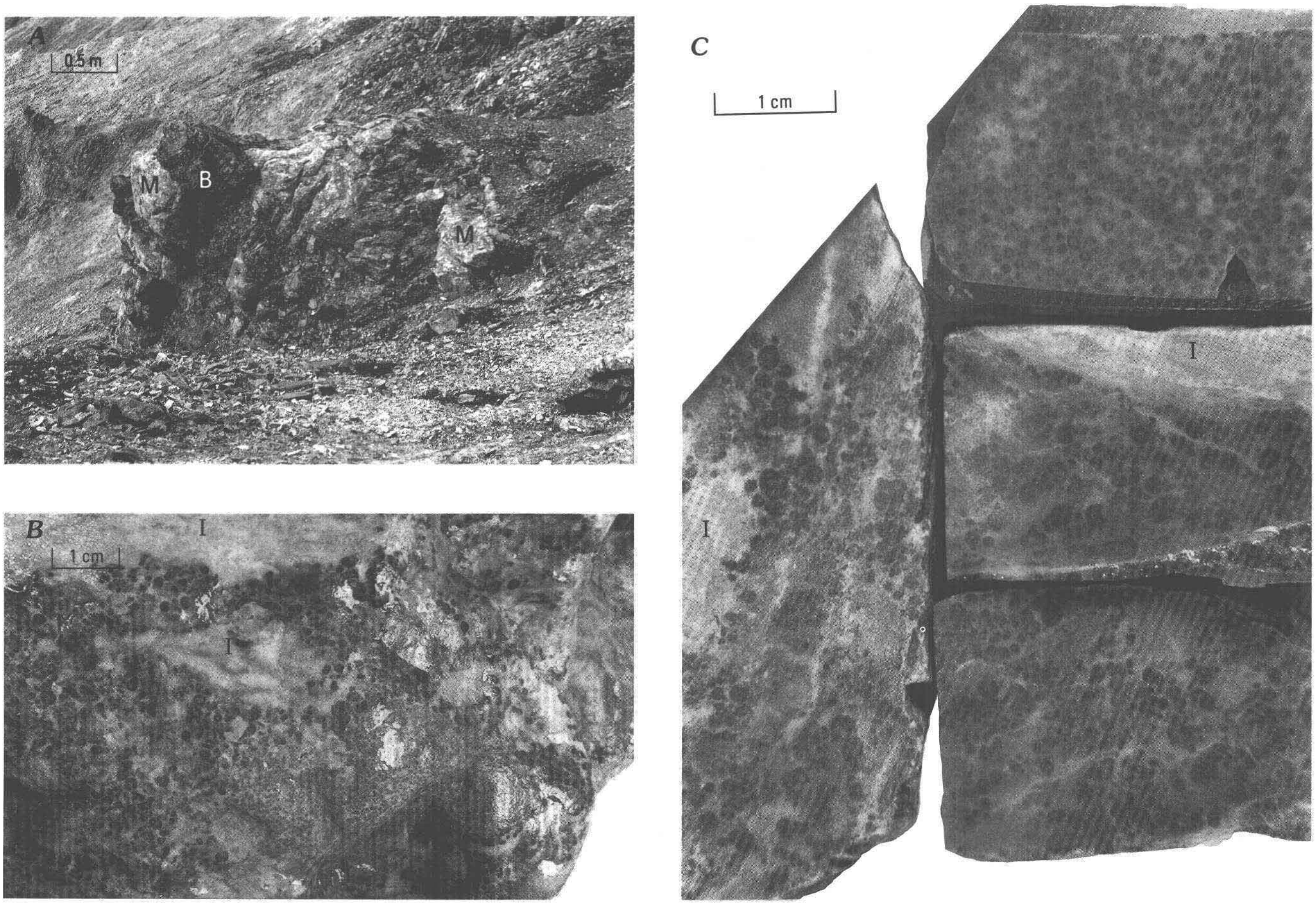


Figure 15. Sedimentary features of metacarbonate rocks of uncertain age. *A*, Marble, M, intercalated with, B, basaltic metavolcanic rocks, northeast side of Wiehl Mountain. *B* and *C*, Slabs showing coated grains and intraclasts with cryptalgal laminae, I, in dolomitic metalimestone, metacarbonate rocks of Dillon Mountain area (fig. 3, loc. 37).

Conodonts indicate an age of Middle Ordovician to Middle Devonian for the metacarbonate rocks at Wiehl Mountain. Black peloidal dolostone on the southwest side of the mountain produced *Panderodus* sp. and a fragment of *Ozarkodina*? sp. indet., denoting a Late Ordovician to Middle Devonian age and a normal-marine, shallow-water depositional environment (USGS colln. 11961–SD). A sample of dolomitic marble taken 1.5 km to the northeast yielded only *Panderodus* sp., indicating a Middle Ordovician to Middle Devonian age (field no. 89AD14A). Two other samples from the Wiehl Mountain metacarbonate rocks were barren.

DILLON MOUNTAIN AREA

Metacarbonate rocks that crop out in the vicinity of Dillon Mountain have certain lithologic features that distinguish them from all other rocks in the study area. They occur in a northeast-trending fault slice that extends at least 15 km from Sukakpak Mountain east to the Mathews River and that is imbricated with metacarbonate rocks to the south and east and calcschist to the north and west. Stratigraphic thickness of this sequence appears to be several hundred meters, but the section may have been tectonically thickened. The rocks are strongly deformed; isoclinal folds are obvious in outcrop.

Major lithologies are marble, dolomitic marble, and dolostone, with rare, meter-thick layers of orange- or green-weathering, calcareous or chloritoid-bearing, quartzose metasedimentary rocks. Most marble is light-gray weathering, white, medium crystalline, and relatively pure; it forms massive cliffs cut by irregular, flaggy foliation planes. Some intervals are distinctly color-banded on a scale of a few millimeters to several meters; the banding is produced by layers of dark-gray micaceous or dolomitic marble, or of orange or gray dolostone. Relict primary features are rare in marble and consist mainly of local parallel to low-angle cross lamination defined by quartz-rich laminae a few millimeters to 2 cm thick. However, sedimentary textures are preserved in many dolomitic layers; these layers consist of grainstone to wackestone made up of a variety of coated grains (fig. 15*B*, *C*).

Coated grains occur in layers 0.5 to 5 cm thick and consist both of ooids and oncoids (usage of Flügel, 1982). Ooids in these rocks are relatively homogeneous in size (average diameter 1.0 mm) and shape (spherical to ellipsoidal) and contain smooth, multiple, concentric laminae. Oncoids vary in size (0.5–3 mm), are more irregular in form, characterized by uneven laminae, and include some composite grains with multiple nuclei. Both sorts of coated grain generally occur in grain support, but some layers contain 20 percent or fewer grains floating in a finely crystalline matrix. Most of the coated grains in these rocks consist of polycrystalline dolomite in a calcite matrix; locally, both grains and matrix are dolomite. Concentric lamination within these dolomite masses is preserved as a palimpsest texture that crosscuts individual dolomite crystals. Coated-grain-bearing layers are most abundant in the lower third of the Dillon Mountain section (for example, fig. 3, loc. 37). A few layers in this interval contain crinkly, hummocky lamination of probable cryptalgal (stromatolitic) origin; cryptalgal laminite also occurs as elongate intraclasts in some coated-grain-rich layers (fig. 15*B*, *C*).

Preserved sedimentary features indicate a peritidal depositional environment for the Dillon Mountain area metacarbonate rocks. Ooids form through inorganic chemical precipitation in warm, wave-agitated saline or hypersaline waters; oncoids are produced by biogenic encrustation, typically by algae or cyanobacteria (Wilson, 1975; Flügel, 1982). Modern ooids and oncoids form in warm, shallow shelf areas of moderate to high wave and current activity; oolitic sands generally occur in waters less than 10 m deep (Choquette, 1978). As noted above, algal mats are most common in intertidal to supratidal settings (James, 1984), particularly in Paleozoic or younger rocks.

Other than oncoids and cryptalgal laminae, no organic structures have been found to constrain the age of the Dillon Mountain area metacarbonate rocks. Several samples were taken for conodonts, but all were barren. Similar carbonate sequences containing abundant coated grains (ooids and oncoids) and stromatolites but lacking other organic remains occur in the western Brooks Range (unnamed units described by Dumoulin, 1988) and in the northeastern Brooks Range (Katakturuk Dolomite; Clough, 1989; Clough and others, 1990). These rocks are thought to be of Late Proterozoic and (or) earliest Paleozoic age in the western Brooks Range (Dumoulin, 1988) and of Proterozoic age in the northeastern Brooks Range (Blodgett and others, 1986).

SNOWDEN MOUNTAIN MASSIF

Massive metacarbonate rocks make up the main massif of Snowden Mountain and are in probable fault contact with Cambrian rocks (Snowden Mountain unit) to the northwest, Upper Ordovician and Silurian metacarbonate rocks (Mathews River unit) to the northeast, Middle Ordovician phyllite and metalimestone (Snowden Creek unit) to the southwest, and metacarbonate rocks of uncertain age (Dillon Mountain area metacarbonate rocks) to the south (fig. 2). Little sedimentologic or paleontologic information has been recovered from the Snowden Mountain massif metacarbonate rocks, at least in part because the steep and rugged terrain has limited helicopter access. No lithologic or biostratigraphic data yet obtained permit definitive correlation of these rocks with any of the metacarbonate units described above; available fossil collections indicate that strata of several ages are present.

Most of the Snowden Mountain massif metacarbonate rocks examined are light-gray-weathering, white to light-gray, fine- to medium-crystalline marble exposed in sheer cliff faces. Some marble is color laminated and contains rare echinoderm debris. Subordinate intervals of pink- to beige-weathering, medium- to dark-gray dolostone preserve relict sedimentary features, including sheet cracks and fenestral fabric.

No megafossil-based ages are reported from massive metacarbonate rocks making up the Snowden Mountain massif, and samples taken for conodonts have been mostly unproductive. Dillon and others (1988) reported three collections from the southern, central, and northern parts of the massif, as well as two barren samples. The southernmost collection was made along Snowden Creek in massive metacarbonate rock 7 m from the contact with black phyllite of the Snowden Creek unit; it yielded a meager fauna of probable late Early through early Middle Ordovician (middle Arenigian through Llanvirnian) age (USGS colln. 9905–CO; fig. 3, loc. 24; loc. 13 of Dillon and others, 1988). A sample of marble about 2 km to the northwest, however, produced a single deformed conodont of Silurian through Mississippian morphotype (fig. 3, loc. 23; loc. 16 of Dillon and others, 1988). The northernmost collection came from massive dolostone 5 m above the contact with Cambrian rocks and consists of a single fragment of Ordovician through Triassic age (fig. 3, loc. 21; loc. 20 of Dillon and others, 1988). Three samples taken from the massif during the present study were barren.

TABLE MOUNTAIN AREA

Massive metacarbonate rocks in the Table Mountain area have some lithologic similarities to the Mathews River unit but include little or no dolostone and have produced no fossils diagnostic of a Silurian or older age. These rocks crop out from the Hammond River northeast to Table Mountain (fig. 3) and make up several thrust sheets imbricated with Devonian siliciclastic rocks (fig. 2).

Table Mountain area metacarbonate rocks are mostly cliff-forming, light- to medium-gray marble and lesser medium- to dark-gray metalimestone; relict sedimentary textures are rare and consist of skeletal-peloidal wackestone and packstone. Recognizable bioclasts are chiefly echinoderm columnals but include brachiopods, ostracodes, and stromatoporoid and bryozoan fragments. Peloids range from 30 to 200 μm in diameter and are rounded to ellipsoidal.

Few fossils have been found to constrain the age of these rocks. Megafossils are poorly preserved; collections from two localities east and southeast of Table Mountain are of Silurian or Devonian age (Brosgé and Reiser, 1964, their locs. 9 and 10). Conodonts are scarce and nondiagnostic. Of seven samples taken during our study, two produced fragments indicative of an Ordovician through Permian or Triassic age (field localities 89TM290A and 90TM468C, respectively), and five were barren. Dillon and others (1988) reported three barren samples from these rocks (their locs. 45, 49, and 62).

SUMMARY OF THE METACARBONATE SUCCESSION IN THE SNOWDEN MOUNTAIN AREA

The massive metacarbonate rocks and subordinate associated lithologies described above represent a pre-Carboniferous stratigraphic succession that has been metamorphosed, deformed, and dismembered by thrust faults. This succession encompasses distinct lithologic units of relatively well-constrained ages, as well as other units of uncertain age. Figures 6 and 8 summarize stratigraphic relationships of well-dated units in the Snowden Mountain area; figure 16 attempts to integrate units of uncertain age within this framework and presents several alternative stratigraphic hypotheses.

Well-dated units in the Snowden Mountain area metacarbonate succession are the Snowden Mountain unit (Middle Cambrian), the Snowden Creek unit (Middle Ordovician), the Mathews River unit (Upper Ordovician through Silurian), and unnamed Lower and (or) Middle Devonian metalimestone. Most contacts between these units are faults, but some contacts between the Snowden Creek and Mathews River units may be depositional, and the contact between the Mathews River unit and overlying Lower and (or) Middle Devonian metalimestone may be an unconformity.

Units of uncertain age but that, by virtue of spatial association and lithologic correlation, also appear to be part of the Snowden Mountain area metacarbonate succession are the metacarbonate rocks of the Wiehl Mountain area, the Dillon Mountain area, the Snowden Mountain massif, and the Table Mountain area. All of these units (with the possible exception of Snowden Mountain massif strata) are fault bounded. All consist of massive metacarbonate rocks generally similar to, but not as dolomitic as, those that make up the Mathews River unit, and all contain some organic remains. Stratigraphic integration of these units within the Snowden Mountain area metacarbonate succession is attempted in figure 16 and is constrained by fossils, lithologic considerations, and local and regional relationships.

The Dillon Mountain area metacarbonate rocks have produced no organic remains other than algal structures (stromatolites, oncolites). Such forms are known from strata of Archean to Holocene age but are most common in Proterozoic rocks (Krumbein, 1983). Both algal lamination and coated grains are found in Paleozoic strata in the Snowden Mountain area; stromatolites occur in tidal-flat facies of the Upper Ordovician through Silurian Mathews River unit, and coated grains (ooids) make up one bed in the Upper Devonian Hunt Fork Shale (discussed below). However, these occurrences also include other fossil debris; algal laminites in the Mathews River unit contain local ostracodes and are interlayered with coral-bearing metalimestone, and ooid grainstone in the Hunt Fork Shale contains brachiopod and echinoderm fragments in addition to coated grains. Strata elsewhere in northern Alaska that contain only algal forms and no other fossils, such as the Katakturuk Dolomite in the northeastern Brooks Range and unnamed rocks in the western Brooks Range, are thought, on the basis of regional relationships and isotopic data, to be of Proterozoic age in the northeastern Brooks Range (Blodgett and others, 1986; Clough and others, 1990) and Late Proterozoic age and (or) Early Cambrian age in the western Brooks Range (Dumoulin, 1988; Till, in press).

We propose that the Dillon Mountain area metacarbonate rocks correlate with other stromatolitic, coated-grain-bearing units in the Brooks Range and infer an age of Proterozoic and (or) Early Cambrian for them. If this inference is correct, the Dillon Mountain area metacarbonate rocks predate the Middle Cambrian Snowden Mountain unit and constitute the basal part of the Snowden Mountain area metacarbonate succession. The Snowden Mountain unit has so far been recognized in only one area, more than 10 km north of the northernmost outcrops of the Dillon Mountain area metacarbonates, so the original stratigraphic relationship between these two units cannot directly be assessed. Did strata of the Snowden Mountain unit originally accumulate on the Dillon Mountain area metacarbonate rocks? Or did spatially associated rocks of unknown age, such as the calcschist exposed north and west of Dillon Mountain (included in unit P̶zmu, fig. 2), originally overlie the metacarbonate rocks and underlie the Snowden Mountain unit? Further mapping and structural analyses are needed to resolve this problem.

Metacarbonate rocks of the Snowden Mountain massif retain little relict texture and have yielded few fossils. Meager conodont collections of (from north to south) Ordovician through Triassic, Silurian through Mississippian, and late Early through early Middle Ordovician age are known (fig. 3, locs. 21, 23, and north end of 24). The

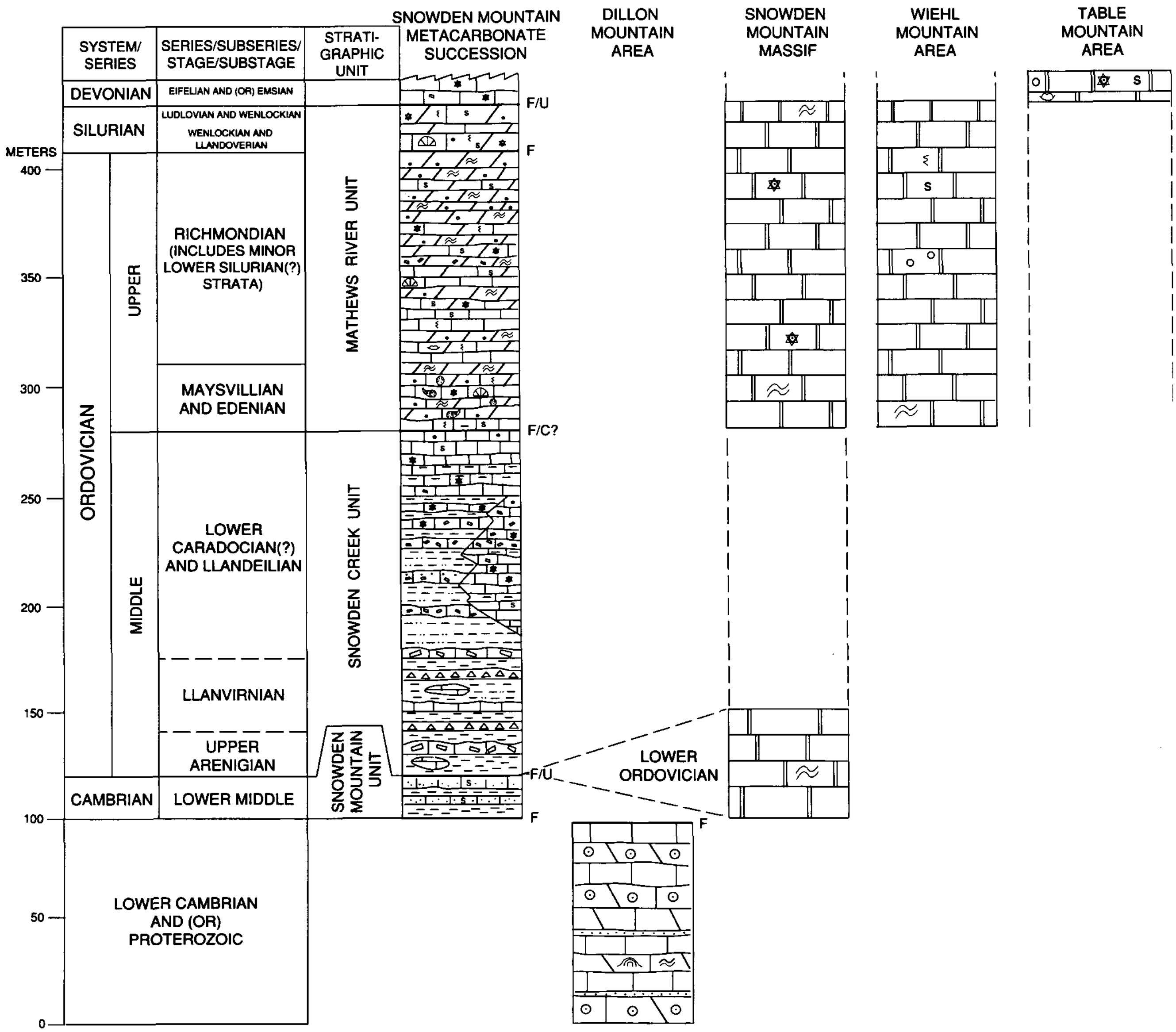


Figure 16. Hypothetical stratigraphic position of units of uncertain age within the metacarbonate succession in the Snowden Mountain area. Parts of columns with symbols indicate preferred correlation. Thicknesses are minima, particularly for Upper Ordovician and Silurian rocks. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American province faunas. See figure 5 for explanation of symbols.

Snowden Mountain massif metacarbonate rocks structurally overlie Middle Cambrian rocks of the Snowden Mountain unit to the north and structurally underlie Middle Ordovician rocks of the Snowden Creek unit to the south, but the exact nature of these contacts is disputed. Dillon and others (1988) included the Snowden Mountain massif metacarbonate rocks in their Skajit Formation, which they considered to be of Devonian age, and interpreted the northern contact as an unconformity and the southern contact as a fault. However, T.E. Moore (written commun., 1991) suggested that the southern contact may be depositional, and we observed some evidence (discussed above) that the northern contact is a fault.

The stratigraphic position of the metacarbonate rocks of the Snowden Mountain massif is thus uncertain, and it is possible that rocks of several ages are included within this unit. Two hypotheses are most compatible with the available data. In the first, the Snowden Mountain massif metacarbonate rocks depositionally overlie Middle Cambrian rocks, depositionally underlie Middle Ordovician strata, young from north to south, and are of Early to earliest Middle Ordovician age. In this interpretation, the lower age of the unit is limited by the Ordovician-Triassic conodont fragment obtained just above the contact with Middle Cambrian rocks, the upper age is constrained by the late Early through early Middle Ordovician age of the fauna collected just below the contact with Middle Ordovician rocks, and the Silurian-Mississippian collection must be attributed to a fault sliver of younger rocks.

A second possibility is that the Snowden Mountain massif metacarbonate rocks are a facies equivalent of the Mathews River unit and are of Late Ordovician through Silurian age; they could also be Devonian in age, as suggested by Dillon and others (1988). In this interpretation, the northern contact could be a fault or an unconformity, but the southern contact must be a fault. This hypothesis is compatible with two of the three fossil collections from these strata; conodonts of late Early through early Middle Ordovician age from locality 24 (fig. 3) must be reworked or produced by a sliver of the Snowden Creek unit.

The metacarbonate rocks in the Wiehl Mountain and Table Mountain areas have some lithologic similarities to the Mathews River unit and contain rare fossils of Ordovician to Devonian and Silurian to Devonian age. These data are compatible with, but not diagnostic of, correlation with the Mathews River unit and assignment of a Late Ordovician and Silurian age. Available evidence also permits the interpretation that these rocks are, at least in part, of Devonian age, and they could be entirely younger than the Mathews River unit. Metaigneous rocks like those intercalated with the Wiehl Mountain area metacarbonate rocks have not been noted in the Mathews River unit or in any of the other metacarbonate units discussed above. The Table Mountain area metacarbonate rocks occur north of all other metacarbonate units and are intimately associated with Devonian siliciclastic rocks, particularly those of the Nutirwik Creek unit.

Thus, the Snowden Mountain area metacarbonate succession includes rocks of Middle Cambrian, Middle Ordovician, Late Ordovician, Silurian, and Early and (or) Middle Devonian ages; less well dated parts of the succession may be Proterozoic and (or) Early Cambrian and Early Ordovician in age. Shallow-water shelf or platform deposition occurred during Proterozoic and (or) Early Cambrian, Early Ordovician(?), Late Ordovician and Silurian, and Early and (or) Middle Devonian time; outer-shelf to basinal environments prevailed during Middle Cambrian and Middle Ordovician time. Faunal and lithologic evidence indicate that the deepest water (most basinal) settings existed during the early Middle Ordovician, whereas the shallowest, most restricted depositional regimes existed in the latest Ordovician. Fossils with specific biogeographic affinities found in this succession include Middle Cambrian trilobites and early Late Ordovician conodonts with Siberian affinities, an early Late Ordovician cateniporid coral with Canadian Arctic affinities, and latest Ordovician conodonts with western North American affinities. Fossils of Middle Ordovician, Silurian, and Devonian ages (mainly conodonts) are chiefly cosmopolitan.

DEVONIAN METACLASTIC ROCKS

The pre-Carboniferous Paleozoic metacarbonate rocks described above are structurally juxtaposed with Devonian metaclastic rocks throughout the Snowden Mountain area (fig. 17*A*). These metaclastic rocks consist of the Hunt Fork Shale (Chapman and others, 1964), the Beaucoup Formation (Dutro and others, 1979; Dillon and others, 1988), and the Nutirwik Creek unit (Aleinikoff and others, 1993).

All three units consist chiefly of fine-grained siliciclastic rocks with subordinate layers and lenses of metalimestone and include distinctive subordinate lithologies. The units are further distinguished by characteristic carbonate lithofacies and conodont biofacies. Conodonts obtained from limy layers demonstrate that the three metaclastic units are at least in part correlative and in part of Frasnian age.

Our study concentrated on metalimestone intervals within the metaclastic units and was less detailed than our work on the metacarbonate sequence. The descriptions below are based on reconnaissance outcrop observations and petrologic and paleontologic analyses of spot samples; sections were not measured in the metaclastic units.

BEAUCOUP FORMATION

In the Snowden Mountain area, the Beaucoup Formation consists chiefly of gray slate and phyllite with lesser amounts of quartz-muscovite schist and local mafic intrusions. Limy layers are relatively abundant and constitute 5 to 30 percent of most sections; they are more abundant in outcrops in the southern part of the study area. Some metalimestone bodies are tens of meters thick and as much as 6 km long (Dillon and others, 1988), but most are smaller (2–30 m thick, a few tens of meters long) and distinctly lens shaped.

CARBONATE LITHOLOGIES

The most southerly exposures of the Beaucoup Formation in the study area, in the vicinity of the sharp bend in the Hammond River (figs. 2 and 3), are strongly recrystallized and retain little relict texture. Carbonate layers in these rocks consist of fine- to medium-crystalline marble with minor amounts of detrital quartz and rare brachiopod fragments.

Elsewhere in the Snowden Mountain area, original textures of the Beaucoup Formation are better preserved, and carbonate bodies consist of two main types. The first is mostly gray-weathering, dark-gray to black, fine-grained lime mudstone, wackestone, and lesser packstone, in mound-shaped lenses 3 to 30 m thick (fig. 17*B*). These rocks are generally massive but contain irregularly spaced gray to orange phyllitic partings and local mottled zones produced by bioturbation. Most bodies are texturally and compositionally heterogeneous and tend to be darker, finer

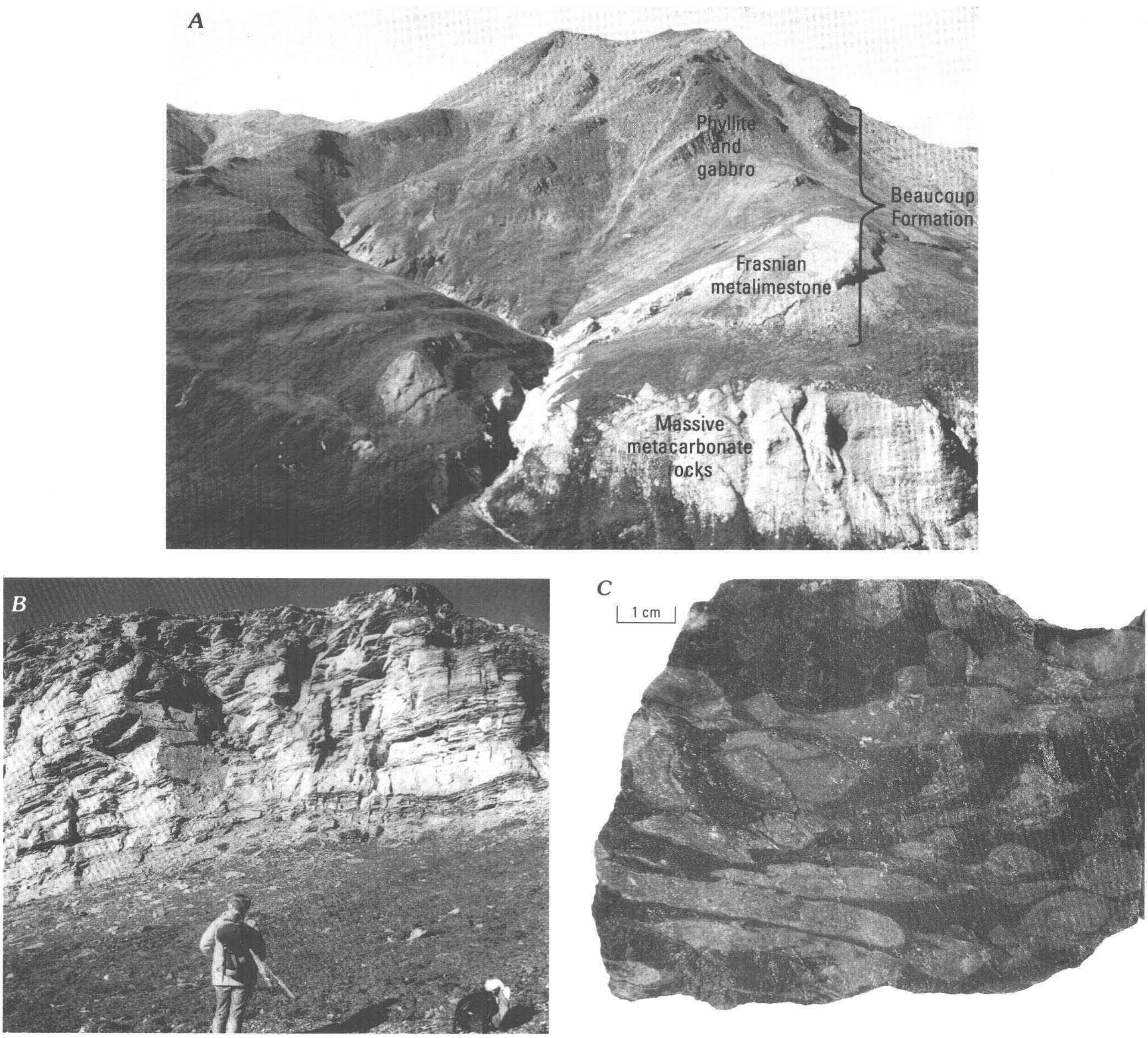


Figure 17. Features of the Beaucoup Formation. *A*, Beaucoup Formation, including phyllite, gabbro, and Frasnian metalimestone, overlies massive metacarbonate rocks (photograph by T.E. Moore). *B*, Thick, mound-shaped layer of fossiliferous metalimestone (fig. 3, loc. 27); a sample from this locality (USGS colln. 11966–SD) produced conodonts of latest Givetian or early Frasnian age (pl. 3, figs. 3, 4). *C*, Deformed corals in metalimestone (field loc. 89ATi39).

grained, richer in clay, and less recrystallized toward the periphery.

The predominant lithology is slightly recrystallized lime mudstone. Most samples contain 2 to 10 percent bioclasts and peloids disseminated in a matrix of calcite crystals 8 to 25 μm in diameter. Bioclasts, locally bored and micritized, include echinoderm columnals and spines, ostracodes, and bryozoans. Peloids are ellipsoidal, 40 to 160 μm in diameter, and organic rich. Some samples are couplets, a few centimeters thick, of relatively pure lime mudstone grading up into finer grained, phyllitic lime mudstone.

Bioclastic-peloidal wackestone and packstone form zones a few centimeters to several meters thick within these muddy mounds. Bioclasts here are chiefly corals, stromatoporoids, and fewer brachiopods and echinoderms. Fossils are not uniformly distributed; some patches are rich in corals or stromatoporoids, for example, whereas others contain mostly brachiopods. Corals are tabulate forms and solitary and colonial rugosans (fig. 17*C*). Coral genera include *Alveolites*? sp., *Cladopora*? sp., *Macgeea* sp., *Spongophyllum*? sp., and *Thamnopora* sp.; stromatoporoids include *Amphipora* sp. and massive forms (Dillon and others, 1988). Articulated brachiopod shells and articulated crinoid columnals occur locally and indicate relatively quiet water conditions.

The second type of carbonate body consists of buff- to orange-weathering, gray lime packstone to grainstone in relatively elongate lenses 2 to 10 m thick. Some intervals appear thoroughly bioturbated, and discrete *Chondrites*-type burrows occur locally. Clasts, mostly skeletal material and peloids, range from very fine to coarse sand sized; individual samples are fairly well sorted. Bioclasts are generally broken and abraded, and many are micritized. Identifiable biotic grains consist of crinoid columnals and fewer brachiopod fragments, foraminifers, and algal oncolites. Peloids in these bodies are more irregular in size and shape than those in the muddy mounds; they range from 50 to 700 μm in diameter, and at least some may be micritized skeletal grains. Most samples also contain 1 to 25 percent disseminated, angular, quartz silt and sand.

Euhedral rhombs of dolomite, 30 to 50 μm in diameter, occur locally in all of the calcareous lithologies described above. They are most common in mudstones and grain-poor wackestones and constitute 5 to 30 percent of some samples. Silicification of skeletal material is rare but was noted at a few outcrops.

AGE AND BIOFACIES

Conodonts indicate that the Beaucoup Formation in the study area is of latest Givetian and Frasnian (latest Middle and early Late Devonian) age. Megafossils in these rocks are chiefly poorly preserved corals, stromatoporoids, brachiopods, and mollusks of Middle through early Late Devonian age (Brosgé and Reiser, 1964, locs. 2 and 3; Brosgé and others, 1979, locs. 136 and 143; Dillon and others, 1988, locs. 2, 3, 11, 28, 51, 60, 61). Conodonts have been obtained from 19 collections at 17 localities (fig. 3, locs. 3, 15, 26, 27, 33). Some conodont collections merely indicate a broad Middle to Late Devonian age, but others are more diagnostic. Four collections are latest Givetian to early Frasnian in age (fig. 3, locs. 15, 26, 27, 33), one represents an interval within the early Frasnian (upper part of *transitans* Zone into lower part of Upper *hassi* Zone; USGS colln. 12078–SD, about 30 km east of the study area, listed in app. 1 and not shown on fig. 3), and another is long-ranging within the Frasnian (Upper *hassi* Zone to *linguiformis* Zone; fig. 3, loc. 3). Map distribution of these diagnostic samples suggests that younger parts of the Beaucoup Formation are exposed to the north. Conodonts from the Beaucoup Formation mostly represent a polygnathid-icriodid biofacies, which typifies normal-marine, relatively shallow-water, and locally high-energy depositional environments.

DISTRIBUTION

The Beaucoup Formation occurs in large thrust sheets throughout the Snowden Mountain area (fig. 2). It is tectonically interleaved with the Hunt Fork Shale and Nutirwik Creek unit in the north and with the Mathews River unit, the Snowden Creek unit, and metasedimentary rocks of uncertain age to the south.

DEPOSITIONAL ENVIRONMENT

Siliciclastic strata predominate throughout the Beaucoup Formation, indicating that conditions suitable for carbonate accumulation were only locally or occasionally achieved. Lithologic and faunal evidence demonstrates that limy layers in this unit accumulated in situ as shallow-water bioherms and bioclastic shoals. Turbidity strongly inhibits primary carbonate production (for example, Wilson, 1975); thus, limy strata formed only in times and (or) places of reduced siliciclastic influx.

The two types of carbonate bodies described above formed in slightly different settings. We interpret mudstone-wackestone "mounds," locally rich in corals, stromatoporoids, and other fossils, as biohermal buildups; the abundance of mud and the presence of articulated brachiopods and crinoid columnals suggest deposition in quiet water below fair-weather wave base. The fauna is predominantly stenohaline and denotes open circulation and normal-marine salinity. Peloids in these rocks resemble modern fecal pellets. Thinner layers of packstone and grainstone accumulated in shallower and (or) higher energy settings, as demonstrated by abraded, size-sorted grains and rarity of mud. Some layers were probably deposited in carbonate sand shoals; others may be grain-rich lags derived from bioherms through current winnowing. Peloids in these rocks are most likely micritized grains; micritization is most common in the shallow photic zone where it is mediated by algae (Bathurst, 1976).

Different lithologies in the Beaucoup Formation produce distinct conodont assemblages. Samples from muddy biohermal buildups produce few conodonts; those that occur represent chiefly the polygnathid-icriodid biofacies, with or without pandorinellinids (pl. 3, figs. 1–4). More diverse and abundant faunas are found in bioclastic packstone-grainstone layers. Polygnathids dominate these collections but occur with ancyrodellids, *Mesotaxis*, and rare icriodontids and *Klapperina* (pl. 3, figs. 5–11). It appears that *Pandorinellina*, *Icriodus*, and polygnathids lived over the biohermal buildups, whereas *Ancyrodella*, *Mesotaxis*, and many polygnathids lived over and peripheral to grain-rich bioclastic shoals and aprons surrounding the buildups.

HUNT FORK SHALE

The Hunt Fork Shale consists of as much as 1,000 m of dark-gray to black shale, slate, and phyllite with lesser amounts of fine- to medium-grained sandstone, siltstone, calcareous sandstone, and ferruginous fossiliferous limestone (Brosgé and others, 1979; Nilsen, 1981; Moore and Nilsen, 1984) (fig. 18*A*). The unit was defined by Chapman and others (1964) from exposures in the Killik River quadrangle, 150 km west of Snowden Mountain but has since been recognized throughout the Brooks Range. It is the basal formation of the Endicott Group (Tailleur and others, 1967) and grades upward into marginal marine and nonmarine clastic rocks (Noatak Sandstone and Kanayut Conglomerate). In the Philip Smith Mountains quadrangle, the Hunt Fork Shale is at least 700 m thick and comprises quartzite, calcareous sandstone, limestone, shale, and wacke members (Brosgé and others, 1979). The limestone member consists of lenticular beds, 1 to 15 m thick, that occur mostly in a persistent zone as much as 50 m thick about 200 to 300 m below the top of the formation. In addition, minor thin limy beds occur in other members. Most calcareous layers examined for this study are part of the shale member of Brosgé and others (1979).

CARBONATE LITHOLOGIES

In the Snowden Mountain area, the Hunt Fork Shale contains fewer, thinner limy layers than does the Beaucoup Formation. Calcareous beds make up 5 percent or less of most sections and are generally 5 cm to 1.5 m thick; rare carbonate intervals as much as 100 m thick occur at some outcrops. Many limy layers in the Hunt Fork Shale contain a mixture of calcareous and siliciclastic grains. In the descriptions below, calcarenite describes rocks that include more than 10 percent noncarbonate detrital clasts.

Thinner calcareous beds in the Hunt Fork Shale are graded (fig. 18*B*), locally bioturbated, and consist mostly of orange-weathering, medium-gray to black bioclastic grainstone, lesser packstone, and calcarenite composed of fossil debris (5–70 percent), carbonate lithic clasts (1–30 percent), and siliciclastic detritus (1–80 percent) (fig. 18*C*, *D*). Most samples are poorly sorted and contain coarse bioclasts (a few millimeters to several centimeters in diameter) in a matrix of fine to very fine carbonate and siliciclastic sand cemented by sparry calcite or (rarely) silica. Muddy rip-up clasts are locally abundant, and many bioclasts are filled and (or) coated with mud. Fossils include corals (solitary and colonial rugosans), brachiopods, echinoderms, bryozoans, gastropods, ostracodes, foraminifers, ichthyoliths, and hydraulically sorted, reworked conodonts of mixed biofacies (pl. 3, figs. 12–15). Carbonate clasts are primarily lime mudstone and peloidal packstone; most are rounded to irregular and of probable intrabasinal origin, but some are angular, contain calcite veins truncated at the clast margin, and are most likely extrabasinal. Noncarbonate grains are angular to subangular and consist chiefly of monocrystalline quartz, less abundant chert, and minor amounts of plagioclase feldspar, phyllite, white mica, chlorite, phosphate, and opaques.

Dark-gray, medium-bedded oolitic grainstone (fig. 18*E*) forms a 30-cm-thick bed in the Hunt Fork Shale 2 km south of Atigun Pass (fig. 3, loc. 1). Ooids average 0.5 mm in diameter, display both concentric and radial lamination, and occur in a matrix of sparry calcite cement; many have quartz silt nuclei. Other grains make up less than 5 percent of this bed and consist of brachiopod and echinoderm debris, quartz sand, and intraclasts of oolitic packstone.

Rare, thicker (2–100 m) carbonate intervals in the Hunt Fork Shale consist of nodular bedded to massive, bioclastic-peloidal lime wackestone and mudstone. These rocks contain corals, stromatoporoids, bryozoans, and gastropods dispersed in a matrix of peloids and slightly dolomitic lime mud.

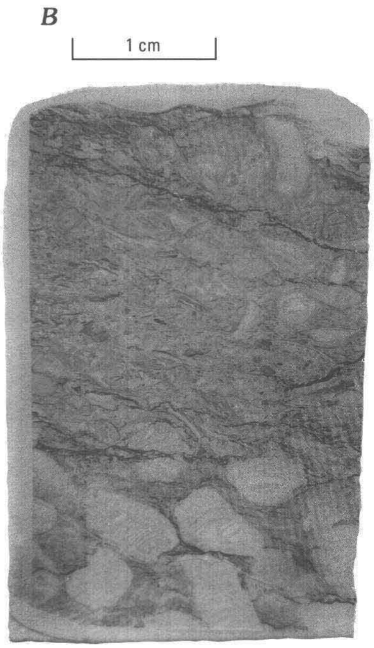
AGE AND BIOFACIES

Megafossils indicate a Frasnian and Famennian (early and late Late Devonian) age for the Hunt Fork Shale in the Philip Smith Mountains quadrangle (Brosgé and others, 1979). Frasnian corals, brachiopods, pelecypods, mollusks, and plants have been obtained from the limestone, calcareous sandstone, and shale members of the formation, but the uppermost wacke member yields Famennian brachiopods and pelecypods.

In the Snowden Mountain area, conodont assemblages from limy layers in the Hunt Fork Shale are dominated by polygnathids and suggest a middle to late Frasnian age (pl. 3, figs. 12–15). Nine samples from eight localities yielded conodonts (fig. 3, locs. 1, 2). Collections are more abundant than those from the Beaucoup Formation, and polygnathids are more diverse; they are chiefly *Polygnathus pacificus* (pl. 3, fig. 13), *P. aequalis*, *P. evidens* (pl. 3, fig. 12), and *P. samueli* (pl. 3, fig. 14). Some of these species have previously been reported only from late Frasnian rocks of the Hay River area, southwestern Northwest Territories, Canada (Klapper and Lane, 1985), and southeast Alaska (Savage, 1992). Most collections represent a post-mortem biofacies mixture derived from normal-marine, relatively shallow to moderately deep shelf environments.

DISTRIBUTION

The Hunt Fork Shale crops out only in the northernmost part of the study area in the vicinity of Atigun Pass



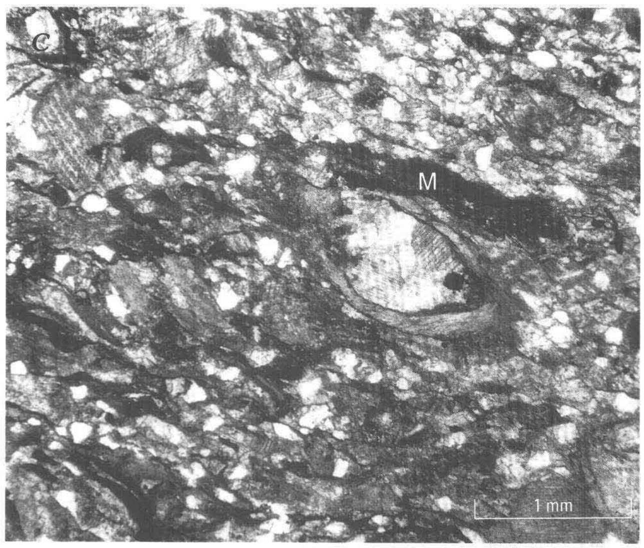


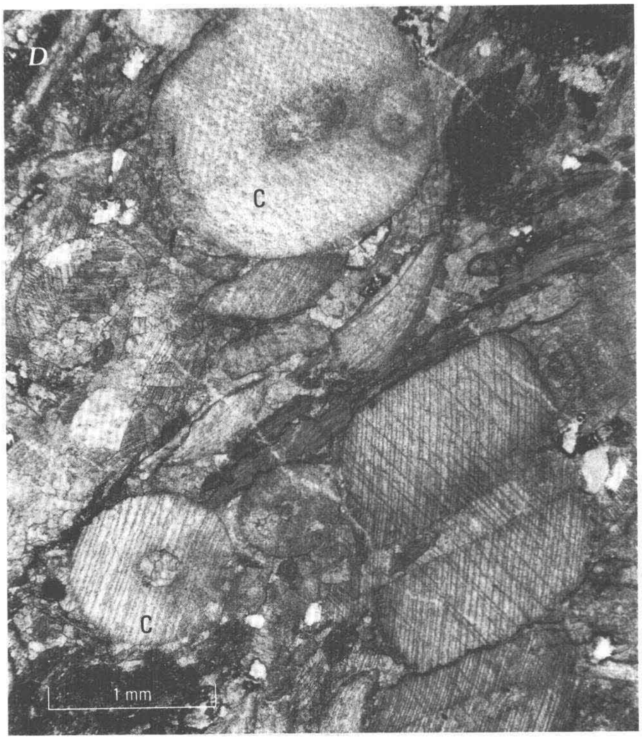
Figure 18. Sedimentary features of the Hunt Fork Shale. *A*, Typical outcrop of phyllite containing subordinate layers of metasiltstone and metasandstone (hammer, 40 cm long). *B*, View of thin section (reflected light) showing graded metalimestone bed; coarse grains at base of sample are coral fragments (field loc. 90TM527). *C*, Photomicrograph of thin calcareous bed containing abundant detrital quartz grains, as well as, M, mudstone clasts and skeletal debris (fig. 3, loc. 1). *D*, Photomicrograph of thin calcareous bed made chiefly of carbonate bioclasts such as, C, crinoid ossicles (field loc. 90TM570). *E*, Photomicrograph of oolitic grainstone (fig. 3, loc. 1).

(fig. 2). It forms several large fault sheets thrust above the Beaucoup Formation to the south and the Kanayut Conglomerate to the north.

DEPOSITIONAL ENVIRONMENT

The Hunt Fork Shale, like the Beaucoup Formation, accumulated in a marine regime dominated by siliciclastic influx. But Hunt Fork limy layers are thinner and rarer than those in the Beaucoup Formation and indicate a depositional environment even more inimical to in situ carbonate production.

Previous workers observed that the Hunt Fork Shale grades upward from deep- to shallow-marine facies (for example, Nilsen, 1981; Moore and Nilsen, 1984). Most of the unit accumulated in a low-energy, relatively deep (below fair-weather wave base) depositional environment such as a prodelta slope, but the uppermost wacke member records delta progradation across a shallower (outer shelf?) setting (Moore and Nilsen, 1984). The lower part of the Hunt Fork Shale contains thin, graded beds of siliciclastic sandstone and siltstone that increase in abundance upward. Some of these beds contain partial Bouma sequences and are probably turbidites, whereas others may have formed through vertical settling from storm-generated overflows (Nilsen, 1981). Sandstone bodies in the upper part of the Hunt Fork represent shoals, channel-mouth bars, and submerged linear ridges (Nilsen, 1981).



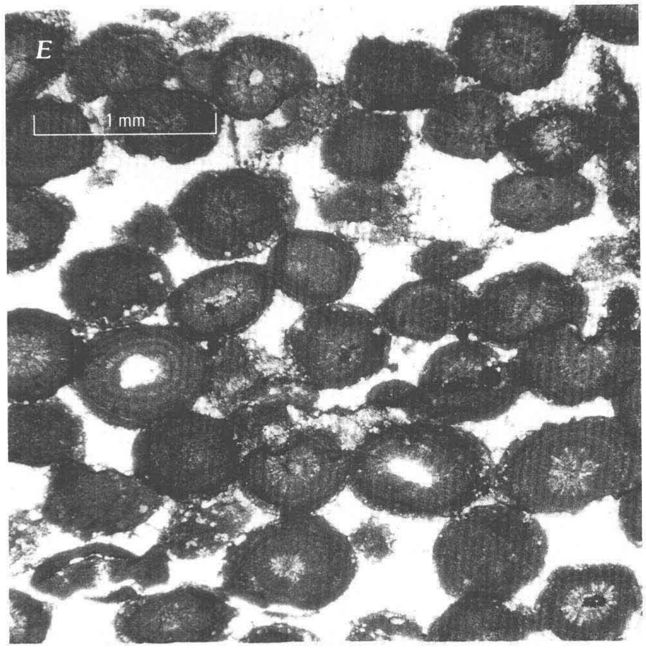


Figure 18.—Continued.

Sedimentologic and faunal evidence indicate that most limestone layers of the Hunt Fork Shale in the study area were not generated in place but were redeposited by storm waves and (or) turbidity currents. A tempestite origin may best explain many of the thin calcareous beds. They do not display sedimentary structures characteristic of Bouma sequences, such as parallel and cross lamination, but do possess typical storm deposit features (Flügel, 1982), including grading, shale rip-up clasts, a variety of carbonate lithoclasts, and a mix of fossils derived from various shallow-water biofacies. The condition and composition of conodont collections from these layers support the interpretation of redeposition. Assemblages consist chiefly of robust elements, and most specimens are broken and abraded. Platform elements are usually incomplete, and very few ramiform elements are recognizable to morphotype, indicating post-mortem, relatively high energy hydraulic transport.

A few carbonate layers in the Hunt Fork Shale appear to have formed in place in relatively shallow water. Oolitic grainstone most likely accumulated in local high-energy shoals, and rare thick layers of bioclastic-peloidal wackestone and mudstone probably represent muddy biohermal buildups like those in the Beaucoup Formation.

The scarcity of limestone in the Hunt Fork Shale relative to the Beaucoup Formation could reflect several factors. The Hunt Fork may have been deposited in deeper and (or) colder water; in situ carbonate production is highest in warm, shallow seas (Wilson, 1975; Flügel, 1982). Alternately, or additionally, conditions during Hunt Fork deposition may have been too turbid to allow establishment of much neritic carbonate production; siliciclastic input may have been greater and more continuous than during accumulation of the Beaucoup Formation.

NUTIRWIK CREEK UNIT

The Nutirwik Creek unit consists of purple and green phyllite with subordinate volcaniclastic metasandstone, pebble conglomerate, and felsic igneous rocks (Aleinikoff and others, 1993). Some purple and green phyllite sections contain minor calcareous black phyllite and metalimestone, which we here provisionally include within the Nutirwik Creek unit. These limy layers appear to be in the upper part of the unit (T.E. Moore, written commun., 1991). Rocks presently assigned to the Nutirwik Creek unit were considered part of the Beaucoup Formation and (or) the rocks of Whiteface Mountain (informal unit) by previous authors (Brosgé and others, 1979; Dillon and others, 1988). Most exposures of the Nutirwik Creek unit occur in the Table Mountain area, where the rocks are intercalated with massive metacarbonate rocks (Pzt) (fig. 2).

CARBONATE LITHOLOGIES

Limestone is even less common in the Nutirwik Creek unit than in the other Devonian siliciclastic units discussed above; it occurs intercalated with recessive intervals of slightly calcareous black phyllite and makes up at most a few percent of the overall section. Most calcareous beds are 3 to 20 cm thick and consist of finely laminated, carbonaceous, dark-gray to black, medium- to dark-gray-weathering lime mudstone to wackestone. Bioclasts are chiefly pelagic fossils such as tentaculitids and calcitized radiolarians, as well as, less commonly, echinoderm debris. Other silt- and sand-sized grains in these predominantly fine-grained rocks include peloids and minor amounts of detrital quartz.

A few limy beds consist of redeposited, grain-rich packstone like that found in the Hunt Fork Shale. These beds are thicker (as much as 1 m), weather orange, and contain a mix of bioclasts, calcareous lithic clasts, and minor amounts of lime mud. Fossils include coral, bryozoan, and echinoderm fragments; carbonate clasts consist of lime mudstone or skeletal wackestone.

AGE AND BIOFACIES

Limestone layers included in the Nutirwik Creek unit yield megafossils and conodonts of Middle to early Late Devonian age. Megafossils (Dillon and others, 1988, locs. 47, 49, and 50) include solitary and colonial rugose corals, tabulate corals (*Cladopora*? sp.), and stromatoporoids (*Amphipora*? sp.) of early Late Devonian and Middle to early Late Devonian age and brachiopods (*Mucrospirifer* sp.) of Middle(?) Devonian age.

Four samples from the Nutirwik Creek unit yielded conodonts; the most diagnostic collections are of middle Frasnian (early Late Devonian) age (fig. 3, locs. 4, 5, 12; pl. 3, figs. 16–21). Skeletal packstone (fig. 3, loc. 5) produced abundant and diverse conodonts indicative of the upper part of the Lower *hassi* Zone. Bioclastic limestone (fig. 3, loc. 4) yielded conodonts of the Upper *hassi* Zone to Lower *rhenana* Zone. These assemblages, unlike those obtained from the Beaucoup Formation and the Hunt Fork Shale, are not dominated by polygnathids. Instead they commonly contain ancyrodellids and palmatolepids, as well as lesser numbers of *Ancyrognathus* spp., icriodids, and polygnathids. Most of these conodonts represent the polygnathid-ancyrodellid-palmatolepid biofacies and are characteristic of an outer shelf or slope environment.

Two metafelsite samples from the Nutirwik Creek unit produced Early Devonian zircon ages (393 ± 2 and about 385–390 Ma) (Aleinikoff and others, 1993). These ages, together with the paleontologic data, suggest that the Nutirwik Creek unit was formed by a long-lived depositional regime that existed from at least Early to Late Devonian time. Alternatively, the unit could represent a heterogeneous assemblage of fault slices of various Devonian ages. Thus far, limestone layers we include in the Nutirwik Creek unit have yielded chiefly Late Devonian (Frasnian) fossils.

DISTRIBUTION

The Nutirwik Creek unit crops out in the north-central part of the study area (fig. 2), where it forms several large thrust sheets intercalated with massive metacarbonate rocks. Metacarbonate rocks and the Nutirwik Creek unit are also intercalated on a smaller scale. At locality 12 (fig. 3), a 20-m-thick, fault-bounded layer of the Nutirwik Creek unit is structurally overlain and underlain by Upper Ordovician massive metacarbonate rocks of the Mathews River unit. The Nutirwik Creek unit at this locality consists of black phyllite with fewer carbonaceous lime wackestone beds that yield Frasnian conodonts (fig. 3, loc. 12).

DEPOSITIONAL ENVIRONMENT

Lithologic and faunal evidence suggest that calcareous layers in the Nutirwik Creek unit accumulated in a more offshore and (or) deeper water environment than that postulated for limestone in the Beaucoup Formation or the Hunt Fork Shale. Most of the Nutirwik Creek limy beds are fine-grained, laminated, carbonaceous, and contain rare, chiefly pelagic fossils. These beds are interpreted as distal turbidites, derived from bioherms or other carbonate deposits on an adjacent platform or shelf, and deposited in quiet water at some distance from the original source. Less abundant, thicker layers of skeletal packstone probably reflect the passage of rare, high-magnitude hydraulic events, such as unusually large turbidity currents and (or) storm waves. In situ shallow-water carbonate deposits, such as the muddy bioherms and ooid grainstone that occur in the Beaucoup Formation and Hunt Fork Shale, have not been observed in the Nutirwik Creek unit.

Conodont biofacies analysis supports the conclusions outlined above. Conodont assemblages from the Nutirwik Creek unit show evidence of hydraulic breakage and sorting and include a mix of shallow and deeper water species. However, most conodonts obtained from this unit are characteristic of an outer shelf or slope environment (polygnathid-ancyrodellid-palmatolepid biofacies). Thus, Nutirwik Creek conodont assemblages formed through post-mortem transport of moderate- to shallow-water cosmopolitan species into a deeper water setting.

SUMMARY OF DEVONIAN METACLASTIC ROCKS IN THE SNOWDEN MOUNTAIN AREA

Three metaclastic units of Devonian age are recognized in the Snowden Mountain area: the Beaucoup Formation, the Hunt Fork Shale, and the Nutirwik Creek unit. Each of these units consists chiefly of fine-grained siliciclastic rocks and includes subordinate amounts of metalimestone. However, the units contain distinctive subordinate lithologies; mafic intrusions are apparently restricted to the Beaucoup Formation, quartzose metasandstone beds are most abundant in the Hunt Fork Shale, and the association of purple and green phyllite, volcaniclastic sandstone, and felsic igneous rocks distinguishes the Nutirwik Creek unit.

Previous authors (for example, Dutro and others, 1979) proposed that rocks here included in the Beaucoup Formation and Nutirwik Creek unit depositionally overlie massive metacarbonate rocks of Devonian and older age (Snowden Mountain area metacarbonate succession of this paper) and are themselves overlain by the Hunt Fork Shale. Other workers suggested that most boundaries between these clastic units and the Snowden Mountain area metacarbonate succession are faults. The Beaucoup Formation and Nutirwik Creek unit are widely distributed throughout the study area and are closely associated with rocks of the Snowden Mountain area metacarbonate succession, but the Hunt Fork Shale occurs only in the northernmost part of the map area and is nowhere in contact with the metacarbonate succession (fig. 2).

Our work indicates that characteristic carbonate lithologies and conodont biofacies distinguish the three metaclastic units, but all the units are in part correlative and in part of Frasnian age (fig. 19). Metalimestone is most abundant in the Beaucoup Formation and accumulated mainly in relatively shallow water (shelf or platform environment) as in situ muddy bioherms and bioclastic shoals. Calcareous material is less abundant in the Hunt Fork Shale and is chiefly redeposited. Most limy layers in this unit are tempestites or turbidites; such deposits can form in a variety of settings, but tempestites are most common in inner to outer shelf environments. In situ bioclastic-ooid shoals and biohermal buildups are also found in the Hunt Fork Shale and suggest midshelf or shallower conditions. Metalimestone is least abundant in the Nutirwik Creek unit and occurs mostly as fine-grained, distal turbidites. Lithologic and faunal evidence infer a more offshore and (or) deeper water environment (outer shelf or slope) for this unit.

Available fossil data suggest that limy layers in the Beaucoup Formation are in part older than limy layers in the other two metaclastic units, whereas limy layers in the Hunt Fork Shale are in part younger, but all three units include some strata of middle(?) Frasnian age. The oldest well-dated beds in the Beaucoup Formation yield latest Middle to earliest Late Devonian (latest Givetian to earliest Frasnian) conodonts, but other intervals are early Frasnian and middle to early late Frasnian in age. The most diagnostic conodont collections from the Nutirwik Creek unit are middle Frasnian in age, but Middle(?) Devonian brachiopods are also reported from this unit. Limy layers in the Hunt Fork Shale contain conodonts of middle to late Frasnian age, but the upper (wacke) member of this unit yields Famennian brachiopods. Some of the conodont species found in the Hunt Fork Shale have previously been noted only in northern Canada (Northwest Territories) and southeast Alaska; specific biogeographic affinities have not been suggested for other faunal elements of the metaclastic units.

REGIONAL RELATIONSHIPS

Pre-Carboniferous (meta)carbonate[4] rocks are widely distributed across northern Alaska (fig. 20), but the lithofacies, biostratigraphy, and interrelationships of these sequences are only beginning to be deciphered. In many areas, such as the Arctic quadrangle in the eastern Brooks Range and the Survey Pass and Ambler River quadrangles in the west, pre-Carboniferous metacarbonate successions are known to occur (Dumoulin and Harris, 1988 and unpub. data), but they have not yet been closely studied. However, stratigraphic successions that correlate at least in part with rocks in the Snowden Mountain area have been described in relative detail from several localities: the Doonerak window just west of the study area (Dutro and others, 1976, 1984a, 1984b; Repetski and others, 1987; Julian, 1989), the Baird Mountains in the western Brooks Range (Dumoulin and Harris, 1987a, 1987b; Dumoulin, 1988; Karl and others, 1989; Till, in press), the Shublik and Sadlerochit Mountains in the eastern Brooks Range (Blodgett and others, 1986, 1988, 1992a), and the York Mountains on the Seward Peninsula (Sainsbury, 1969, 1972; Till and Dumoulin, in press).

Of the sections known in detail, metacarbonate rocks of the Snowden Mountain area are lithologically and faunally most similar to strata of the Baird Mountains, 400 km to the west (fig. 20). The Proterozoic(?) to Devonian metacarbonate succession of the Snowden Mountain area correlates best with rocks in the eastern Baird Mountains, whereas the Devonian siliciclastic units correlate with rocks exposed in the eastern and western Baird Mountains.

PRE-CARBONIFEROUS METACARBONATE SUCCESSIONS

The overall progression of lithofacies, depositional environments, conodont faunas, and biofacies in the eastern Baird Mountains succession is strikingly similar to that in the Snowden Mountain area. In the sections that follow, metacarbonate rock units in the eastern Baird Mountains are briefly described and compared with correlative units in the Snowden Mountain area. Other pre-Carboniferous sedimentary successions in northern Alaska are then summarized and compared in turn with Snowden Mountain area rocks.

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[4](Meta)carbonate is used for successions of pre-Carboniferous rocks that include metamorphosed and nonmetamorphosed carbonate rocks.

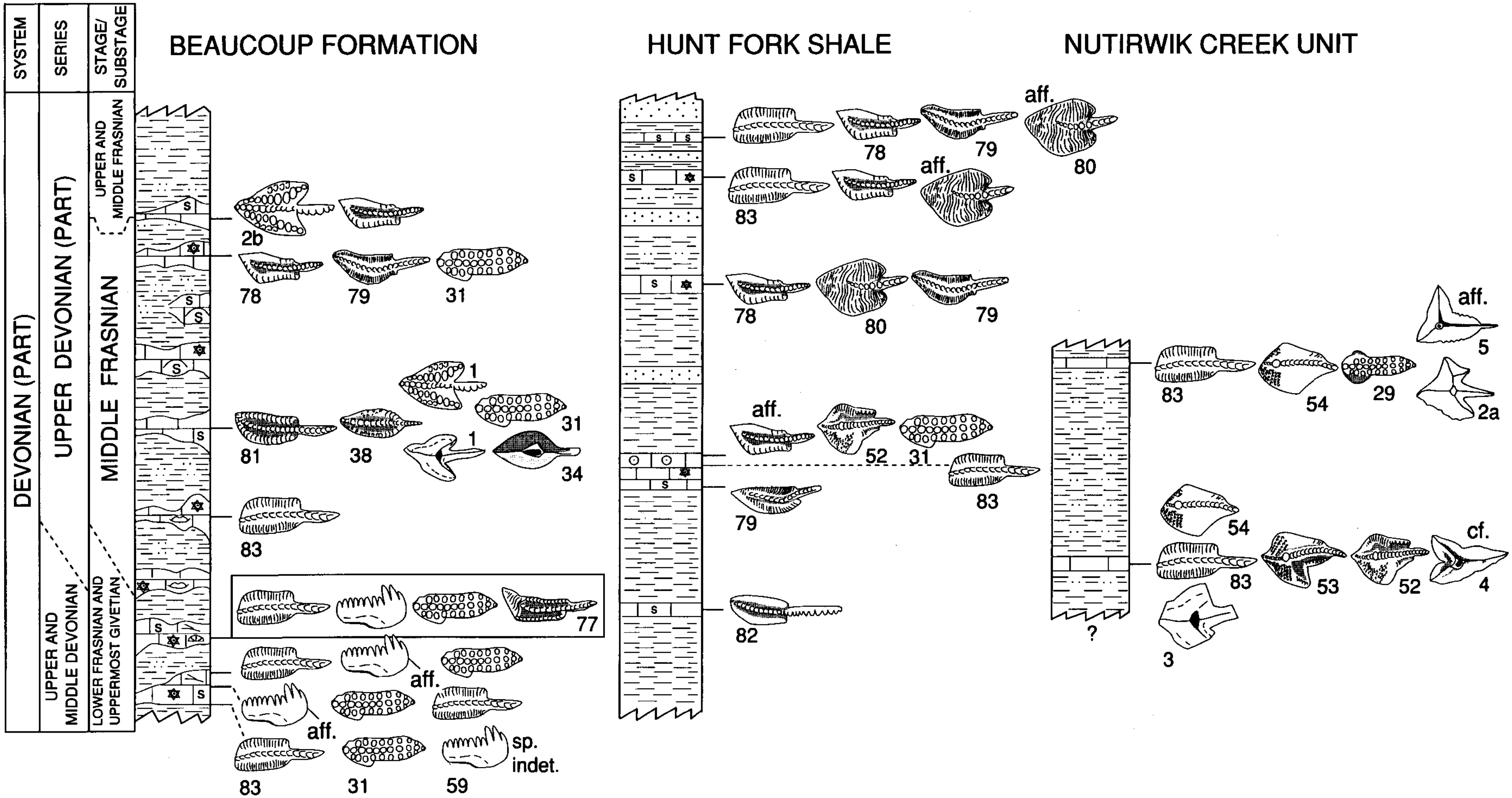

Figure 19. Schematic sections (based on field observations, conodont biostratigraphy, and published descriptions), selected conodonts (relative abundance decreases from left to right), and age relations of the Beaucoup Formation, Hunt Fork Shale, and Nutirwik Creek unit. Only the calcareous part of the Nutirwik Creek unit is shown. See figure 5 and table 1 for explanation of symbols and numerical identification of fossils, respectively.

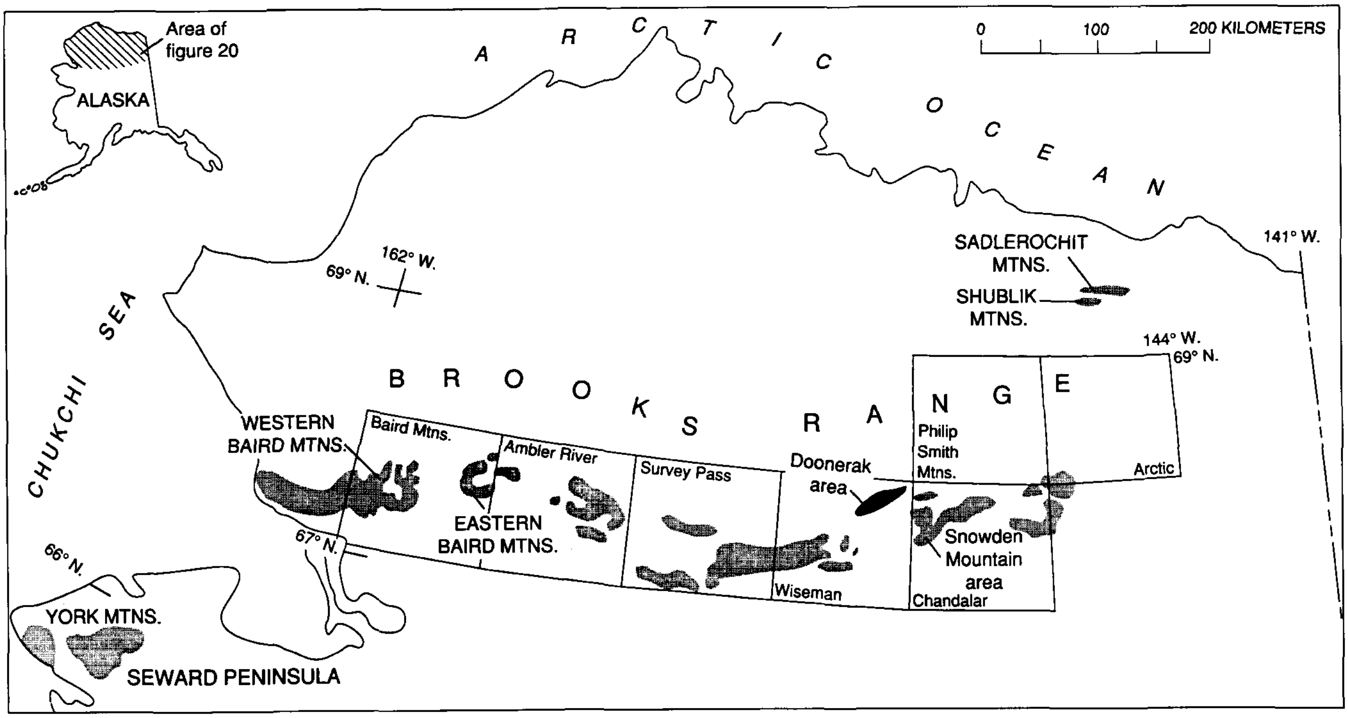

Figure 20. Map of northern Alaska showing general distribution of pre-Carboniferous (meta)carbonate rocks (gray pattern) and quadrangle and geographic names referred to in text.

EASTERN BAIRD MOUNTAINS METACARBONATE SUCCESSION

Carbonate rocks in the eastern Baird Mountains, like those in the Snowden Mountain area, have been deformed, metamorphosed (to blueschist and greenschist facies), and yield conodonts with CAIs of 5 or higher (Dumoulin and Harris, 1987a). In the eastern Baird Mountains (Mt. Angayukaqsraq area), dolostone and marble of Proterozoic and (or) Cambrian age contain stromatolites and coated grains and are overlain by fossiliferous Middle and Upper Cambrian carbonate rocks. These strata are succeeded by a condensed Lower and lower Middle Ordovician section of carbonaceous phyllite, rare radiolarian chert, and carbonate turbidites, which shallows upward into Upper Ordovician to Devonian(?) dolostone and metalimestone deposited in warm, locally restricted marine environments. The lithologic and biostratigraphic summary of the eastern Baird Mountains metacarbonate succession given below is taken chiefly from Dumoulin and Harris (1987a, b), Dumoulin (1988), Harris and others (1988), Karl and others (1989), and Till (in press) and includes some of our previously unpublished data.

PROTEROZOIC AND (OR) CAMBRIAN ROCKS

The basal unit in the eastern Baird Mountains metacarbonate succession is at least 100 m thick and consists of cliff-forming, orange- to light-gray-weathering, dark- to light-gray dolostone, metalimestone, and marble with subordinate layers of quartz-rich metasedimentary rocks and metabasite (unit ЄPzvc of Till, in press; unit PzPcb of Karl and others, 1989)[5] (fig. 21). Original sedimentary textures are locally well preserved; major carbonate lithologies include stromatolitic boundstone and cross-laminated grainstone composed of ooids, oncoids, composite grains, and rare pisoids. Stromatolitic morphologies range from tabular sheets to club-shaped mounds as much as 15 cm high. Regional relationships suggest that these rocks are of Proterozoic and (or) Cambrian age; the assemblage of sedimentary features indicates an intertidal to shallow subtidal depositional environment.

The massive dolostone unit appears to grade upward and laterally into a section at least 90 m thick of orange- and gray-weathering, variously impure metalimestone, marble, and dolostone, and lesser gray to green phyllite and calcareous and chloritic schists (unit ЄPic of Till, in press; subunit one of unit OЄc of Karl and others, 1989[5]). Prominent lithologies include quartzose and (or) chloritic calcarenite and packstone and grainstone containing

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[5] ЄPvc, Proterozoic and (or) Cambrian dolostone, conglomerate, and mafic volcanic rocks; ЄPic, Proterozoic and (or) Cambrian impure marble and phyllite; Єc, Cambrian dolostone and metalimestone; Opc, Ordovician phyllite, metalimestone, dolostone, and marble; DOc, Devonian(?) to Upper Ordovician marble and dolostone unit of Till (in press). PzPcb, Paleozoic and (or) Proterozoic carbonate rocks and metabasite; OЄc, Ordovician and Cambrian carbonate rocks; DOc, Devonian(?) to Ordovician carbonate rocks units of Karl and others (1989).

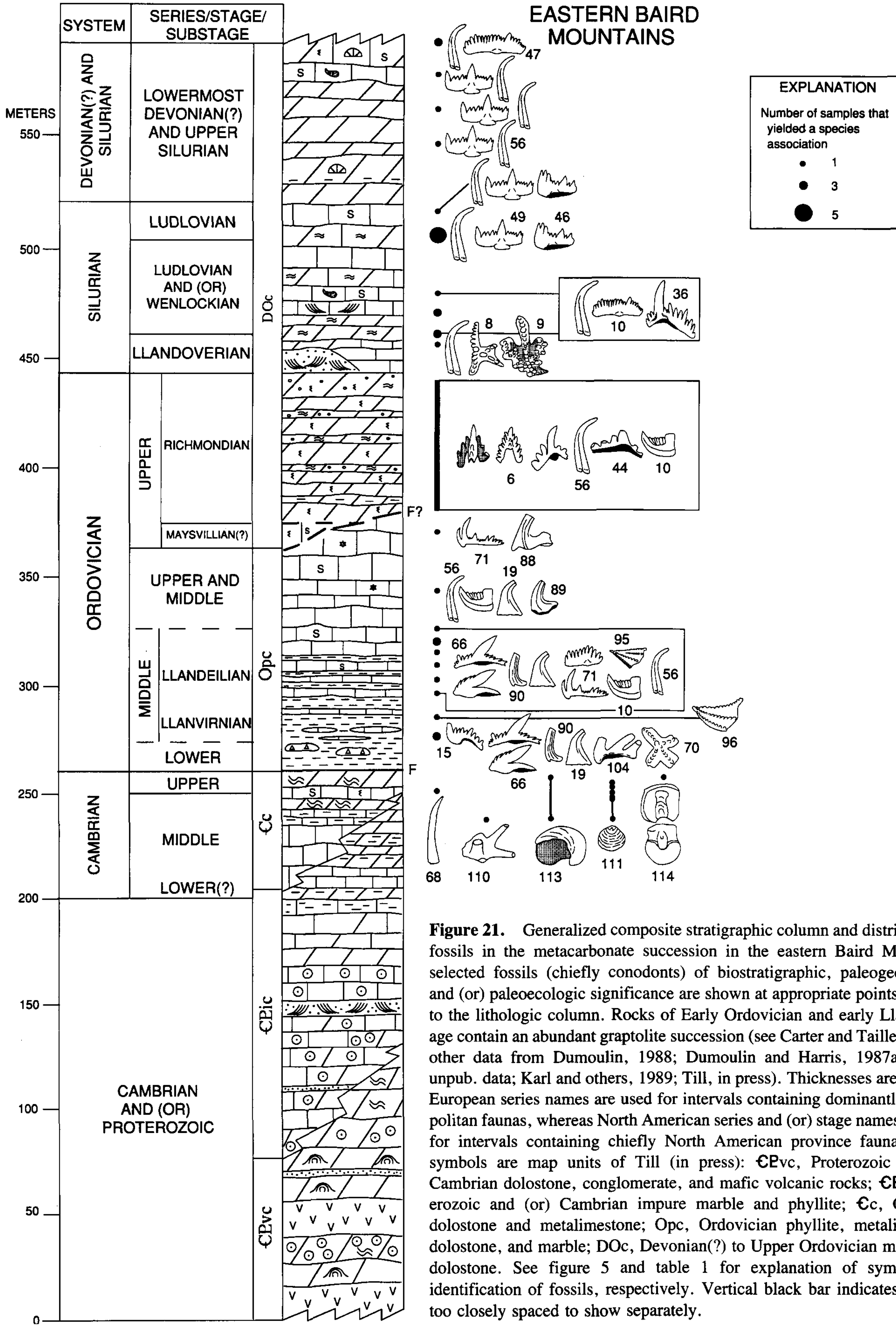


Figure 21. Generalized composite stratigraphic column and distribution of fossils in the metacarbonate succession in the eastern Baird Mountains; selected fossils (chiefly conodonts) of biostratigraphic, paleogeographic, and (or) paleoecologic significance are shown at appropriate points adjacent to the lithologic column. Rocks of Early Ordovician and early Llanvirnian age contain an abundant graptolite succession (see Carter and Tailleur, 1984; other data from Dumoulin, 1988; Dumoulin and Harris, 1987a, b, and unpub. data; Karl and others, 1989; Till, in press). Thicknesses are minima. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American province faunas. Letter symbols are map units of Till (in press): ꞒPvc, Proterozoic and (or) Cambrian dolostone, conglomerate, and mafic volcanic rocks; ꞒPic, Proterozoic and (or) Cambrian impure marble and phyllite; Ꞓc, Cambrian dolostone and metalimestone; Opc, Ordovician phyllite, metalimestone, dolostone, and marble; DOc, Devonian(?) to Upper Ordovician marble and dolostone. See figure 5 and table 1 for explanation of symbols and identification of fossils, respectively. Vertical black bar indicates samples too closely spaced to show separately.

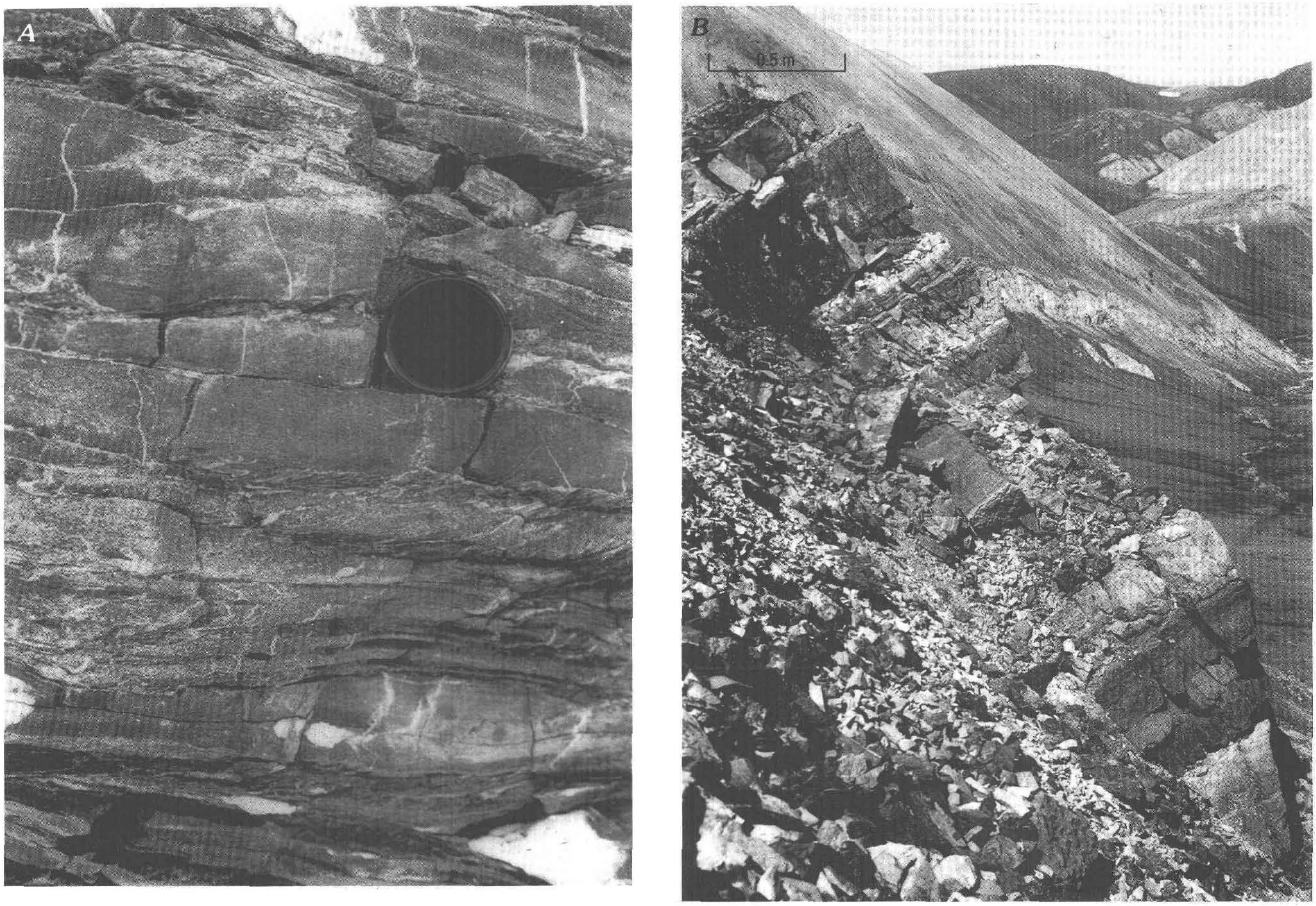


Figure 22. Sedimentary features of metacarbonate succession in the eastern Baird Mountains. *A*, Middle Ordovician carbonate turbidites (Opc, Ordovician phyllite and carbonate of Till, in press; lens cap, 6 cm in diameter). *B*, Upper Ordovician shallowing-upward cycles of dark-weathering bioturbated pack-grainstone and light-weathering cryptalgal laminite (lower part of DOc unit of Till, in press).

locally abundant coated grains. Some layers are graded, contain parallel and cross lamination, and are interpreted as turbidites. No fossils have been found in this unit, but map relations suggest that it is a deeper water facies equivalent of the upper part of unit ꞒPvc and the lower part of unit Ꞓc (see below and footnote 5).

Rocks of definite Cambrian age overlie both units ꞒPvc and ꞒPic and make up a section at least 60 m thick (unit Ꞓc of Till, in press; subunit two of unit OꞒc of Karl and others, 1989). The basal part of this section is massive marble; it grades up into thin-bedded, platy metalimestone and then into thin couplets of bioturbated metalimestone and laminated dolostone interpreted as shallowing-upward peritidal deposits. Protoconodonts, chancellorid sclerites, hyolithids, and phosphatized steinkerns of monoplacophoran mollusks indicate a maximum age of Early (but not earliest) Cambrian for the lower part of this unit; acrotretid brachiopods and agnostid arthropods demonstrate Middle (probably late Middle) and Late Cambrian ages, respectively, for the middle and upper parts of the unit (fig. 21). Fossils and sedimentary features infer that most of the section was deposited in a shallow subtidal to supratidal environment; the fauna is cosmopolitan and suggests no specific paleogeographic affinities.

LOWER AND MIDDLE ORDOVICIAN ROCKS

A condensed Lower and lower Middle Ordovician section at least 50 to 100 m thick overlies rocks of Middle and Late Cambrian age in the eastern Baird Mountains (unit Opc of Till, in press; subunits three and four of unit OꞒc of Karl and others, 1989; see footnote 5). Carbonaceous phyllite with rare layers of radiolarian-bearing metachert and fine-grained metalimestone makes up the basal part of the sequence. Calcareous layers increase in thickness and abundance upward. Thin graded beds of metalimestone, separated by phyllitic partings (fig. 22*A*), pass up into thicker bedded, bioturbated, bioclastic packstone and grainstone. The unit contains an excellent Arenigian to Llanvirnian graptolite succession (Carter and Tailleur, 1984) and cosmopolitan, chiefly cool-water conodonts of Llanvirnian, latest Llanvirnian to Llandeilian, and late Llandeilian to earliest Caradocian(?) age (fig. 21). Lithologic and biostratigraphic criteria indicate a shallowing-upward depositional regime; basinal phyllite grades up into shelf-margin carbonate turbidites and then into mid- to inner-shelf bioclastic grainstones. The turbidites contain a mix of warm- and cool-water conodont species.

UPPER ORDOVICIAN TO DEVONIAN(?) ROCKS

Lower and Middle Ordovician strata in the eastern Baird Mountains are succeeded by more than 200 m of Upper Ordovician, Silurian, and Devonian(?) dolostone and less abundant metalimestone (unit DOc of Karl and others, 1989 and Till, in press; see footnote 5). The lower part of this section forms steep cliff exposures; the upper strata crop out as rubble-covered hills. The lower interval is distinctively color banded on a scale of one-half to several meters; the bands represent cyclic alternations of dark-gray to black, bioturbated pack-grainstone and light-gray cryptalgal laminite with fenestral fabric (fig. 22*B*). Similar lithologies occur in the upper part of the section, along with layers of bioclastic packstone and wackestone that contain corals, stromatoporoids, and pentamerid brachiopods.

Conodonts and brachiopods (*Tcherskidium* n. sp.) constrain the age of this unit. The cliff-forming lower part of the section is of Late Ordovician age; the basal beds contain *Protopanderodus insculptus* and the Siberian-northern North American conodont *Plectodina*? cf. *P.*? *dolboricus* and may be as old as middle Maysvillian, but most strata yield chiefly *Aphelognathus divergens*, a western North American Midcontinent Province (WNAMP) conodont, and are Richmondian (latest Ordovician). The rubble-forming upper strata are mostly Llandoverian to Ludlovian in age (Early and Late Silurian); the uppermost beds are no younger than Early Devonian and could be as old as latest Silurian. Fossils and sedimentary structures indicate a warm, shallow-water depositional environment for these rocks; the shallowest, most restricted conditions prevailed during Richmondian time.

COMPARISON OF THE SNOWDEN MOUNTAIN AND EASTERN BAIRD MOUNTAINS METACARBONATE SUCCESSIONS

The Snowden Mountain metacarbonate succession (used hereafter for the Snowden Mountain area metacarbonate succession) has many lithologic and faunal similarities to the succession in the eastern Baird Mountains. Ordovician and Silurian strata in the two areas correlate particularly well, but points of correspondence exist throughout both metacarbonate successions (fig. 23).

Both the Snowden Mountain and the eastern Baird Mountains metacarbonate successions include strata of Cambrian and possible Proterozoic age. Massive metacarbonate rocks of the Dillon Mountain area are lithologically similar to and may correlate with unit ꞒPvc (fig. 23) in the eastern Baird Mountains. The major carbonate lithologies in both units are crossbedded, coated-grain grainstone and algal (stromatolitic) boundstone; both units contain layers of quartzose metasedimentary rocks and were deposited in peritidal environments. Stromatolites are more abundant and display a wider range of morphologies in the eastern Baird Mountains strata, but this difference may reflect a preservational bias; stromatolites are best preserved in the dolomitic parts of unit ꞒPvc, and dolostone is relatively uncommon in the Dillon Mountain area. Unit ꞒPvc also differs from the metacarbonate rocks in the Dillon Mountain area because it contains layers of metabasite and is spatially associated with rocks of known Cambrian age.

Correspondence between other pre-Ordovician units in the two areas is less precise. The Snowden Mountain unit may correlate with the upper part of unit ꞒPic or, less likely, with the lowermost part of unit Ꞓc. Lithologically, the Snowden Mountain unit is more like unit ꞒPic. Both units include gray phyllite, impure metalimestone, and quartzose metalimestone, and both accumulated in an outer shelf or slope setting. The well-dated uppermost part of the Snowden Mountain unit is of early Middle Cambrian age, older than part of unit Ꞓc, and the shallow-water depositional environment inferred for unit Ꞓc is at odds with the setting proposed for the Snowden Mountain unit. No rocks have yet been found in the Snowden Mountain area that correlate with the Upper Cambrian part of unit Ꞓc. Proof that strata of this age once existed in this region, however, is provided by the presence of redeposited Late Cambrian conodonts in basal parts of the Snowden Creek unit.

Cambrian faunas in the Snowden Mountain area may have been more provincial than those in the eastern Baird Mountains; Snowden Mountain unit trilobites have Siberian biogeographic affinities, whereas the biota of unit Ꞓc is cosmopolitan. Such paleobiogeographic interpretations remain preliminary, however, because the Cambrian fauna thus far recovered from the Snowden Mountain area is much more limited than that found in the eastern Baird Mountains, and strictly comparable forms with well-defined Cambrian provinciality (for example, trilobites) have not been obtained from the eastern Baird Mountains.

Ordovician strata in the Snowden Mountain area and the eastern Baird Mountains correlate well. Lithofacies and biofacies of the Snowden Creek unit correspond closely with those of unit Opc. Lower parts of both sections consist of carbonaceous phyllite with layers of radiolarian metachert and allodapic metalimestone; higher strata are predominantly calcareous and comprise dark, thin-bedded turbidites grading up into lighter colored, thicker bedded bioclastic pack-grainstone. Both units accumulated in

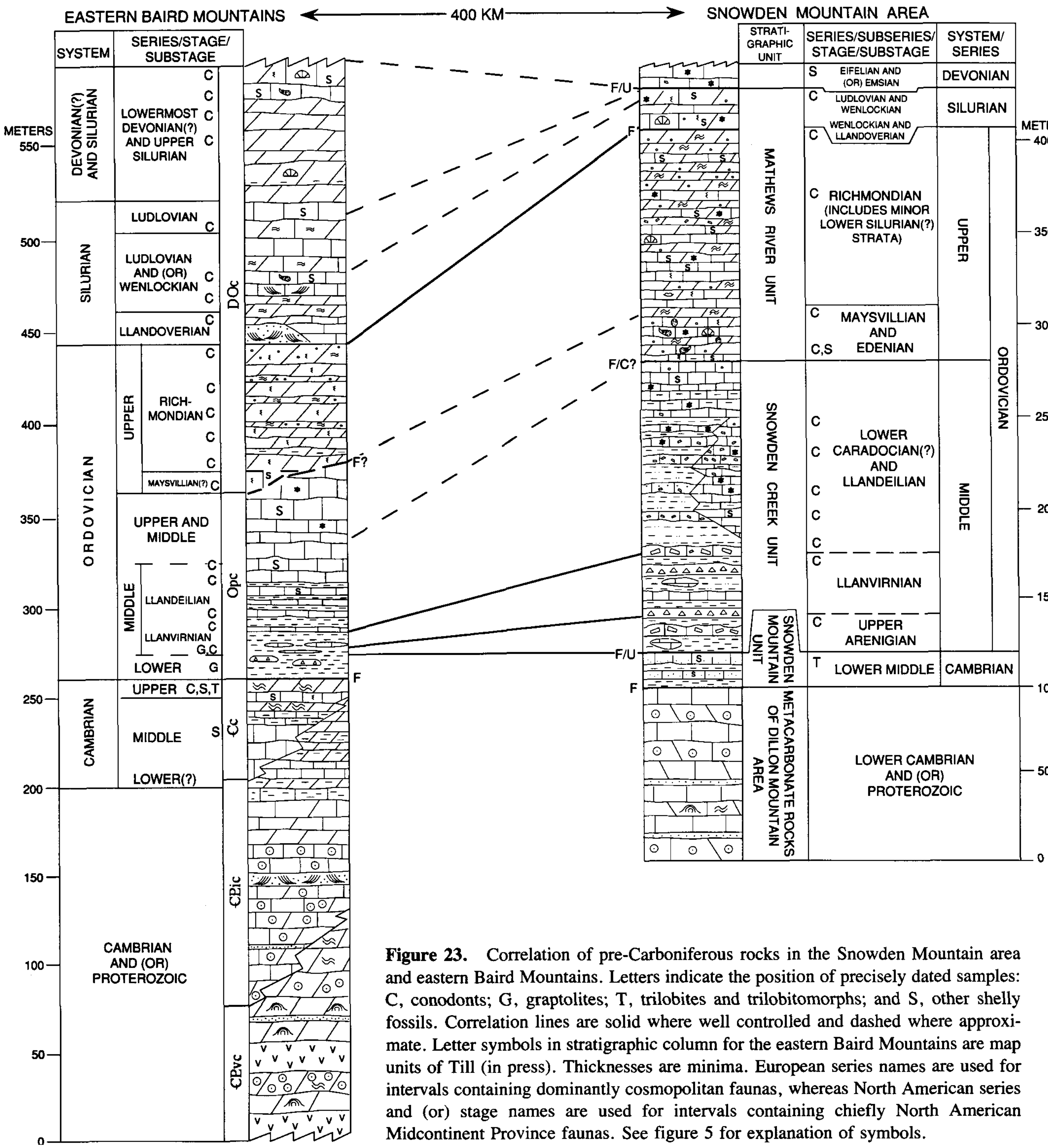


Figure 23. Correlation of pre-Carboniferous rocks in the Snowden Mountain area and eastern Baird Mountains. Letters indicate the position of precisely dated samples: C, conodonts; G, graptolites; T, trilobites and trilobitomorphs; and S, other shelly fossils. Correlation lines are solid where well controlled and dashed where approximate. Letter symbols in stratigraphic column for the eastern Baird Mountains are map units of Till (in press). Thicknesses are minima. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American Midcontinent Province faunas. See figure 5 for explanation of symbols.

shallowing-upward depositional regimes that evolved from poorly oxygenated basins to shallow subtidal carbonate shoals, and turbidites in both units contain hydraulically sorted conodont assemblages, which include a mixture of warm- and cool-water species. Conodonts represent chiefly cosmopolitan forms of the protopanderodid-periodontid biofacies and indicate that deposition of the two sections was essentially coeval; the lowest exposed beds of unit Opc are slightly older than the oldest dated strata in the Snowden Creek unit.

Middle Ordovician strata display subtle compositional differences between the eastern Baird Mountains and the Snowden Mountain area that appear to reflect local variations in depositional environment and turbidite provenance.

The lower part of the Snowden Creek unit is more siliceous and less phyllitic than the lower part of unit Opc. Graptolites have not been found in the Snowden Creek area, but this may be an artifact of preservation—cleavage must parallel bedding in phyllitic rocks in order for graptolites to be observed. Siliciclastic turbidites are rare in both sections but slightly more common in the Snowden Creek unit, and Snowden Creek calcareous turbidites are in general more impure than those in unit Opc. Rare reworked conodonts of anomalous (older) age occur in Snowden Creek turbidites but have not yet been found in any turbidites of unit Opc.

Upper Ordovician and Silurian strata in the Snowden Mountain area and eastern Baird Mountains also correlate well. The Mathews River unit is lithologically and faunally similar to unit DOc. Both are massive, dolomitic, and characterized by meter-scale color bands; the bands reflect shallowing-upward peritidal cycles of bioturbated, bioclastic and (or) peloidal carbonate deposits overlain by cryptalgal laminite. Both units contain similar mega- and microfaunas and were deposited in warm, shallow-water depositional environments that were shallowest and most restricted during Richmondian time. Some Upper Ordovician strata in both areas produce conodonts characteristic of Siberian-northern North American faunas, whereas latest Ordovician assemblages are dominated by WNAMP faunas, and Silurian faunas are predominantly cosmopolitan. Devonian rocks are rare in the Snowden Mountain metacarbonate succession and rare or absent in the eastern Baird Mountains succession.

OTHER PRE-CARBONIFEROUS (META)SEDIMENTARY SUCCESSIONS

Several other (meta)sedimentary successions in northern Alaska are at least in part coeval with the Snowden Mountain area strata and have been described in sufficient detail for sedimentologic and biostratigraphic comparisons to be made. (Meta)carbonate successions in the western Baird Mountains, the York Mountains, and the Shublik and Sadlerochit Mountains have similarities to the metacarbonate succession in the Snowden Mountain area but differ in some particulars. Most notably, these successions contain a relatively thick sequence of Lower Ordovician platform carbonate rocks. Lower Paleozoic metasedimentary rocks are also exposed in the Doonerak window; these strata are chiefly siliciclastic and volcaniclastic but include minor amounts of carbonate that may have been derived from the Snowden Mountain metacarbonate succession (Julian, 1989).

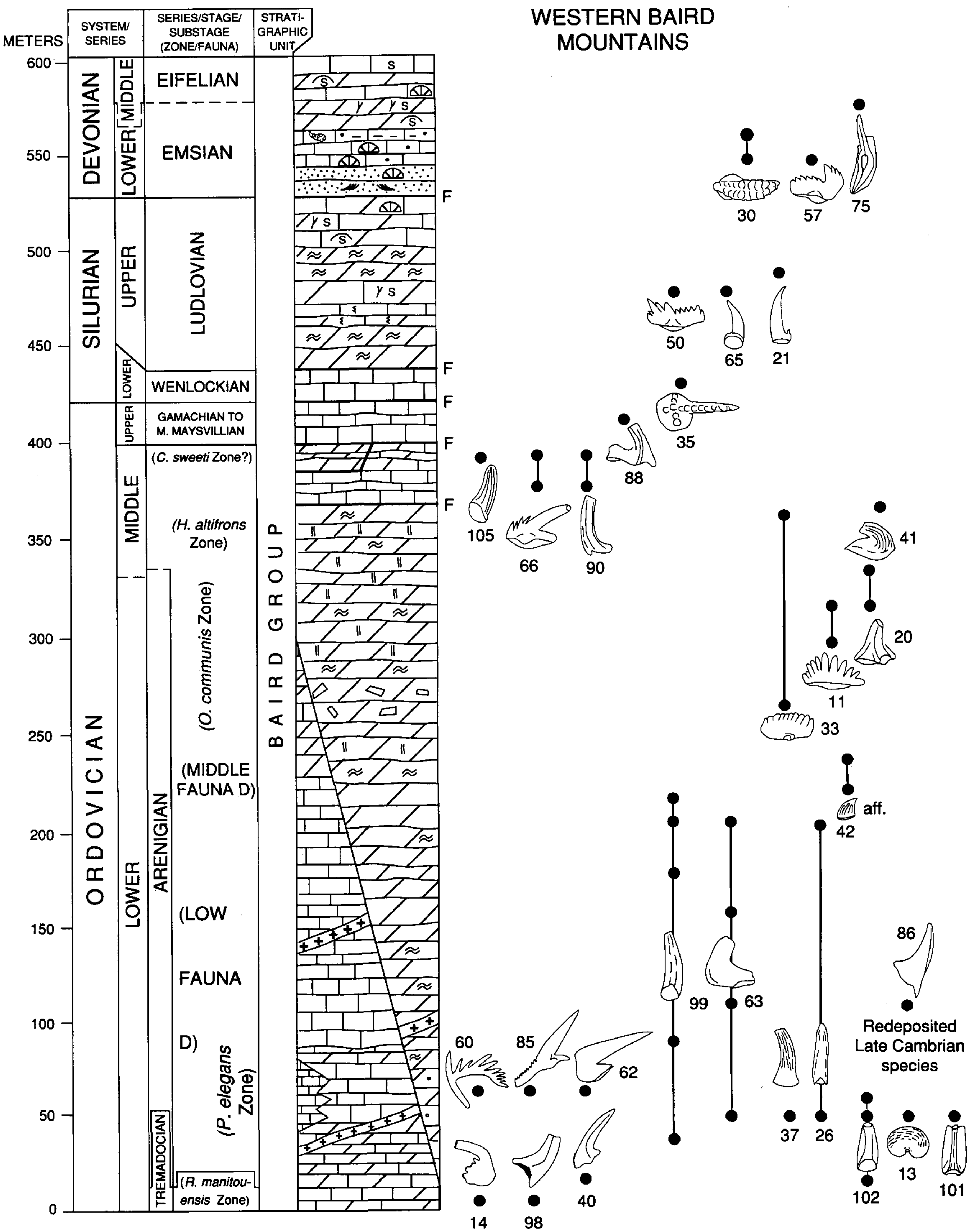
WESTERN BAIRD MOUNTAINS

Description.—Pre-Carboniferous metacarbonate rocks are widespread in the western Baird Mountains; these rocks constitute the Baird Group. In this paper, we restrict the Baird Group to metacarbonate rocks of Ordovician through Middle Devonian age in the western Baird Mountains; we do not include partly coeval metacarbonate rocks of the Maiyumerak Mountains and eastern Baird Mountains or impure carbonate rocks of Middle and Upper Devonian age (for example, Eli Limestone). Like the metacarbonate succession in the eastern Baird Mountains, these strata have been metamorphosed to greenschist and blueschist facies and contain conodonts with CAIs of 5 or higher. But overall stratigraphic successions in the two areas differ in detail (Dumoulin and Harris, 1987a, b, and unpub. data; Harris and others, 1988; Karl and others, 1989).

Rocks of pre-Ordovician age have not been recognized in the western Baird Mountains; the metacarbonate succession begins with a relatively thick (at least 400 m) interval of Lower and Middle Ordovician carbonate strata deposited chiefly in restricted to normal marine, very shallow to deeper water platform environments (fig. 24). These rocks comprise two distinct, roughly coeval facies: dolostone with abundant fenestral fabric and bioturbated to laminated, argillaceous metacarbonate rocks. Conodonts indicate that these strata were deposited during early Early to early Middle Ordovician time (*Rossodus manitouensis* Zone to *Histiodella altifrons* Zone of the NAMP conodont zonation); the bulk of both facies accumulated during early Fauna D time. Conodont faunas include chiefly WNAMP and some Siberian-Alaskan (SAP) province endemics. One sample of argillaceous metalimestone contains reworked conodonts of Late Cambrian age, in addition to Early Ordovician conodonts (fig. 24). A thin layer of dark, fine-grained metalimestone occurs in the lower part of the argillaceous metacarbonate section, and similar layers overlie the section. These layers contain cool-water conodonts of middle Early and early Middle Ordovician age, respectively; that is, slightly older than the oldest dated strata of unit Opc in the eastern Baird Mountains, and equivalent in age to the middle beds of unit Opc.

Younger Ordovician rocks appear to be rare in the western Baird Mountains and are of uncertain thickness. Middle Middle Ordovician dolostone contains Siberian province conodonts indicative of a very restricted, warm, shallow-water, innermost platform environment. A single locality of definitively Upper Ordovician marble contains a

Figure 24. Generalized composite stratigraphic section and ▶ selected conodonts of the metacarbonate succession in the western Baird Mountains (data from Dumoulin and Harris, 1987a, b, and unpub. data; Karl and others, 1989). Thicknesses are minima. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American province faunas. See figure 5 and table 1 for explanation of symbols and identification of fossils, respectively.


WESTERN BAIRD MOUNTAINS
METERS
SYSTEM/ SERIES
SERIES/STAGE/ SUBSTAGE (ZONE/FAUNA)
STRATIGRAPHIC UNIT
600
550
500
450
400
350
300
250
200
150
100
50
0
DEVONIAN
LOWER
MIDDLE
EIFELIAN
EMSIAN
SILURIAN
UPPER
LOWER
LUDLOVIAN
WENLOCKIAN
ORDOVICIAN
UPPER
GAMACHIAN TO M. MAYSVILLIAN
MIDDLE
(C. sweeti Zone?)
(H. altifrons Zone)
LOWER
ARENIGIAN
(O. communis Zone)
(MIDDLE FAUNA D)
(LOW FAUNA D)
TREMADOCIAN
(P. elegans Zone)
(R. manitouensis Zone)
BAIRD GROUP
F
F
F
F
F
30
57
75
50
65
21
35
88
105
66
90
41
20
11
33
aff.
42
99
63
86
60
85
62
37
26
Redeposited Late Cambrian species
102
13
101
14
98
40

cosmopolitan conodont fauna that includes some North American forms; these strata are equivalent in age to the lower part of the Mathews River unit in the Snowden Mountain area and the lowest part of unit DOc in the eastern Baird Mountains and appear to have been deposited in a middle to outer shelf setting.

Silurian strata are lithologically and biostratigraphically similar to those in the eastern Baird Mountains but are more restricted in age (Llandoverian rocks have not been recognized) and areal distribution; the section may be several hundred meters thick. Lower and Middle Devonian (Emsian and Eifelian) carbonate strata, rare or absent in the Snowden Mountain area and eastern Baird Mountains, are widely distributed and were deposited in a variety of shelf and platformal environments. These rocks contain chiefly shallow-water, cosmopolitan conodonts, as well as representatives of a more provincial form, *Icriodus taimyricus*, a Siberian-northern North American endemic. The section is at least 60 m (and probably more than 100 m) thick and contains locally abundant amphiporid stromatoporoids, corals, bryozoans, gastropods, and brachiopods.

Correlation.—The metacarbonate succession in the western Baird Mountains has some points of correspondence with the metacarbonate succession in the Snowden Mountain area but has other notable differences. Cambrian conodonts reworked into Lower Ordovician carbonate deposits testify that pre-Ordovician sediments once existed in the western Baird Mountains, but no strata similar to the Dillon Mountain area metacarbonate rocks, or the Cambrian Snowden Mountain unit, have been found in the western Bairds. On the other hand, the thick, widely distributed Lower Ordovician section in the western Baird Mountains has no established counterpart in the Snowden Mountain area. No lithologic equivalent of the basinal Middle Ordovician Snowden Creek unit is known in the western Bairds, although brief episodes of cooler and (or) deeper water produced a few thin dark carbonate layers. Upper Ordovician and Silurian strata are lithologically similar in the two regions, but rocks of definite Early Silurian age are not known in the western Bairds. Lower and Middle Devonian metacarbonate rocks are widespread in the western Bairds but appear to be rare in the Snowden Mountain area.

YORK MOUNTAINS

Description.—The (meta)carbonate succession in the western Baird Mountains is similar in many ways to that in the York Mountains on the western Seward Peninsula (fig. 20). The York Mountains carbonate succession consists of more than 1 km of Ordovician, Silurian, and Devonian(?) limestone, argillaceous limestone, and dolostone deposited in predominantly shallow water environments (Sainsbury, 1969, 1972; Till and Dumoulin, in press; Dumoulin and Harris, unpub. data; Harris and others, 1988; Vandervoort, 1985). It is largely unmetamorphosed; most conodonts have CAIs of 2 to 4.

Ordovician rocks predominate in the York Mountains carbonate succession (fig. 25). The oldest dated rocks are Early Ordovician and comprise two lithofacies, units Oal and Ol[6] of Sainsbury (1969). Unit Oal consists of at least 350 m of dolomitic, locally argillaceous, limestone. Unit Ol is primarily micritic limestone and is at least 450 m thick. Both units are characterized by 8- to 15-m-thick, shallowing-upward cycles (Vandervoort, 1985) deposited in a range of subtidal to supratidal environments; the overall section accumulated in a deepening-upward regime. Units Oal and Ol produce chiefly tropical, cosmopolitan conodonts of early Arenigian (low Fauna D) age and yield some WNAMP and some SAP elements. The uppermost beds of unit Ol contain early middle Arenigian, cooler and (or) deeper water conodonts of the Baltoscandic Province, and trilobites very similar to forms described from Novaya Zemlya, northern Siberia (Ormiston and Ross, 1976).

Unit Ol is overlain, apparently conformably, by 7 to 30 m of black, graptolitic shale with minor interbedded black limestone, which grades upward into flaggy, thin-bedded limestone with shale partings (unit Olsh[6] of Sainsbury, 1969). The lower limestone beds contain calcified radiolarians; higher beds are graded and allodapic. Unit Olsh is at least 300 m thick; it yields cool-water, pandemic conodonts of latest Arenigian and earliest Llanvirnian age and accumulated in a shallowing-upward regime. A fault-bounded section of dark limestone (unit Odl[6] of Sainsbury, 1969) yields cephalopods of late Llanvirnian to early Llandeilian age and probably accumulated in middle to outer shelf conditions.

Upper Ordovician and Silurian strata (unit SOdl[6] of Sainsbury, 1972) are at least 340 m thick in the York Mountains. Upper Ordovician beds are slightly dolomitic, fossiliferous limestone; rugose corals (*Bighornia*) indicate a possibly Richmondian age. Conodonts from these strata include pandemic forms, WNAMP elements, and some SAP elements (*Plectodina*? *tunguskaensis*) and are characteristic of a warm, relatively shallow-water biofacies. These rocks also contain the trilobite *Monorakos*, a form known previously only from the Siberian and Kolyma platforms (Ormiston and Ross, 1976), and brachiopods and gastropods with Siberian affinities (Potter, 1984; Blodgett and others, 1992b). Silurian rocks are chiefly dolostone, contain 5- to 8-m-thick shallowing-upward cycles, and are of Ludlovian age. The youngest rocks known in the York Mountains carbonate succession are of probable late Ludlovian to Early Devonian age (Allan Pedder, Geological Survey of Canada, oral commun., 1988).

[6]Oal, Ordovician argillaceous limestone and limestone; Ol, Ordovician limestone and argillaceous limestone; Olsh, Ordovician limestone and shale; Odl, dark limestone; SOdl, Silurian and Ordovician limestone and dolomitic limestone.

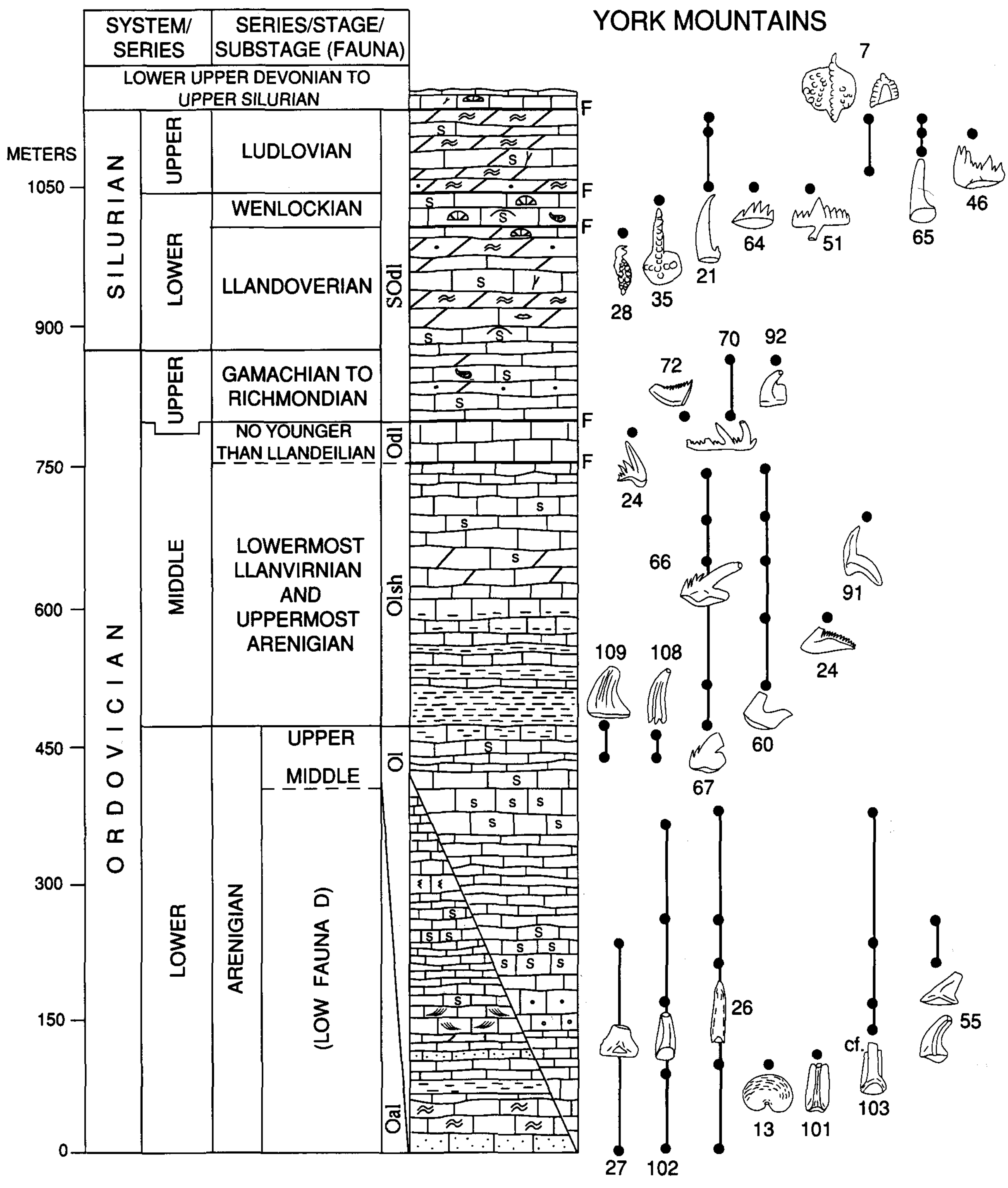


Figure 25. Generalized composite stratigraphic section and selected conodonts of the carbonate succession in the York Mountains (data from Sainsbury, 1969, 1972; Till and Dumoulin, in press; Dumoulin and Harris, unpub. data). Letter symbols represent map units of Sainsbury (1969, 1972): Oal, Ordovician argillaceous limestone and limestone; Ol, Ordovician limestone and argillaceous limestone; Olsh, Ordovician limestone and shale; Odl, dark limestone; SOdl, Silurian and Ordovician limestone and dolomitic limestone. All thicknesses are minima, based on partial sections measured by the authors; Sainsbury (1969) reports greater thicknesses for most of these units, but his estimates probably include structural repetitions. European series names are used for intervals containing dominantly cosmopolitan faunas, whereas North American series and (or) stage names are used for intervals containing chiefly North American province faunas. See figure 5 and table 1 for explanation of symbols and identification of fossils, respectively.

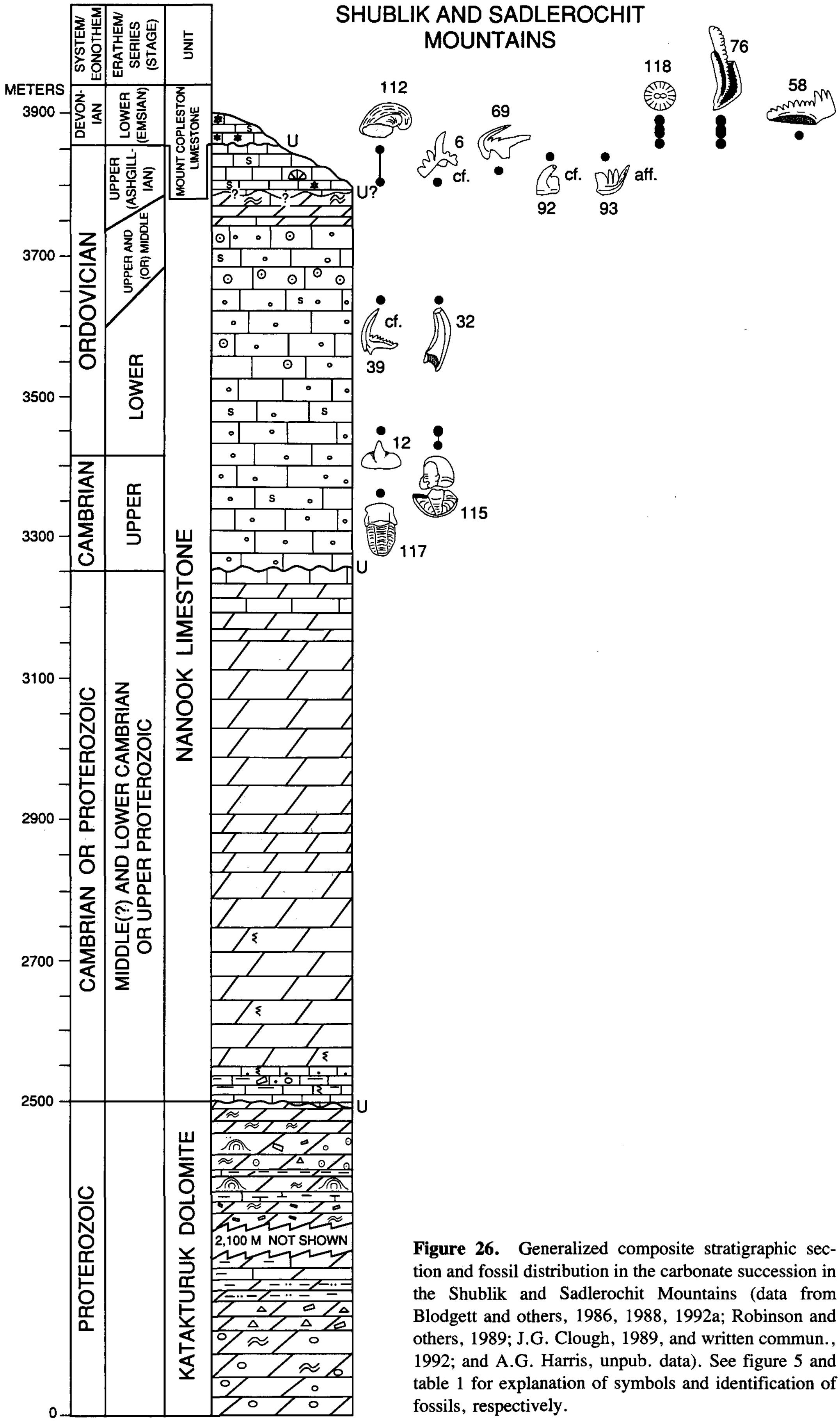


Figure 26. Generalized composite stratigraphic section and fossil distribution in the carbonate succession in the Shublik and Sadlerochit Mountains (data from Blodgett and others, 1986, 1988, 1992a; Robinson and others, 1989; J.G. Clough, 1989, and written commun., 1992; and A.G. Harris, unpub. data). See figure 5 and table 1 for explanation of symbols and identification of fossils, respectively.

Correlation.—Differences between the York Mountains and Snowden Mountain (meta)carbonate successions are most marked in pre-Middle Ordovician rocks. No definitively Cambrian or older strata are known in the Yorks, but Lower Ordovician rocks are thick and widely distributed. Middle Ordovician and younger rocks in the two areas correspond better. The lower part of unit Olsh correlates lithologically and faunally with part of the Snowden Creek unit, which suggests that basins existed in both regions during early Middle Ordovician time. The Snowden Mountain area basin received more siliciclastic input and persisted longer than its counterpart in the York Mountains. Upper Ordovician and Silurian strata are also similar in the two areas, but Richmondian rocks in the York Mountains formed in slightly more normal marine and deeper water than coeval Snowden Mountain area strata. Definitively Devonian carbonate rocks are rare or absent in the York Mountains and appear to be uncommon in the Snowden Mountain metacarbonate succession.

SHUBLIK AND SADLEROCHIT MOUNTAINS

Description.—A carbonate platform succession somewhat similar to that in the western Baird and York Mountains occurs in the Shublik and Sadlerochit Mountains in the northeastern Brooks Range (Clough, 1989; Blodgett and others, 1986, 1988, 1992a; Clough and others, 1988, 1990). These rocks are not metamorphosed and yield conodonts with a CAI of 4. The succession comprises the Ķatakturuk Dolomite (at least 2,500 m thick), the Nanook Limestone (about 1,200 m thick), and the Mount Copleston Limestone (71 m thick) (fig. 26).

The Shublik-Sadlerochit Mountains carbonate succession (as used herein) is distinguished by a thick sequence of pre-Ordovician carbonate rocks. The Katakturuk Dolomite consists of a variety of carbonate lithologies deposited in shallow subtidal to supratidal settings; it includes abundant stromatolites and coated grains and is considered to be of Proterozoic age. The overlying Nanook Limestone also contains a variety of shallow-water carbonate lithofacies; the lower two-thirds of the formation have yielded no body fossils (although the basal part of the unit contains burrows) and is thought to be chiefly Proterozoic or Early and Middle(?) Cambrian in age. These unfossiliferous strata are overlain by at least 160 m of Upper Cambrian peloidal pack-grainstone, which yields trilobites with North American paleobiogeographic affinities.

The upper part of the Shublik-Sadlerochit Mountains carbonate succession is Ordovician (upper one-third of the Nanook Limestone) and Devonian (Mount Copleston Limestone) in age. Lower Ordovician strata are as much as 300 m thick and consist chiefly of peloidal pack-grainstone. These rocks yield trilobites with affinities to the Bathyurid Province, which occupied low-paleolatitude sites in North America, Greenland, northeastern Russia, and Kazakhstan, and locally abundant *Clavohamulus densus*, a NAMP conodont that indicates a warm, partly restricted, very shallow water depositional environment. *Clavohamulus densus* is diagnostic of the *Rossodus manitouensis* Zone of early Early Ordovician age. An interval of Middle and (or) Late Ordovician age, as much as 120 m thick, lies between definitive Lower and Upper Ordovician strata. The uppermost 44 m of the Nanook Limestone are definitively Late Ordovician in age, consist of interbedded dolostone and lime mudstone, and yield a relatively diverse gastropod fauna, as well as other mollusks and ostracodes and the pentamerid brachiopod *Tcherskidium* sp., which has Siberian biogeographic affinities. Upper Ordovician strata produce conodont faunas similar to those from the eastern Baird Mountains, including the Siberian-northern North American element *Phragmodus* n. sp. but having a greater diversity of WNAMP species such as *Aphelognathus* aff. *A. divergens, Culumbodina occidentalis*, and *Pseudobelodina vulgaris vulgaris*. Locally, in the Shublik Mountains, the Mount Copleston Limestone of Emsian (late Early Devonian) age disconformably overlies the Nanook Limestone. This Devonian unit is mostly lime mudstone with local banks of pentamerid brachiopods and lagoonal deposits rich in amphiporid stromatoporids; other fossils include two-hole crinoid columnals and conodonts of the *gronbergi* to *serotinus* Zones, inclusive.

Correlation.—The carbonate succession in the Shublik and Sadlerochit Mountains differs considerably from that in the Snowden Mountain area. The Shublik-Sadlerochit pre-Ordovician section is much thicker than known or suspected coeval rocks in the Snowden Mountain area; well-dated Cambrian strata are younger than the Middle Cambrian Snowden Mountain unit and include faunas with North American, not Siberian, biogeographic affinities. The relatively thick, Lower Ordovician part of the Nanook Limestone has no dated equivalents in the Snowden Mountain area, and the basinal, Middle Ordovician Snowden Creek unit has no lithologic counterpart in the Shublik-Sadlerochit carbonate succession. Upper Ordovician strata in the upper part of the Nanook correspond lithologically and faunally with coeval rocks in the Snowden Mountain metacarbonate succession, but Silurian strata are missing in the Shublik and Sadlerochit Mountains. The Emsian Mount Copleston Limestone is lithologically similar to, and may correlate with, Emsian and (or) Eifelian metalimestone in the Snowden Mountain area. Both units contain the distinctive two-hole crinoid columnals.

DOONERAK WINDOW

Description.—Lower Paleozoic rocks, informally named the Apoon assemblage (Julian, 1986), are exposed in a structural high near Mount Doonerak, about 40 km northwest of Snowden Mountain (fig. 20). The assemblage consists of black slate and argillite, green and gray phyllite, volcaniclastic conglomerate, mafic tuff and pyroclastic breccia, massive basalt, and minor marble; it is severely deformed and metamorphosed to lowest greenschist facies (Julian, 1986, 1989). Structural complexity precludes determination of stratigraphic thickness; structural thickness of the assemblage exceeds 3,000 m (Julian, 1989).

The age of the Apoon assemblage is poorly constrained but appears to be early Paleozoic. A few fossils have been recovered from metasedimentary rocks in the western part of the Doonerak window. North of Frigid Crags (about 15 km southwest of Mount Doonerak), dark-gray phyllite contains Early Silurian (Llandoverian) graptolites and Silurian conodonts, and siliceous volcaniclastic rocks produced Ordovician, probably Middle Ordovician, conodonts (Repetski and others, 1987). In the hills south of Wolf Creek (about 30 km southwest of Mount Doonerak), sandy metalimestone contains Middle (probably early Middle) Cambrian trilobites, as well as protoconodonts, hyolithids, and acrotretid brachiopods; the fauna has Siberian biogeographic affinities (Dutro and others, 1984a, 1984b). Two marble bodies in this area produced protoconodonts of Middle Cambrian to Early Ordovician age (Dutro and others, 1984a). Mafic dikes and sills in the Apoon assemblage have been dated by K-Ar and Ar-Ar techniques and yield ages of about 470 and 350 Ma (Dutro and others, 1976); these values fall within the early Middle Ordovician and late Early Mississippian, respectively (based on Harland and others, 1990; Bally and Palmer, 1989).

The Apoon assemblage is interpreted as a subduction-related magmatic arc complex, deposited in a back-arc basin (Julian, 1989). An undated marble body in the eastern Doonerak area locally preserves a limestone breccia texture, contains shale-rip-up clasts, and is thought to be a carbonate debris-flow deposit (Julian, 1989). Cambrian metacarbonate layers from the Wolf Creek area contain calcareous lithiclasts (Dumoulin, unpub. data) and could also have been redeposited.

Correlation.—Julian (1989) suggested that limy debris-flow deposits within the Apoon assemblage were derived from a carbonate platform in the Snowden Mountain area. However, no lithologic or faunal data have yet been found to confirm this suggestion because dated metacarbonate layers in the Apoon assemblage are older (Middle Cambrian to Early Ordovician) than the main period of platform carbonate deposition at Snowden Mountain (Late Ordovician and Silurian).

DEVONIAN SILICICLASTIC UNITS

Metasedimentary rocks that are at least in part correlative with Devonian siliciclastic units in the Snowden Mountain area occur in the western (and possibly, in the eastern) Baird Mountains. The Baird Mountains units are briefly described below (description based on data in Karl and others, 1989) and then compared to the Snowden Mountain units.

DEVONIAN SILICICLASTIC UNITS IN THE BAIRD MOUNTAINS

NAKOLIK RIVER UNIT

The Nakolik River unit is an informal name proposed by Karl and others (1989) for metasedimentary rocks that crop out in the western Baird Mountains. Two subunits are distinguished, units Dnl and Dnu.[7] Unit Dnl consists of metalimestone and marble intercalated with subordinate (20–40 percent) quartzose metaclastic rocks (fig. 27*A*). Metalimestone intervals are a few to several tens of meters thick, contain locally abundant corals (fig. 27*B*), stromatoporoids, and brachiopods, and formed as biohermal buildups on a shelf or platform subject to periodic influx of siliciclastic material. Other limy layers consist of quartzose calcarenite deposited by storms or in high-energy shoals. Unit Dnl yields rare conodonts of latest Givetian and Frasnian age that represent the polygnathid-icriodid biofacies. Unit Dnu consists primarily of green, gray, and maroon phyllite, as well as lesser amounts of metalimestone, quartzose metasandstone, and metaconglomerate; it is laterally gradational to, and locally gradationally overlies, unit Dnl. Metalimestone layers are similar to those in unit Dnl but are generally less than 10 m thick. Conodonts obtained from these layers are of Frasnian age; polygnathids dominate the assemblages, but minor ancyrodellids and palmatolepids occur and suggest an outer shelf depositional environment.

The Nakolik River unit is gradationally overlain by the Hunt Fork Shale; the base of the unit is not exposed. The unit is transitional in time and space between the Lower and Middle Devonian carbonate platform sequence of the upper part of the Baird Group to the south and the dominantly clastic, mostly Upper Devonian Endicott Group to the north.

UNIT Pzqs

Unit Pzqs[8] of Karl and others (1989) crops out in the northeastern Baird Mountains and consists of quartz-pebble metaconglomerate, quartzose, locally calcareous metasandstone, and green, maroon, and black (carbonaceous) phyllite. Coarse-grained metaclastic rocks are primarily quartzose but include some volcanic rock fragments, and the unit

[7]Dnl, Devonian limestone of Nakolik River; Dnu, Devonian phyllite, carbonate, and clastic rocks of Nakolik River, undivided.

[8]Pzqs, Paleozoic quartz conglomerate, sandstone, and siliceous phyllite.

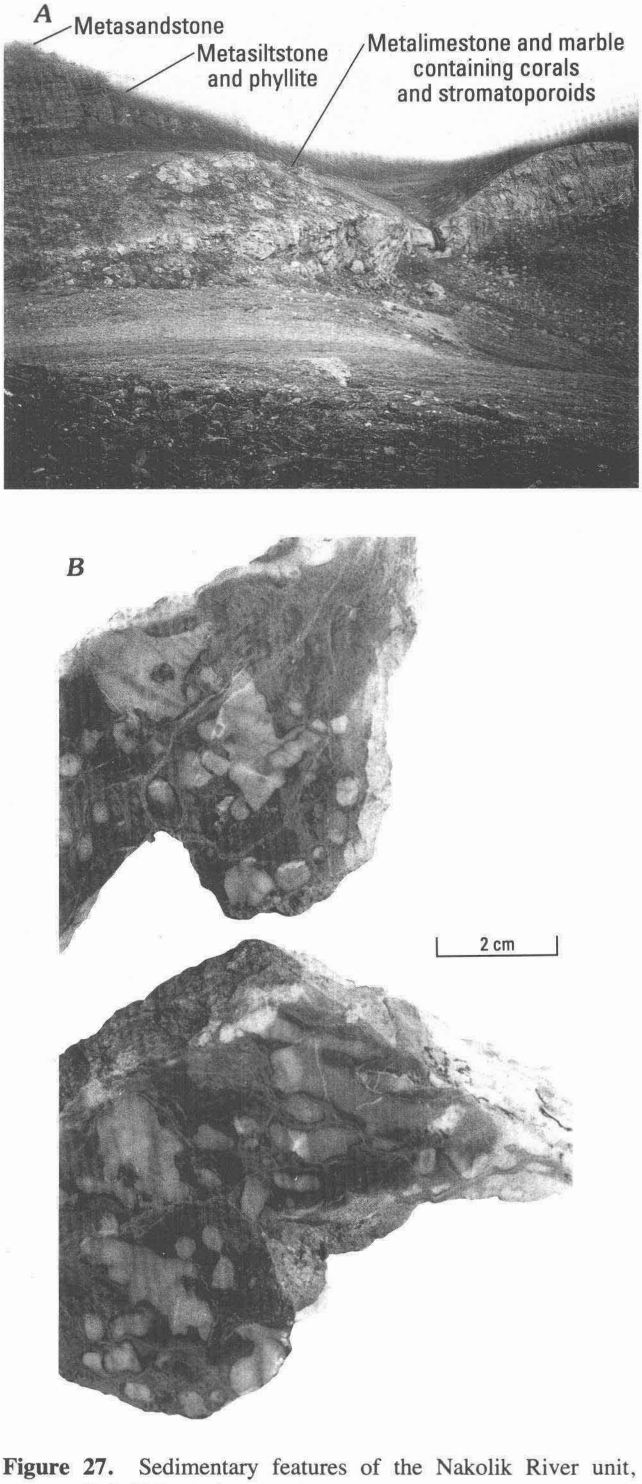


Figure 27. Sedimentary features of the Nakolik River unit, western Baird Mountains. *A*, Outcrops of the Nakolik River unit. *B*, Colonial coral in fossiliferous metalimestone.

is "intimately associated" (Karl and others, 1989, p. 33) with siliceous volcanic rocks (metarhyolite). No fossils have been recovered from unit Pzqs, but the unit is thought to be Middle and Late Devonian in age on the basis of regional relationships (Karl and others, 1989). Unit Pzqs overlies the Devonian(?) and older eastern Baird Mountains metacarbonate succession described above. In most places the contact is a fault, but a depositional contact has been reported from one locality (Karl and others, 1989). The unit is overlain by gray phyllite assigned to the Hunt Fork Shale; this contact is covered and may be structural and (or) stratigraphic.

HUNT FORK SHALE

Rocks referred to the Hunt Fork Shale by Karl and others (1989) crop out in both the eastern and western Baird Mountains. These strata have been metamorphosed to lower greenschist facies and consist of gray to green or black phyllite and subordinate siliceous or calcareous metasiltstone and metasandstone. Metasandstone layers are graded, as much as 1 m thick, and interpreted as turbidites; some contain transported fossil debris. In both its eastern and western outcrop areas, the Hunt Fork Shale is intruded by massive mafic sills and dikes; at one western locality, the unit contains a 30-m-thick section of pillowed(?) mafic flows. No fossils have been found in this unit in the eastern Baird Mountains, but western outcrops yield brachiopods and mollusks of late Frasnian or early Famennian age. Karl and others (1989) suggest a prodelta, outer shelf or slope depositional setting.

COMPARISON OF SNOWDEN MOUNTAIN AND BAIRD MOUNTAINS DEVONIAN SILICICLASTIC UNITS

Like the Snowden Mountain area, the Baird Mountains contain several siliciclastic units of Devonian age that are structurally intercalated with older metacarbonate rocks. The lithology, fauna, age, and general depositional setting of the Nakolik River unit are similar to those of the Beaucoup Formation and Nutirwik Creek units in the Snowden Mountain area. Unit Dnl and the Beaucoup Formation contain fine- and coarse-grained siliciclastic rocks, biohermal buildups, redeposited calcarenite layers, and conodonts of the polygnathid-icriodid biofacies. Unit Dnl is more calcareous than the Beaucoup Formation and appears to be, in part, older; the oldest faunas known from unit Dnl are Eifelian or early Givetian in age, whereas well-dated samples from the Beaucoup Formation are no older than latest Givetian. Unit Dnu and the Nutirwik Creek unit consist primarily of purple and green phyllite but include some conglomerate and minor metalimestone; limy layers produce Frasnian conodonts, including some forms typical of deeper water (outer shelf or slope) settings. Unit Pzqs is also lithologically similar to much of the Nutirwik Creek unit; both include pebble conglomerate, maroon, green, and black phyllite, and volcanic material. Limestone lenses have not been noted in unit Pzqs, however, and its age is poorly constrained. Unit Pzqs, the Nakolik River unit, and the Nutirwik Creek unit are spatially associated with, and may have been deposited on, older metacarbonate successions.

Age, lithology, and depositional setting of the Hunt Fork Shale are similar in both the Baird Mountains and Snowden Mountain area, although the unit appears to contain less limestone and is consequently less well dated in the Baird Mountains. The Hunt Fork Shale is thought to depositionally overlie the Nakolik River unit in the western Baird Mountains (Karl and others, 1989), but all contacts between the Hunt Fork Shale and the Beaucoup Formation and Nutirwik Creek units in the Snowden Mountain area appear to be faults. Finally, mafic igneous rocks intrude the Beaucoup Formation in the Snowden Mountain area but are intercalated with and intrude the Hunt Fork Shale in the Baird Mountains.

DISCUSSION

The present configuration of pre-Carboniferous rocks in northern Alaska is a result of Mesozoic tectonism; the original configuration of these rocks is unknown. Paleogeographic reconstruction of northern Alaska remains contentious because fundamental tectonic questions are unresolved. In particular, the cause and effects of Devonian orogeny in the Brooks Range, and the position of northern Alaska prior to Mesozoic opening of the Canada basin, are poorly understood (Nelson and others, 1993; Lawver and Scotese, 1990).

Most workers interpret pre-Carboniferous carbonate strata of northern Alaska as a platform or continental margin assemblage formed on continental crust, but the Paleozoic position of this crust is poorly constrained. Proposed Paleozoic configurations include northern Alaska as a northwest-protruding extension of the North American craton (Churkin and others, 1984, 1985) or as an isthmus connection between North America and Siberia (Churkin and Trexler, 1981; Rowley and others, 1985). Other authors have hypothesized that northern Alaska and the Chukotka region of northeastern Siberia constituted a discrete continental block with a Paleozoic kinematic history distinct from that of North America (for example, Sweeney, 1982).

Alternatively, pre-Carboniferous strata now found in northern Alaska may have accumulated along several disparate continental margins and then juxtaposed by later tectonic events. Grantz and others (1991) suggested that the Brooks Range is underlain by Siberian and North American crustal fragments assembled during early Paleozoic convergence. These authors interpret rocks with "Siberian" faunas, such as pre-Devonian strata in the Snowden Mountain area, as Siberian crustal fragments and metavolcanic rocks in the Doonerak window as remnants of the arc formed during this convergent event.

Various techniques can be used to test the models for origin of pre-Carboniferous carbonate strata in northern Alaska discussed above. Approaches include (1) establishing displacement histories of carbonate successions through paleomagnetic studies, (2) identifying structures and (or) rock associations (such as ophiolite assemblages or volcanic arc deposits) that mark suture zones between carbonate successions, (3) using microfacies analyses to assess the degree of lithologic and biotic similarity between individual (meta)carbonate successions, and (4) comparing paleobiogeographic affinities of faunas in distinct (meta)carbonate successions. Reliable primary magnetic components have not been obtained from Paleozoic rocks of the Brooks Range or the Seward Peninsula (Plumley and Tailleur, 1987; Plumley and Reusing, 1984), but the other three methods have been used to investigate the origin of pre-Carboniferous strata of northern Alaska.

Identifying boundaries between Paleozoic crustal fragments is hindered by the masking effects of younger tectonic events on older structures and the difficulty of recognizing and precisely dating ancient suture assemblages. Metavolcanic rocks of early Paleozoic age in the Doonerak window, and of Early and Late Cambrian age in the northeastern Brooks Range, have been interpreted as possible remnants of oceanic crust trapped during a pre-Carboniferous continental collision (Moore, 1987; Grantz and others, 1991) (fig. 20). These rocks yield ambiguous geochemical signatures, however, and could also have formed along the North American continental margin (Moore, 1987).

Deep-water carbonate rocks are another lithology that might occur along suture zones between continental carbonate terranes, but these strata could also accumulate in intracratonic basins. Slope and basinal carbonate rocks of Cambrian to Devonian(?) age occur on the northeastern and southeastern Seward Peninsula (Dumoulin and Till, 1985; Till and others, 1986; Ryherd and Paris, 1987; Dumoulin and Harris, unpub. data), and carbonate turbidites of Silurian and (or) Devonian age crop out in the Ambler River and Wiseman quadrangles (Dumoulin and Harris, 1988 and unpub. data) (fig. 20). Nothing is known, however, about the type of basement (oceanic or continental) on which these sequences were deposited.

Zones where disparate continental fragments may have been juxtaposed are marked by suture assemblages, but distinguishing the fragments requires detailed stratigraphic comparisons. Comparative lithofacies analysis and paleobiogeography have been used in the Appalachians (Williams and Hatcher, 1983) and the North American

Cordillera (Monger and Ross, 1984) to recognize “exotic” Paleozoic terranes thought to have been displaced great distances before accretion to the North American continental margin. Application of such techniques to the pre-Carboniferous strata of northern Alaska has been limited, however, because relatively detailed paleontologic and sedimentologic data have only recently been obtained from much of this region. These data are summarized below, and their implications for the Paleozoic history of northern Alaska are briefly explored.

COMPARATIVE MICROFACIES ANALYSIS

One approach that could help identify “exotic” continental fragments in northern Alaska is comparative analysis of microfacies in the pre-Carboniferous (meta)carbonate successions. Carbonate rocks deposited along the same margin or platform should show similar successions of lithofacies, biofacies, and depositional environments. Coeval rocks formed on separate continents, in contrast, could differ greatly, because they might have different sediment sources, paleoclimates, and (or) subsidence histories. Distinction between these end-member cases is not necessarily straightforward, however. Intracratonic basins can develop within a single continental block and give rise to a variety of dissimilar but coeval facies. Alternatively, global changes such as eustatic shifts could produce uniform effects on disparate continental margins.

Similarities and differences between the (meta)carbonate successions of northern Alaska are summarized below and in figure 28. The metacarbonate succession in the Snowden Mountain area correlates best, lithologically and faunally, with the metacarbonate succession in the eastern Baird Mountains, but also has similarities with (meta)carbonate successions in the western Baird, York, and Shublik and Sadlerochit Mountains. Differences between these (meta)carbonate successions could reflect origins in several discrete carbonate platforms but also could be explained through variation in subsidence rates, erosion, and clastic input along a single continental margin.

Strata of Proterozoic and Cambrian age are thickest in the Shublik and Sadlerochit Mountains and have not been observed in the York and western Baird Mountains. Relatively deep-water facies (deposited in outer shelf and (or) slope settings) of Middle Cambrian and older(?) age are known in the eastern Baird and Snowden Mountain metacarbonate successions and may also occur in Doonerak window rocks. Relatively shallow-water facies of Late Cambrian age are recognized in the eastern Baird and Shublik-Sadlerochit (meta)carbonate successions.

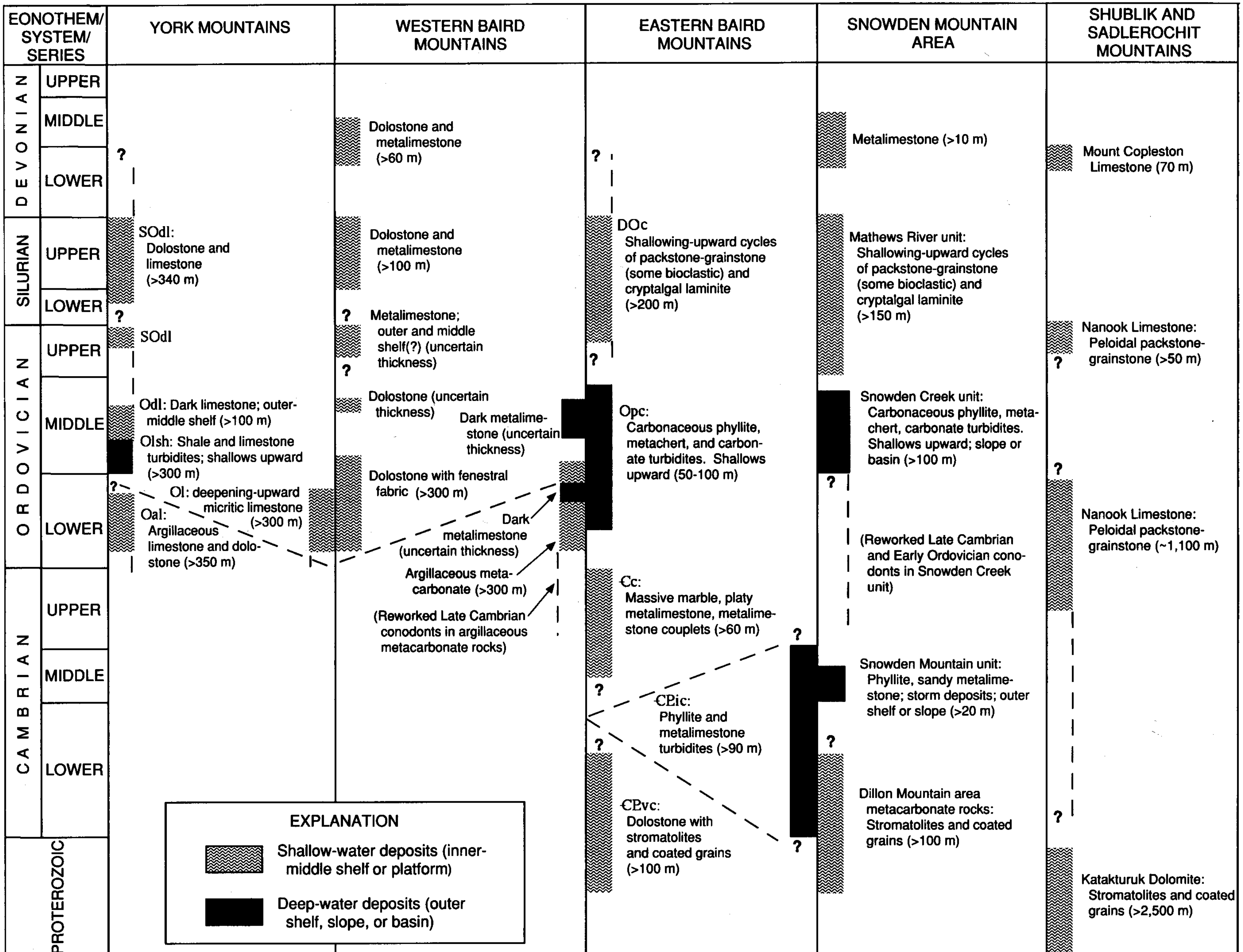
Lower Ordovician platform carbonate rocks are widely distributed in the York, western Baird, and Shublik and Sadlerochit Mountains. The western sections are thicker and differentiated into at least two distinct lithofacies; the Shublik-Sadlerochit section appears relatively uniform. Carbonate platform rocks of Early Ordovician age have not been identified in the eastern Baird Mountains or Snowden Mountain area; instead, basinal facies (carbonaceous phyllite, siltstone, and metachert) appear to have accumulated during this time.

Middle Ordovician strata in the eastern Baird and Snowden Mountain metacarbonate successions consist chiefly of deep-water slope to basinal facies; both sections shallow upward and contain abundant fine-grained siliciclastic detritus. The Middle Ordovician section in the York Mountains is similar but contains less siliciclastic material and a larger proportion of somewhat shallower (outer to middle shelf) facies. Other Middle Ordovician sections are dominated by platform carbonate rocks; deep-water facies of Middle Ordovician age appear to be a minor part of the western Baird metacarbonate succession and have not been reported from the Shublik and Sadlerochit Mountains. Global sea level was high during the Llanvirnian; relatively deep-water facies characterize many Llanvirnian sections worldwide.

Carbonate strata of Late Ordovician through Middle Devonian age are generally similar across northern Alaska; variations appear to reflect differential erosion during Early Silurian and (or) post-Early Devonian time. Upper Ordovician strata were deposited in a shallowing-upward shelf or platform setting; this pattern has been documented in all successions with the exception of the western Baird Mountains, where Upper Ordovician strata appear to be scarce. Lower and Upper Silurian strata occur in the York, eastern and western Baird, and Snowden Mountain (meta)carbonate successions. No Silurian rocks have been found in the Shublik and Sadlerochit Mountains.

Meter-scale shallowing-upward cycles have been noted in Upper Ordovician strata in the eastern Baird and Snowden Mountain metacarbonate successions and in Silurian strata in the York, western Baird, eastern Baird, and Snowden Mountain (meta)carbonate successions. Carbonate facies and depositional patterns in Ordovician and Silurian strata in northern Alaska correlate well with published eustatic curves for the early Paleozoic. Global sea level was high at the base of the Ashgillian and then fell sharply throughout the remainder of the Late Ordovician (Ross and Ross, 1988). The Silurian eustatic curve is marked by a number of short-term rises and falls (Ross and Ross, 1988) so small-scale depositional cycles are not surprising in strata of this age.

Lower and Middle Devonian carbonate rocks appear to be rare in the Snowden Mountain area, are rare or absent in the eastern Baird and York Mountains, and are only locally present in the Shublik and Sadlerochit Mountains. The thickest and most widely distributed section of Lower and Middle Devonian carbonate rocks occurs in the western Baird Mountains. Global sea level was relatively low during


EONOTHEM/ SYSTEM/ SERIES
YORK MOUNTAINS
WESTERN BAIRD MOUNTAINS
EASTERN BAIRD MOUNTAINS
SNOWDEN MOUNTAIN AREA
SHUBLIK AND SADLEROCHIT MOUNTAINS
DEVONIAN
UPPER
MIDDLE
LOWER
SILURIAN
UPPER
LOWER
ORDOVICIAN
UPPER
MIDDLE
LOWER
CAMBRIAN
UPPER
MIDDLE
LOWER
PROTEROZOIC
SOdl: Dolostone and limestone (>340 m)
SOdl
Odl: Dark limestone; outer-middle shelf (>100 m)
Olsh: Shale and limestone turbidites; shallows upward (>300 m)
Ol: deepening-upward micritic limestone (>300 m)
Oal: Argillaceous limestone and dolostone (>350 m)
Dolostone and metalimestone (>60 m)
Dolostone and metalimestone (>100 m)
Metalimestone; outer and middle shelf(?) (uncertain thickness)
Dolostone (uncertain thickness)
Dark metalimestone (uncertain thickness)
Dolostone with fenestral fabric (>300 m)
Dark metalimestone (uncertain thickness)
Argillaceous metacarbonate (>300 m)
(Reworked Late Cambrian conodonts in argillaceous metacarbonate rocks)
DOc
Shallowing-upward cycles of packstone-grainstone (some bioclastic) and cryptalgal laminite (>200 m)
Opc: Carbonaceous phyllite, metachert, and carbonate turbidites. Shallows upward (50-100 m)
Cc: Massive marble, platy metalimestone, metalimestone couplets (>60 m)
CPic: Phyllite and metalimestone turbidites (>90 m)
CPvc: Dolostone with stromatolites and coated grains (>100 m)
Metalimestone (>10 m)
Mathews River unit: Shallowing-upward cycles of packstone-grainstone (some bioclastic) and cryptalgal laminite (>150 m)
Snowden Creek unit: Carbonaceous phyllite, metachert, carbonate turbidites. Shallows upward; slope or basin (>100 m)
(Reworked Late Cambrian and Early Ordovician conodonts in Snowden Creek unit)
Snowden Mountain unit: Phyllite, sandy metalimestone; storm deposits; outer shelf or slope (>20 m)
Dillon Mountain area metacarbonate rocks: Stromatolites and coated grains (>100 m)
Mount Copleston Limestone (70 m)
Nanook Limestone: Peloidal packstone-grainstone (>50 m)
Nanook Limestone: Peloidal packstone-grainstone (~1,100 m)
Katakturuk Dolomite: Stromatolites and coated grains (>2,500 m)
EXPLANATION
Shallow-water deposits (inner-middle shelf or platform)
Deep-water deposits (outer shelf, slope, or basin)

the Early Devonian but began to rise in the Eifelian (Ross and Ross, 1988).

Carbonate-siliciclastic rocks of Middle and Late Devonian age occur in the Snowden Mountain area and western Baird Mountains; carbonate content is higher in the Baird Mountains units. Possibly correlative sequences that contain little carbonate material crop out in the eastern Baird Mountains. No strata definitively of this age are known in the York or Shublik and Sadlerochit Mountains.

Thus, carbonate platform development started as early as the latest Proterozoic in at least some parts of northern Alaska and had ended by the Early or Middle Devonian in all of the (meta)carbonate successions discussed above. Clastic influx and (or) Devonian orogeny may have caused the demise of early Paleozoic carbonate platforms in northern Alaska. Successions of mixed carbonate and siliciclastic material (with carbonate generally subordinate) of Middle and Late Devonian age are widely distributed across northern Alaska. A depositional relationship between older carbonate platform successions and younger carbonate-clastic units has been postulated by some workers but has not been proven in most areas. The best case for such a relationship can be made in the western Baird Mountains, where a continuous Devonian succession of Emsian, Eifelian, Givetian, Frasnian, and possibly Famennian age is present. The Emsian to Eifelian cessation of carbonate platform deposition in most of northern Alaska appears to roughly coincide (about 390 Ma; Aleinikoff and others, 1993) or slightly predate (370 ± 30 Ma; Nelson and others, 1993; Dillon and others, 1987b) intrusion of granitic plutons. These ages fall within the Early Devonian and Frasnian, respectively (based on Harland and others, 1990; Bally and Palmer, 1989).

Lithologic data from the pre-Carboniferous (meta)carbonate successions of northern Alaska could be explained through origin on three discrete carbonate platforms. The Snowden Mountain and eastern Baird metacarbonate successions are distinguished from other northern Alaska (meta)carbonate successions by well-developed basinal assemblages of chiefly Middle Ordovician age and the apparent absence of Lower Ordovician shallow-water carbonate rocks. The York and western Baird (meta)carbonate successions are characterized by a thick section of Lower Ordovician platformal carbonates and by relatively minor amounts of Middle Ordovician deeper water facies. The Shublik-Sadlerochit carbonate succession is similar to the York and western Baird (meta)carbonate successions but includes a thick section of Proterozoic and Cambrian strata not known in the west.

◀ **Figure 28.** Correlation and depositional environments of (meta)carbonate successions in the York, western and eastern Baird, Snowden, and Shublik and Sadlerochit Mountains. All rocks shown in the western Baird Mountains column are part of the Baird Group. Number in parentheses indicates thickness of unit.

An alternate explanation of the available data is that the pre-Carboniferous carbonate successions described above formed along a single continental margin that was near, and shared some faunal elements with, both the North American and Siberian continents (fig. 29). During Early and Middle Ordovician time, an intracratonic basin developed along part of the north Alaskan margin (eastern Baird and Snowden Mountain metacarbonate successions) while carbonate platform deposition continued elsewhere (York, western Baird, and Shublik-Sadlerochit (meta)carbonate successions). By Late Ordovician time, shallow-water carbonate deposition had spread again across the north Alaska margin, and these conditions persisted, with some interruptions, through at least the Early Devonian.

PALEOBIOGEOGRAPHY

Paleobiogeographic analysis is another technique that can shed light on the Paleozoic configuration of northern Alaska. "Siberian" and "North American" biogeographic affinities have been reported for various fossils from the pre-Carboniferous (meta)carbonate successions described above. The biogeography of Cambrian trilobites has attracted the most attention (Palmer and others, 1984; Dutro and others, 1984a, b; Grantz and others, 1991), but provinciality has also been noted in Ordovician trilobites, conodonts, brachiopods, gastropods, and corals. Silurian and Devonian faunas in northern Alaska appear relatively cosmopolitan.

The biogeographic affinities of Cambrian and Ordovician faunas from northern Alaska are summarized in table 2. Late Cambrian trilobites in the Shublik-Sadlerochit carbonate succession have North American affinities (Blodgett and others, 1986); Early Cambrian trilobites found in limy beds in the Marsh Fork volcanic rocks (informal unit of Moore, 1987), 50 km south of the Shublik Mountains, also have North American affinities (Dutro and others, 1972). Middle Cambrian rocks in the Doonerak window and at Snowden Mountain yield trilobites with Siberian affinities (Palmer and others, 1984). Lower Ordovician strata in the Shublik-Sadlerochit carbonate succession produce trilobites with affinities to the Bathyurid Province, which occupied low-paleolatitude sites in North America, northeastern Russia, Kazakhstan, and Greenland (Blodgett and others, 1986). Early and Late Ordovician trilobites from the York Mountains carbonate succession have Siberian affinities (Ormiston and Ross, 1976). Late Ordovician brachiopods and gastropods with Siberian affinities occur in the York, eastern Baird, and Shublik-Sadlerochit (meta)carbonate successions (Blodgett and others, 1988; Potter, 1984; Blodgett and others, 1992b). Some corals from the York Mountains (Oliver and others, 1975;

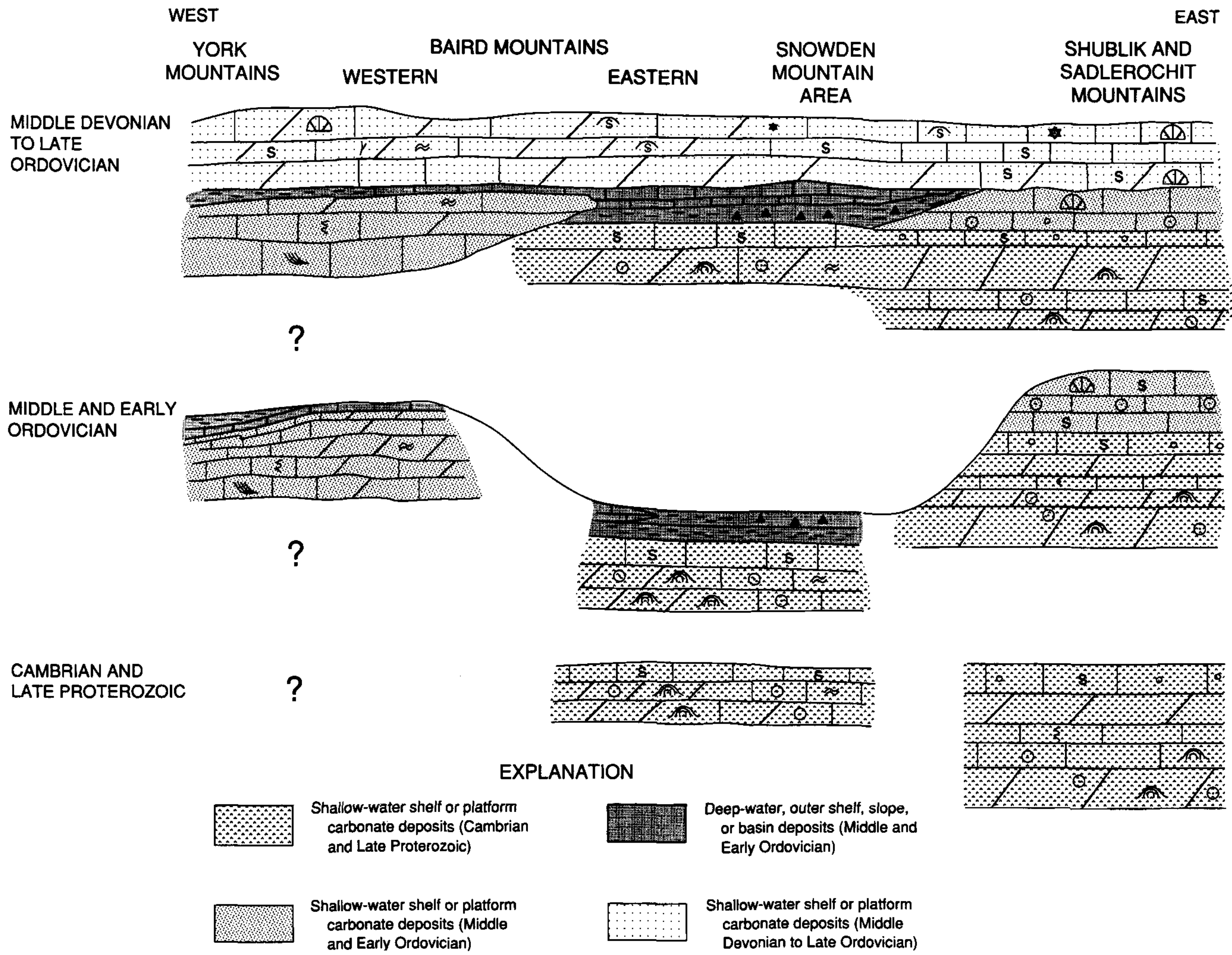


Figure 29. Schematic reconstruction of pre-Carboniferous carbonate successions in northern Alaska. During Late Proterozoic and Cambrian time, chiefly shallow-water carbonate facies accumulated in the eastern Baird Mountains, Snowden Mountain area, and Shublik and Sadlerochit Mountains; rocks of this age have not been found in the York Mountains or western Baird Mountains. During Early and Middle Ordovician time, chiefly shallow-water carbonate facies were deposited in the York Mountains and western Baird Mountains, basinal facies accumulated in the eastern Baird Mountains and Snowden Mountain area, and only shallow-water carbonate facies formed in the Shublik-Sadlerochit Mountains. During Late Ordovician to Middle Devonian time, neritic carbonate deposits accumulated across northern Alaska. See figure 5 for explanation of symbols.

R.J. Elias, University of Manitoba, written commun., 1986) and Snowden Mountain area (T.E. Bolton, written commun., 1992) have North American affinities.

Provinciality has also been noted in Ordovician conodont faunas from northern Alaska; species typical of WNAMP and SAP have been identified. Lower Ordovician strata in the York and western Baird (meta)carbonate successions yield chiefly tropical cosmopolitan (for example, *Acanthodus lineatus, Variabiloconus bassleri, Protopanderodus leei, Rossodus floweri, Scolopodus bolites,* and "*S.*" *gracilis*) and pandemic species (*Drepanodus arcuatus, Drepanoistodus forceps, Paltodus subaequalis*, and *Paroistodus parallelus)* together with fewer WNAMP (*Clavohamulus* n. sp., *Rossodus* n. sp., and *Histiodella* n. sp.) and SAP (*Fryxellodontus*? = *Acodina*? *bifida* of Abaimova, 1975) elements. Lowermost Ordovician beds in the Shublik and Sadlerochit Mountains yield NAMP conodonts (*Clavohamulus densus*). Middle Ordovician rocks in all of the northern Alaskan (meta)carbonate successions contain chiefly cosmopolitan forms, with the exception of some intervals in the western Baird metacarbonate succession; lowermost Middle Ordovician strata in this area contain NAMP elements and middle Middle Ordovician beds are dominated by SAP species (mostly acanthocodinids and stereoconids) (fig. 24). Upper Ordovician strata reveal a relatively complex pattern of conodont faunal affinities. Early Late Ordovician collections in the eastern Baird, Snowden, and Shublik-Sadlerochit

Table 2. Paleobiogeographic affinities of faunas from Cambrian and Ordovician (meta)carbonate successions in northern Alaska.

[All conodont data are from Dillon and others (1987a), Dumoulin and Harris (1987a), Blodgett and others (1988), Harris and others (1988), Karl and others (1989), unpublished data from U.S. Geological Survey collections, and this report. Numeral following entry indicates number of samples used for analysis was known. NAMP, North American Midcontinent Province conodonts; WNAMP, western North American Midcontinent Province conodonts; SAP, Siberian-Alaskan Province conodonts (Siberian as used here implies affinities with conodonts from lower Paleozoic rocks of the Siberian platform)]

Age	York Mountains	Western Baird Mountains	Eastern Baird Mountains	Snowden Mountain Area	Shublik and Sadlerochit Mountains
Late Ordovician	Brachiopods and gastropods: Siberian affinities (Potter, 1984; Blodgett and others, 1992b). Solitary rugose corals: Chiefly North American (Oliver and others, 1975; R.J. Elias, written commun., 1986) (2). Trilobites: Siberian affinities (Ormiston and Ross, 1976) (3). Conodonts: Chiefly mixture of WNAMP and SAP elements and fewer tropical cosmopolites and pandemics (4).	Conodonts: Pandemics and tropical cosmopolites (2).	Brachiopods: Siberian affinities (1). Conodonts: Richmondian—WNAMP (11); Maysvillian and Richmondian(?)—Chiefly pandemic with fewer Siberian-northern North American elements (1).	Colonial corals: Northern North American forms (T.E. Bolton, written commun., 1992) (1). Conodonts: Richmondian—WNAMP (1); Edenian and Maysvillian—Siberian-northern North American elements (7).	Brachiopods and gastropods: Siberian-Alaskan affinities (Blodgett and others, 1988) (5). Conodonts: Chiefly WNAMP and rare Siberian-northern North American elements (12).
Middle Ordovician	Conodonts: Dominantly pandemics and rare tropical cosmopolites (6).	Conodonts: NAMP and SAP elements (12); some pandemic and tropical cosmopolites (3).	Graptolites: Australasian realm (Carter and Tailleur, 1984) (5). Conodonts: Chiefly pandemics, fewer tropical cosmopolites, and rare SAP elements (14).	Conodonts: Chiefly pandemics and fewer NAMP and tropical cosmopolitan elements (17).	
Early Ordovician	Trilobites: Siberian affinities (Ormiston and Ross, 1976). Conodonts: Mixture of chiefly tropical cosmopolites and pandemics and fewer WNAMP and SAP elements (29).	Conodonts: Chiefly WNAMP, pandemic, and tropical cosmopolites and fewer SAP elements (84).	Graptolites: Australasian realm (Carter and Tailleur, 1984) (10).		Trilobites: Bathyurid Province forms (tropical cosmopolites) (Blodgett and others, 1986) (5). Conodonts: NAMP and tropical cosmopolites (3).
Late Cambrian			Monoplacophoran mollusks and agnostid arthropods; cosmopolitan forms (Dumoulin and Harris, 1987a) (1).		Trilobites: North American affinities (Blodgett and others, 1986) (3).
Middle Cambrian			Acrotretid brachiopods: Cosmopolitan forms (A.J. Rowell, written commun., 1989) (3). Monoplacophoran mollusks and chancellorid sclerites: Cosmopolitan elements (Karl and others, 1989) (2). Protoconodonts: Cosmopolites (2).	Trilobites: Siberian affinities (Palmer and others, 1984) (2).	
Early Cambrian					Trilobites: North American affinities in Marsh Fork volcanic rocks, about 50 km south of Shublik Mountains (Dutro and others, 1972) (1).

(meta)carbonate successions are dominated by Siberian-northern North American forms, whereas latest Ordovician faunas in these areas contain WNAMP conodonts (predominantly aphelognathids). Upper Ordovician strata in the York Mountains yield WNAMP and SAP conodonts; the single known locality of Upper Ordovician rocks in the western Baird Mountains produced cosmopolitan conodonts.

Specific elements of the paleobiogeographic pattern outlined above have been used to infer the presence of "exotic" continental fragments in northern Alaska. The occurrence of Cambrian trilobite faunas with Siberian affinities in the Doonerak-Snowden Mountain area, and with North American affinities in the Shublik and Sadlerochit Mountains, has been cited as evidence that the Brooks Range is underlain by "Siberian" and "North American" crustal fragments (Grantz and others, 1991). The Siberian affinities of Ordovician trilobites in the York Mountains led Ormiston and Ross (1976) to conclude that the Seward Peninsula was part of a Siberia-Kolyma continent during the early Paleozoic and was not connected to the rest of Alaska and North America until the Mesozoic.

Long-distance translation of tectonic blocks is not the only mechanism that can produce "anomalous" faunal distributions, however. Modern biogeographic patterns are controlled by many variables, including global circulation, continental configuration, and larval ecology. Position of the paleoequator relative to northern Alaska during the Paleozoic is one factor that may have affected faunal distributions. The biogeography of the present-day Great Barrier Reef demonstrates the importance of continental configuration. The reef occurs along the eastern margin of the Indian-Australian plate and is oriented roughly perpendicular to the equator; it is more than 2,000 km long and extends through 15° of latitude. Distinct biotic zones occur within the reef as a direct result of pronounced latitudinal variations in temperature and salinity (Davies and others, 1987). Recent paleogeographic reconstructions (for example, Scotese, 1986) have positioned northern Alaska at a moderate angle to the paleoequator during the early Paleozoic, so biotic differentiation in pre-Carboniferous strata may reflect, at least in part, latitudinally controlled ecologic variation.

Larval ecology also influences biogeography. Many modern marine organisms produce pelagic larvae that are able to survive long-distance transport by ocean currents; such dispersal results in pantropic species distributions. Studies of comparative larval morphology suggest that some ancient species also had teleplanic larvae (Smith and others, 1990). The occurrence of "Tethyan" species in Paleozoic faunas of the North American Cordillera may reflect pantropic dispersal of certain species rather than large-scale tectonic displacements (Newton, 1988). Such dispersal mechanisms also may have affected faunal distributions in northern Alaska.

The most precise biogeographic studies compare fossils of the same age and depositional environment and consider all elements of a given fauna. The "Siberian" trilobites in the central Brooks Range are of Middle Cambrian age, whereas the "North American" trilobites in the northeastern Brooks Range are Early and Late Cambrian in age. Trilobites of exactly the same age have not been found in the two areas, and conclusions based on noncoeval species may be misleading. Middle Cambrian trilobites of "Siberian" aspect have recently been reported from rocks in southwestern Alaska that are considered part of the North American continental margin (Babcock and Blodgett, 1992). The Middle Cambrian may have been a time when faunal exchange between Alaska and Siberia was particularly pronounced. Ordovician conodont faunas also show temporal variations in biogeographic affinities; in most northern Alaskan (meta)carbonate successions, "Siberian" faunal elements in lower Upper Ordovician strata give way to "North American" faunal elements in upper Upper Ordovician rocks. Analogous temporal variations in the proportion of "Tethyan" species occur in Paleozoic and Mesozoic Cordilleran faunas and are attributed to climate-related pulses of larval distribution (Newton, 1988).

It is also important to consider the biogeographic implications of as many fossil groups as possible within a given fauna. Potter (1984) studied brachiopods, corals, and trilobites in Upper Ordovician strata of the York Mountains and suggested that the biogeographic affinities of the entire fauna indicated faunal exchange between the York Mountains area, the North American continent, Chukotka, the Siberian platform, and Kazakhstan. The distribution of a variety of Late Ordovician brachiopod and gastropod species led Blodgett and others (1992b) to argue that, in early Paleozoic time, Arctic Alaska, the Seward Peninsula, and Chukotka formed a single tectonic block with faunal ties to the Kolyma region.

In our view, the available biogeographic data from northern Alaska are best explained by postulating that pre-Carboniferous carbonate successions accumulated on a single continental margin or platform that had faunal exchange with both Siberia and North America. If northern Alaska represented a collage of distinct crustal fragments, one would expect to find "Siberian" faunas throughout one carbonate succession and "North American" faunas throughout another. This pattern is not observed. Rather, both "Siberian" and "North American" faunal affinities occur at different times and in different fossil groups within all of the (meta)carbonate successions discussed above. "Siberian" influences are particularly noteworthy in Middle Cambrian and early Late Ordovician time. This interpretation agrees well with the Phanerozoic plate tectonic reconstructions of Scotese (1986) and Scotese and McKerrow (1990) (fig. 30). They treat northern Alaska-Chukotka as a discrete continental block that lay between Siberia and North America throughout the early Paleozoic. Their recon-

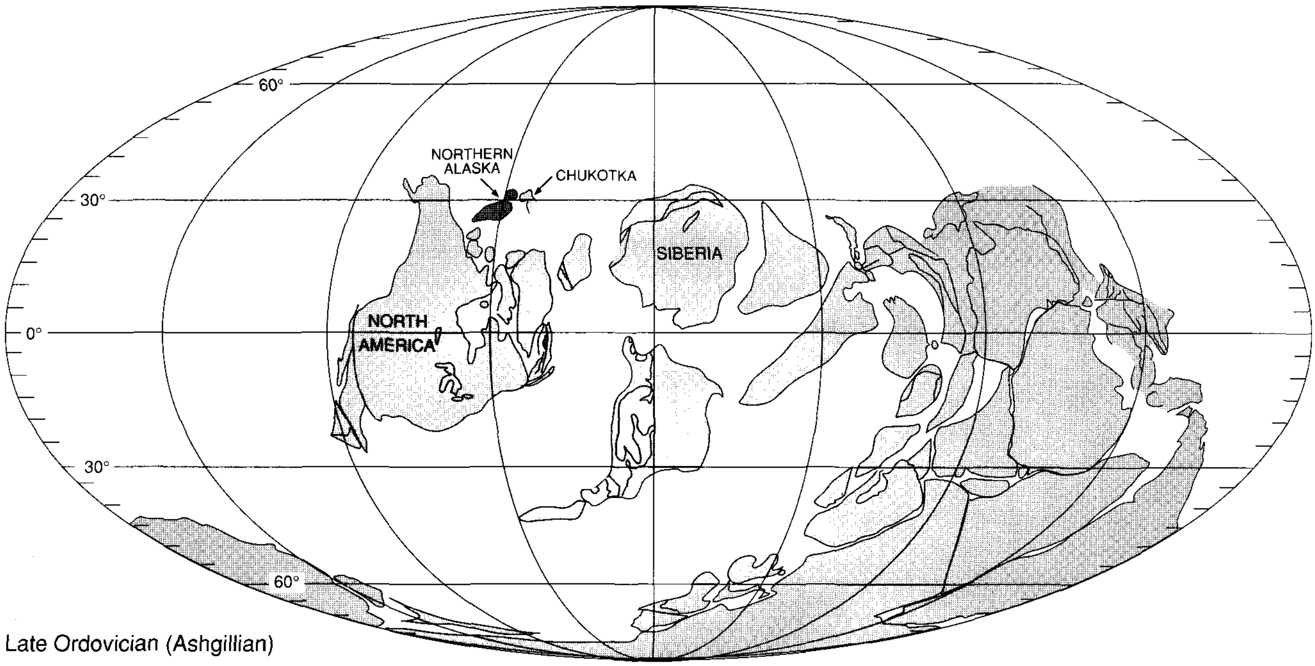


Figure 30. Global plate tectonic reconstruction for part of Late Ordovician (Ashgillian) time, showing relative proximity of northern Alaska, Siberia, and North America (modified from Scotese and McKerrow, 1990).

structions indicate particular proximity between Siberia and Alaska during Middle Cambrian and Late Ordovician time.

CONCLUSIONS

Pre-Carboniferous rocks of the Snowden Mountain area consist of a dominantly metacarbonate succession of Proterozoic(?) through Early or Middle Devonian age that has been structurally dismembered and intercalated with predominantly metaclastic rocks of chiefly early Late Devonian age.

Ordovician through Silurian rocks constitute the most precisely dated and best studied part of this metacarbonate succession. Middle Ordovician strata are mainly carbonaceous phyllite, metachert, and allodapic metalimestone deposited in a slope or basinal environment; their vertical sequence indicates a shallowing-upward depositional regime. These strata are succeeded by Upper Ordovician and Silurian metacarbonate rocks that were deposited in warm, shallow-water environments.

Devonian metaclastic units contain subordinate metalimestone that yields late Givetian(?) and Frasnian conodonts. Thicker limy layers formed as in situ shallow-water buildups; thinner layers are mostly calcarenite redeposited by storms and (or) turbidity currents.

The metacarbonate succession in the Snowden Mountain area correlates best, lithologically and biostratigraphically, with metacarbonate rocks in the eastern Baird Mountains and also has similarities with (meta)carbonate successions on the Seward Peninsula and in the western and eastern Brooks Range. Detailed comparisons of the lithology, biofacies, and biogeographic affinities of pre-Carboniferous carbonate successions across northern Alaska suggest that these rocks represent a single carbonate platform or continental margin dismembered by later tectonic events, rather than a collage of "exotic terranes."

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Appendix 1. Locality register for key faunal components and lithologic features.

[Named taxa are conodonts and were identified by A.G. Harris, unless otherwise noted. See figures 2 and 3 for geologic and geographic location]

Map no. (map unit)	Field no.[1] (USGS colln. no.)	Latitude N./ Longitude W.	Key faunal components and lithologies	Fossil age	CAI
1 (Dh)	90ABd37A (12067–SD)	68°06.9′/149°32.5′	Skeletal wacke-packstone *Polygnathus evidens* (pl. 3, fig. 12) *Polygnathus* of the *Po. xylus* group	early Late Devonian (Frasnian)	5
(Dh)	90ABd37B	68°06.9′/149°32.5′	Oolitic grainstone interbedded with 90ABd37A.		
2 (Dh)	90ABd34 (12065–SD)	68°06.8′/149°32.2′	Quartzose skeletal grainstone *Polygnathus pacificus* (pl. 3, fig. 13) *Polygnathus* aff. *Po. planarius* *Polygnathus samueli* (pl. 3, fig. 14)	early Late Devonian (Frasnian, probably late Frasnian).	5
3 (Db)	90TM529A (12082–SD)	68°04.1′/149°12.3′	Skeletal grainstone *Ancyrodella nodosa* (pl. 3, fig. 8) *Polygnathus* aff. *Po. pacificus*	early Late Devonian (middle to late Frasnian; Upper *hassi* Zone to *linguiformis* Zone).	5–5.5
4 (Dn)	84DN199 (11083–SD)	68°00.1′/149°34.5′	Crinoidal marble *Ancyrodella gigas* *Ancyrodella lobata* (pl. 3, fig. 19) *Ancyrognathus* aff. *A. triangularis* (pl. 3, fig. 21). *Icriodus symmetricus* (pl. 3, fig. 1)	early Late Devonian (middle Frasnian; Upper *hassi* Zone to Lower *rhenana* Zone).	5.5
5 (Dn)	90TM453B (12076–SD)	67°59.2′/149°21.7′	Intraclast-skeletal packstone *Ancyrodella* sp. *Ancyrognathus* cf. *A. coeni* (pl. 3, fig. 20). *Icriodus* sp. *Palmatolepis plana* (pl. 3, fig. 16) *Palmatolepis proversa* (pl. 3, figs. 17, 18).	early Late Devonian (middle Frasnian; upper part of Lower *hassi* Zone).	5
6 (SOm)	90AD20G (10828–CO)	67°54.8′/149°31.4′	Peloidal-skeletal packstone "*Belodina*" spp. *Panderodus* spp. *Phragmodus* n. sp. (= *Ph.* new species of Barnes, 1974). *Plectodina*? cf. *Pl.*? *dolboricus*	early Late Ordovician (Edenian to Maysvillian).	5
(SOm)	90AD20H	67°54.8′/149°31.4′	Coralline wackestone Coral: *Catenipora* sp. aff. *C. rubra*[2]	probably early Late Ordovician	
(Devonian limestone outcrop too small to show on map)	90ABd31 (12064–SD)	67°54.8′/149°31.4′	Skeletal pack-wackestone (containing probable amphiporid stromatoporids) overlying 90AD20H. *Panderodus* sp. *Ozarkodina* of Silurian-Middle Devonian morphotype. Echinoderms: two-hole crinoid ossicles[3]	late Early to early Middle Devonian (Emsian to Eifelian).	
7 (SOm and Devonian? limestone)	89ATi75	67°53.4′/149°32.7′	Bioturbated dolomitic metalimestone (SOm) overlain by skeletal wackestone containing probable amphiporid stromatoporoids; wackestone is lithologically similar to 90ABd31 and may be Devonian.		

[1]Samples collected by R.B. Blodgett (ABd), J.A. Dumoulin (AD), A.G. Harris (7–84), T.E. Moore (TM), George Plafker (APr), and A.B. Till (ATi), all U.S. Geological Survey; J.T. Dillon (DN) and D.N. Solie (DNS), State of Alaska Division of Geological & Geophysical Surveys.

[2]Identified by T.E. Bolton, Geological Survey of Canada.

[3]Identified by R.B. Blodgett, U.S. Geological Survey.

Appendix 1.—Continued

Map no. (map unit)	Field no.[1] (USGS colln. no.)	Latitude N./ Longitude W.	Key faunal components and lithologies	Fossil age	CAI
8 (SOm)	84DNS110 (10583–CO) 89AD39	67°52.7′/149°41.9′	Fossiliferous dolostone *"Belodina"* sp. *Phragmodus* n. sp. (= *Ph.* new species of Barnes, 1974).	early Late Ordovician (Edenian to Maysvillian).	5.5
(Devonian? limestone)	89AD39D	67°52.6′/149°42.3′	Skeletal wackestone containing probable amphiporid stromatoporoids overlies unit SOm; wackestone is lithologically similar to 90ABd31 and may be Devonian.		
9 (SOm)	84DNS109A (10582–CO)	67°52.7′/149°41.4′	Crinoidal marble *Culumbodina*? cf. *C. occidentalis* (pl. 2, fig. 19). *Panderodus* sp. *Phragmodus* n. sp. (= *Ph.* new species of Barnes, 1974) (pl. 2, fig. 22). *Pseudobelodina dispansa* *Pseudobelodina inclinata* transitional to *Ps. v. vulgaris* (pl. 2, figs. 17, 18)	early Late Ordovician (Edenian to Maysvillian).	5.5
(SOm)	89AD42 (11964–SD)	67°52.8′/149°41.6′	Peloidal dolostone, structurally underlies 84DNS109A. *Icriodella*? sp. indet. *Ozarkodina* aff. *O. oldhamensis* (pl. 2, figs. 7–10). *Oulodus*? n. sp. (pl. 2, figs. 11–14) *Panderodus* sp.	very latest Ordovician to Early Silurian; very probably Early Silurian (Llandoverian).	5–5.5
10 (SOm)	89AD41A (10725–CO)	67°52.5′/149°41.3′	Parallel-laminated metalimestone *Phragmodus* n. sp. (= *Ph.* new species of Barnes, 1974) (pl. 2, figs. 23, 24).	early Late Ordovician (Edenian to Maysvillian).	5
11 (Os, SOm)	89AD40	67°52.6′/149°42.3′	Units Os and SOm in apparent depositional contact at this locality.		
12 (SOm)	90AD21AA (10831–CO)	67°52.2′/149°35.7′	Algal-laminated dolostone *Aphelognathus* aff. *A. divergens* (pl. 2, fig. 16).	late Late Ordovician (Richmondian)	5
(Dn)	90AD21E (12071–SD)	67°52.2′/149°35.7′	Sooty metalimestone in fault contact with 90AD21AA. *Polygnathus* aff. *Po. alatus* *Polygnathus* aff. *Po. planarius*	early Late Devonian (Frasnian)	5
13 (SOm)	89APr170 (10727–CO)	67°51.3′/149°46.5′	Fossiliferous dolostone *Panderodus* sp. (pl. 2, fig. 15) *Phragmodus* n. sp. (= *Ph.* new species of Barnes, 1974) (pl. 2, figs. 20, 21).	early Late Ordovician (Edenian to Maysvillian).	5
14 (SOm and Devonian? limestone)	89AD43 90ABd28	67°51.1′/149°49.2′	Fossiliferous dolostone (SOm) overlain by skeletal wackestone containing probable amphiporid stromatoporoids; wackestone is lithologically similar to 90ABd31 and may be Devonian.		
15 (Db)	89ATi71A (11969–SD)	67°50.8′/149°32.1′	Lime mudstone with sparse bioclasts *Icriodus* sp. indet. *Pandorinellina*? cf. *P. insita* *Polygnathus* spp. indet.	latest Middle to earliest Late Devonian (latest Givetian to early Frasnian).	5

Appendix 1.—Continued

Map no. (map unit)	Field no.[1] (USGS colln. no.)	Latitude N./ Longitude W.	Key faunal components and lithologies	Fossil age	CAI
16 (SOm)	89AD36E (11963–SD)	67°49.5′/149°39.1′	Coralline metalimestone *Icriodella*? sp. indet. (pl. 2, fig. 4) *Oulodus*? sp. indet. *Ozarkodina* cf. *O. cadiaensis* (pl. 2, fig. 3). *Panderodus* sp. *Pterospathodus* aff. *P. cadiaensis* (pl. 2, figs. 1, 2).	Early Silurian (Llandoverian to early Wenlockian).	5
17 (SOm)	89ATi74A (11970–SD)	67°49.6′/149°36.5′	Bioturbated, fossiliferous dolostone *Oulodus*? sp. indet. *Panderodus* sp. *Pterospathodus*? n. sp.	Early Silurian (Llandoverian to early Wenlockian).	5
18 (Os)	90AD25A (10826–CO)	67°49.1′/149°34.8′	Calcareous turbidite *Drepanodus arcuatus* (pl. 1, fig. 20) *Periodon flabellum* (pl. 1, fig. 17) *Protopanderodus* aff. *P. graeai* (pl. 1, fig. 19). *Tripodus laevis* Redeposited Late Cambrian and (or) Early Ordovician conodonts: *Cordylodus* aff. *C. proavus* *Cordylodus* cf. *C. intermedius* *Eoconodontus notchpeakensis* *Phakelodus tenuis* (pl. 1, fig. 22) *Teridontus nakamurai* *Variabiloconus bassleri*	very earliest Middle Ordovician (latest Arenigian) containing redeposited conodonts of Late Cambrian and (or) Early Ordovician age.	5
(Os)	90AD25B (10827–CO)	67°49.1′/149°34.8′	Calcareous turbidite *Drepanodus arcuatus* *Paroistodus* sp. *Tripodus laevis* (pl. 1, fig. 18) Redeposited Late Cambrian and (or) Early Ordovician conodonts: *Cordylodus* sp. indet. (pl. 1, fig. 21) *Eoconodontus notchpeakensis* *Furnishina* sp. "*Oistodus*" *triangularis* *Phakelodus tenuis* *Rossodus manitouensis* (pl. 1, fig. 23) "*Scolopodus*" *gracilis* (pl. 1, fig. 24) *Teridontus nakamurai*	very earliest Middle Ordovician (latest Arenigian) with redeposited conodonts of Late Cambrian and (or) Early Ordovician age.	5
19 (Os)	90TM448 (10851–CO)	67°49.5′/149°32.8′	Calcareous turbidite *Eoplacognathus elongatus* transitional to *Polyplacognathus* sp. (pl. 1, figs. 1, 2). *Erraticodon balticus* (pl. 1, figs. 13, 14). *Protopanderodus varicostatus* (pl. 1, fig. 3). *Pygodus anserinus* (pl. 1, fig. 9) *Spinodus ramosus*	middle Middle Ordovician (latest Llandeilian to earliest Caradocian; *Baltoniodus variabilis* Subzone to Lower *Baltoniodus gerdae* Subzone).	5
20 (Cambrian Snowden Mountain unit)	83DNS300 89AD32	67°48.1′/149°43.9′	Skeletal wacke/packstone Trilobites: *Chondranomocare* cf. *C. speciosum* *Kounamkites* cf. *K. frequens*[4]	early Middle Cambrian	

[4]Identified by A.R. Palmer (*in* Palmer and others, 1984).

Appendix 1.—Continued

Map no. (map unit)	Field no.[1] (USGS colln. no.)	Latitude N./ Longitude W.	Key faunal components and lithologies	Fossil age	CAI
21 (Pzs)	7–27–84C	67°48.0′/149°44.0′	Massive dolostone Indeterminate conodont fragment	Ordovician to Triassic	6
22 (Os)	7–30–84A (9911–CO) 89AD24	67°47.0′/149°44.5′	Carbonaceous metalimestone *Panderodus* sp. *Periodon aculeatus* *Prattognathus rutriformis* (pl. 1, fig. 6) *Protopanderodus varicostatus* *Pygodus* sp. indet. *Spinodus ramosus* (pl. 1, fig. 7) Section also contains phyllite, dolostone with radiolarian ghosts, and metasandstone.	middle Middle Ordovician (latest Llanvirnian to earliest Llandeilian; upper *Pygodus serra* Zone to lower *Pygodus anserinus* Zone).	5
23 (Pzs)	84DN249	67°47.4′/149°41.5′	Marble Ozarkodinid of Silurian-Mississippian morphotype.	Silurian to Mississippian	5.5
24 (Os)	7–27–84H (9908–CO)	67°47.1′/149°38.5′	Carbonaceous phyllitic metalimestone *Panderodus*(?) sp. *Periodon aculeatus* (pl. 1, fig. 8) *Protopanderodus varicostatus* (pl. 1, fig. 4).	middle Middle Ordovician (Llanvirnian to Llandeilian).	5–5.5
(Os)	7–27–84G (9909–CO)	67°47.1′/149°38.5′	Carbonaceous metalimestone, about 20 m above 7–27–84H. *Panderodus* sp. indet. *Periodon* sp. indet. *Protopanderodus varicostatus*	middle Middle Ordovician (Llanvirnian to Llandeilian).	5
(Pzs)	7–27–84J (9905–CO)	67°47.1′/149°38.5′	Massive metalimestone, about 42 m below 7–27–84H. Coniform element of probable middle Arenigian-Llanvirnian age.	probably late Early through early Middle Ordovician (middle Arenigian to Llanvirnian).	5.5
25 (Os)	7–30–84E (9913–CO) 89AD28	67°45.6′/149°37.0′	Carbonaceous metalimestone *Periodon aculeatus* *Protopanderodus varicostatus* *Pygodus anserinus* (pl. 1, fig. 5)	middle Middle Ordovician (latest Llanvirnian to earliest Caradocian; *Pygodus anserinus* Zone to lower *Baltoniodus gerdae* Subzone).	5
26 (Db)	84DN190 (11082–SD)	67°45.6′/149°51.7′	Platy gray marble *Icriodus* sp. indet. *Pandorinellina insita* (pl. 3, fig. 2) *Polygnathus xylus xylus* *Polygnathus* cf. *Po. linguiformis*	latest Middle-earliest Late Devonian (very latest Givetian to earliest Frasnian).	5–5.5
27 (Db)	89APr146 (11966–SD)	67°44.7′/149°54.3′	Lime mudstone with sparse bioclasts *Icriodus* sp. of Middle to Late Devonian morphotype. *Pandorinellina* aff. *P. insita* (pl. 3, figs. 3, 4). *Polygnathus* spp. of late Middle to early Late Devonian morphotype.	latest Middle to earliest Late Devonian (very latest Givetian to early Frasnian).	5
28 (Os)	89AD29Z (10724–CO)	67°44.8′/149°41.8′	Graded crinoidal grainstone (calcareous turbidite). "*Belodina*" spp. *Dapsilodus*? *similaris* *Protopanderodus* aff. *P. varicostatus* *Scalpellodus*? sp. Section also contains metachert with radiolarian ghosts, carbonaceous metalimestone, and massive marble.	middle Middle Ordovician (Llanvirnian to Llandeilian).	5
29 (Os)	89AD27	67°44.5′/149°38.7′	Section contains metachert with radiolarian ghosts, impure carbonate turbidites, and phyllite.		

Appendix 1.—Continued

Map no. (map unit)	Field no.[1] (USGS colln. no.)	Latitude N./ Longitude W.	Key faunal components and lithologies	Fossil age	CAI
30 (Os)	89TM274B (10729–CO) 89AD30	67°43.9′/149°38.1′	Impure calcareous turbidites *Periodon aculeatus* *Protopanderodus* aff. *P.* n. sp. A of McCracken (1989).	early Middle Ordovician (*Pygodus serra* Zone possibly into *Pygodus anserinus* Zone).	5
31 (Os)	90AD26B (10834–CO)	67°42.8′/149°47.7′	Dolostone with radiolarian ghosts (lens in metachert). *Dapsilodus*? *similaris* *Panderodus* sp. *Periodon aculeatus* *Spinodus ramosus*	early through middle Middle Ordovician (Llanvirnian to early Caradocian).	5
32 (Os)	89APr144 (10726–CO)	67°42.3′/149°52.0′	Calcareous turbidite *Pygodus*? sp. indet. New genus, new species of Potter (1975) (pl. 1, fig. 16).	late Early to earliest Middle Ordovician (late Arenigian).	5
33 (Db)	89TM240B (11971–SD)	67°40.4′/149°58.0′	Lime mudstone with sparse bioclasts *Icriodus* sp. indet. *Pandorinellina* sp. indet. *Polygnathus* sp. of late Middle to early Late Devonian morphotype.	latest Middle to early Late Devonian (latest Givetian to early Frasnian).	5
34 (SOm)	90AD2A (12069–SD)	67°39.5′/149°23.7′	Bioturbated skeletal wackestone *Kockelella* sp. indet. (pl. 2, fig. 5) *Panderodus* sp. *Pelekysgnathus* sp. indet. (pl. 2, fig. 6) Section also contains peloidal grainstone.	late Early to early Late Silurian (Wenlockian to Ludlovian).	5–5.5
35 (Os)	89ATi18A (10728–CO)	67°34.9′/150°08.2′	Dolostone with radiolarian ghosts *Belodina* sp. indet. *Dapsilodus*? *similaris* *Panderodus* sp. *Periodon aculeatus* (pl. 1, fig. 15) *Protopanderodus varicostatus* *Pygodus serra* (pl. 1, figs. 10–12) *Spinodus ramosus*	early Middle Ordovician (late Llanvirnian; *Pygodus serra* Zone).	5
36 (Os)	89AD20A (10722–CO)	67°33.9′/149°41.2′	Carbonaceous metalimestone couplets (calcareous turbidites). *Juanognathus*? sp. indet. or *Rossodus*? sp. indet. *Periodon*? sp. indet.	Ordovician, possibly Early to earliest Middle Ordovician (probably Arenigian to Caradocian; possibly Arenigian).	5
37 (ⱣzⱣd)	89AD51	67°41.0′/149°33.0′	Dolostone with coated grains		
Not shown on fig. 3; sample taken about 30 km east of the study area (Db)	90TM476A (12078–SD)	67°59.0′/148°33.7′	Skeletal-peloidal wacke-packstone *Ancyrodella gigas* (pl. 3, fig. 7) *Icriodus* sp. *Klapperina ovalis* (pl. 3, fig. 10) *Mesotaxis falsiovalis* (pl. 3, figs. 5, 6) *Polygnathus aequalis* (pl. 3, fig. 11) *Polygnathus webbi* (pl. 3, fig. 9).	early Late Devonian (early to middle Frasnian; upper *transitans* Zone into lower Upper *hassi* Zone).	5
Not shown on fig. 3; sample from east of map area (Dh)	90TM574A (12084–SD)	68°13.7′/148°58.5′	*Icriodus* sp. *Palmatolepis plana* (pl. 3, fig. 15) Polygnathus aff. *Po. pacificus*	early Late Devonian (middle to late Frasnian; uppermost Lower *hassi* Zone to Upper *rhenana* Zone).	5

PLATES 1–3

PLATE 1

Ordovician conodonts from the Snowden Creek unit

Figures 1, 2. *Eoplacognathus elongatus* (Bergström) transitional to *Polyplacognathus* sp., upper views of stelliplanate elements, ×40, USGS colln. 10851–CO (fig. 3, loc. 19), USNM 475602, 03. The stelliplanate element of this species is similar to *Polyplacognathus ringerikensis* Hamar from Norway; the Alaskan form, however, appears to have a better developed secondary lobe on the posterior processes. Process geometry of the Alaskan form is nearly identical to that of *Polyplacognathus ramosus,* a younger species, but *P. ramosus* has prominently crenulate margins, whereas the Alaskan form has relatively smooth margins. No pastiplanate elements were found in the only collection in which this transition form occurs.

3, 4. *Protopanderodus varicostatus* (Sweet and Bergström)
- 3. Inner lateral view, ×30, USGS colln. 10851–CO (fig. 3, loc. 19), USNM 475604.
- 4. Outer lateral view, ×45, USGS colln. 9908–CO (fig. 3, loc. 24), USNM 413584 (= fig. 3L of Dillon and others, 1987a).

5, 9. *Pygodus anserinus* Lamont and Lindström, upper views of P elements.
- 5. ×100, USGS colln. 9913–CO (fig. 3, loc. 25), USNM 413583 (= fig. 3K of Dillon and others, 1987a).
- 9. ×60, USGS colln. 10851–CO (fig. 3, loc. 19), USNM 475605.

6. *Prattognathus rutriformis* (Sweet and Bergström), upper view of stelliplanate element, ×60, USGS colln. 9911–CO (fig. 3, loc. 22), USNM 413580 (= fig. 3G of Dillon and others, 1987a).

7. *Spinodus ramosus* (Hadding), lateral view of Sa? element, ×65, USGS colln. 9911–CO (fig. 3, loc. 22), USNM 413579 (= fig. 3F of Dillon and others, 1987a).

8, 15. *Periodon aculeatus* Hadding, inner and outer lateral views of Sc and M elements, ×105 and ×50, USGS colln. 9908–CO (fig. 3, loc. 24), USNM 413576 (= fig. 3C of Dillon and others, 1987a) and USGS colln. 10728–CO (fig. 3, loc. 35), USNM 475606.

10–12. *Pygodus serra* (Hadding), upper views of two P elements and lateral view of Sa element, ×40, USGS colln. 10728–CO (fig. 3, loc. 35), USNM 475607–475609.

13, 14. *Erraticodon balticus* Dzik, outer and inner lateral views of M and Sc elements, ×50, USGS colln. 10851–CO (fig. 3, loc. 19), USNM 475610, 475611.

16. New genus, new species (= Persian slipper-shaped elements of Potter, 1975), posterior? view, ×60, USGS colln. 10726–CO (fig. 3, loc. 32), USNM 475612.

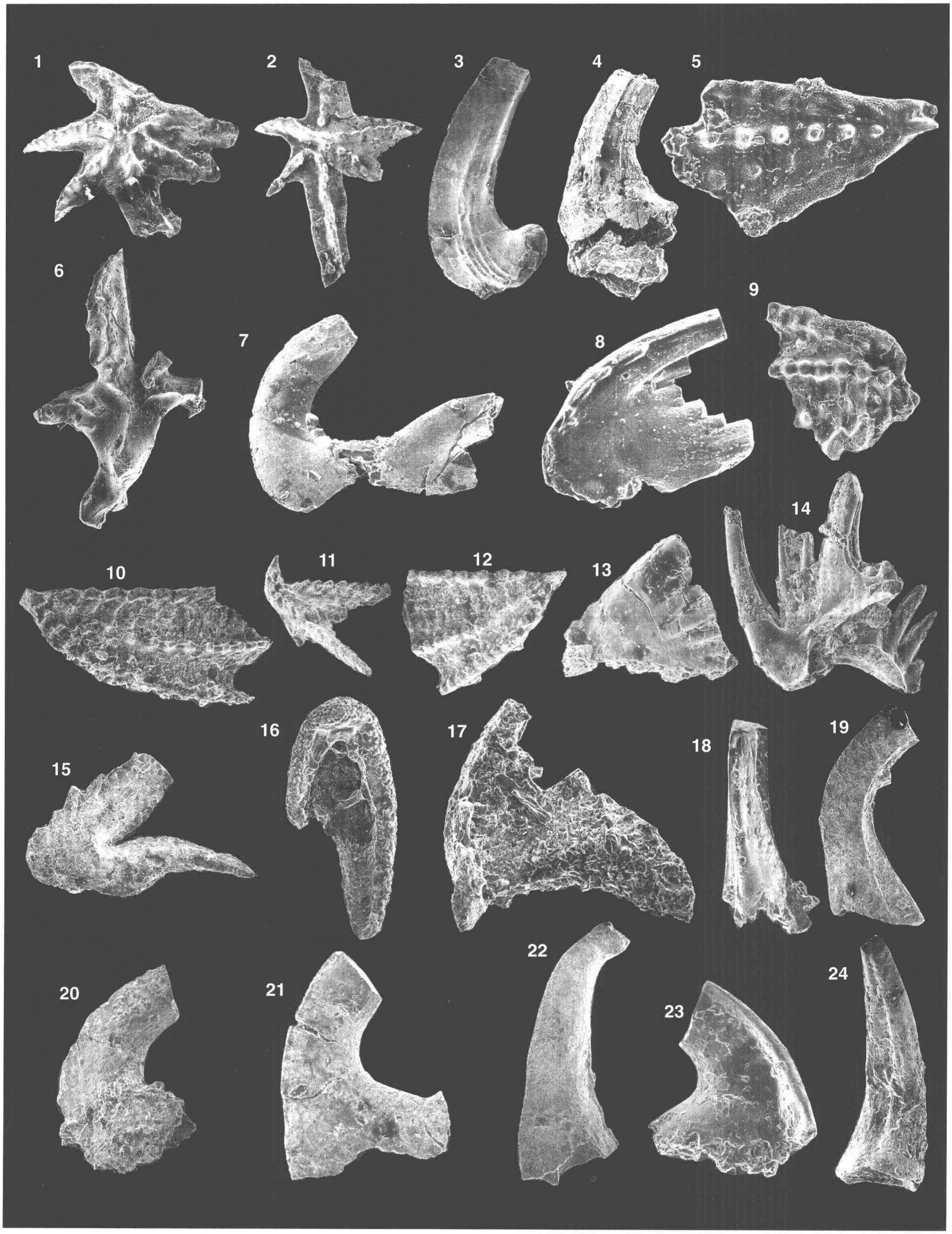
17. *Periodon flabellum* (Lindström), inner lateral view of Sb element, ×100, USGS colln. 10826–CO (fig. 3, loc. 18), USNM 475613.

18. *Tripodus laevis* Bradshaw, oblique posterior view of Sd element, ×90, USGS colln. 10827–CO (fig. 3, loc. 18), USNM 475614.

19. *Protopanderodus* aff. *P. graeai* (Hamar), lateral view, ×30, USGS colln. 10826–CO (fig. 3, loc. 18), USNM 475615.

20. *Drepanodus arcuatus* Pander, inner lateral view, ×60, USGS colln. 10826–CO (fig. 3, loc. 18), USNM 475616.

21–24. Redeposited Late Cambrian and (or) Early Ordovician conodonts, fig. 21, ×90, figs. 22–24, ×80; figs. 21, 23, and 24 from USGS colln. 10827–CO, fig. 22 from USGS colln. 10826–CO (fig. 3, loc. 18).
- 21. *Cordylodus* sp. indet., lateral view of Sc element, USNM 475617.
- 22. *Phakelodus tenuis* (Müller), lateral view, USNM 475618.
- 23. *Rossodus manitouensis* Repetski and Ethington, inner lateral view, USNM 475619.
- 24. "*Scolopodus*" *gracilis* Ethington and Clark, oblique posterior view, USNM 475620.



ORDOVICIAN CONODONTS FROM THE SNOWDEN CREEK UNIT

PLATE 2

Late Ordovician and Silurian conodonts from the Mathews River unit

Figures 1, 2. *Pterospathodus* aff. *P. cadiaensis* Bischoff, lateral and upper views of Pa and Pb elements, ×80, USGS colln. 11963–SD (fig. 3, loc. 16), USNM 475621, 475622.

3. *Ozarkodina* cf. *O. cadiaensis* Bischoff, oblique inner lateral view of Pa element, ×80, USGS colln. 11963–SD (fig. 3, loc. 16), USNM 475623.

4. *Icriodella*? sp. indet., upper view of Pa element fragment, ×40, USGS colln. 11963–SD (fig. 3, loc. 16), USNM 475624.

5. *Kockelella* sp. indet., inner lateral view of M element, ×60, USGS colln. 12069–SD (fig. 3, loc. 34), USNM 475625.

6. *Pelekysgnathus* sp. indet., posterior view of coniform element, ×60, USGS colln. 12069–SD (fig. 3, loc. 34), USNM 475626.

7–10. *Ozarkodina* aff. *O. oldhamensis* (Rexroad), lateral views of Pa, Pb, M, and Sb elements, ×120, USGS colln. 11964–SD (fig. 3, loc. 9), USNM 475627–475630.

11–14. *Oulodus*? n. sp., lateral views of Pa?, Pb_1, Pb_2?, and M elements, ×60, USGS colln. 11964–SD (fig. 3, loc. 9), USNM 475631–475634.

15. *Panderodus* sp., fused cluster of at least 10 elements, ×50, USGS colln. 10727–CO (fig. 3, loc. 13), USNM 475635.

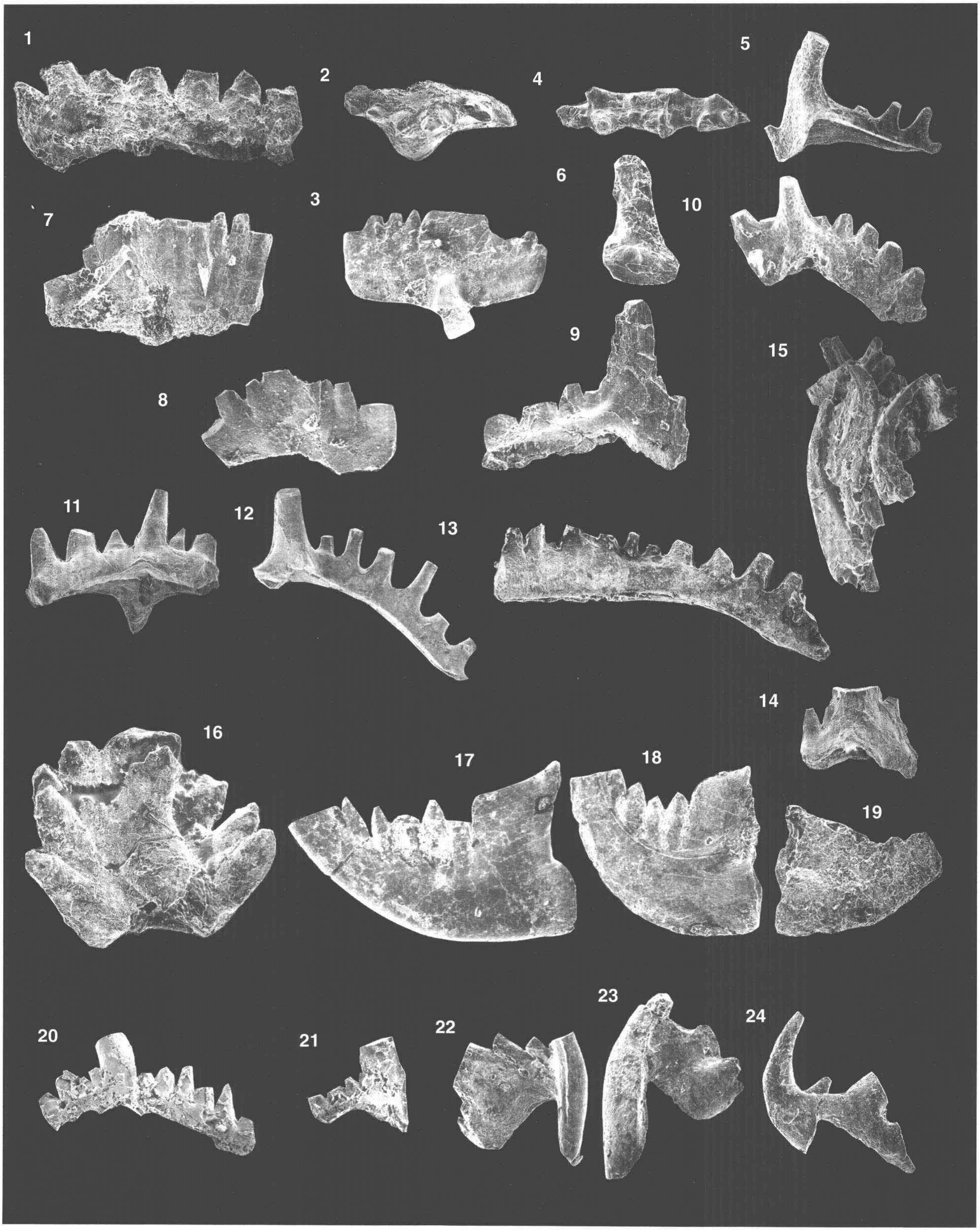
16. *Aphelognathus* aff. *A. divergens* Sweet, inner lateral view of Sb element, ×55, USGS colln. 10831–CO (fig. 3, loc. 12), USNM 484395.

17, 18. *Pseudobelodina inclinata* (Branson & Mehl)? transitional to *Ps. vulgaris vulgaris* Sweet, lateral views, ×50, USGS colln. 10582–CO (fig. 3, loc. 9), USNM 475636, 475637. These specimens have more denticles than *Ps. v. vulgaris* but fewer than *Ps. inclinata* and probably represent a new species.

19. *Culumbodina*? cf. *C. occidentalis* Sweet, outer lateral view, ×90, USGS colln. 10582–CO (fig. 3, loc. 9), USNM 475638.

20–24. *Phragmodus* n. sp. (= *Phragmodus* n. sp. of Barnes, 1974), ×60.

- 20, 21. Anterior and lateral views of P and M elements, USGS colln. 10727–CO (fig. 3, loc. 13), USNM 475639, 475640.
- 22. Inner lateral view of Sb element, USGS colln. 10582–CO (fig. 3, loc. 9), USNM 475641.
- 23, 24. Inner lateral views of Sb and Sc elements, USGS colln. 10725–CO (fig. 3, loc. 10), USNM 475642, 475643.



LATE ORDOVICIAN AND SILURIAN CONODONTS FROM THE MATHEWS RIVER UNIT

PLATE 3

Latest Givetian and Frasnian conodonts from the Beaucoup Formation, Hunt Fork Shale, and Nutirwik Creek unit

[All specimens are Pa elements]

Figure 1. *Icriodus symmetricus* Branson and Mehl, upper view, ×30, USGS colln. 11083–SD (fig. 3, loc. 4), USNM 475644.

2. *Pandorinellina insita* (Stauffer), outer lateral view, ×60, USGS colln. 11082–SD (fig. 3, loc. 26), USNM 475645.

3, 4. *Pandorinellina* aff. *P. insita* (Stauffer), outer lateral views, ×60, USGS colln. 11966–SD (fig. 3, loc. 27), USNM 475646, 475647.

5, 6. *Mesotaxis falsiovalis* Sandberg, Ziegler, and Bultynck, upper and lower views of Pa elements, ×50, USGS colln. 12078–SD (sample listed near end of app. 1), USNM 475648, 475649.

7, 9–11. From USGS colln. 12078–SD (sample listed near end of app. 1).

- 7. *Ancyrodella gigas* Youngquist, upper view, ×30, USNM 475650.
- 9. *Polygnathus webbi* Stauffer, upper view, ×30, USNM 475652.
- 10. *Klapperina ovalis* (Ziegler and Klapper), lower view, ×40, USNM 475653.
- 11. *Polygnathus aequalis* Klapper and Lane, upper view, ×30, USNM 475654.

8. *Ancyrodella nodosa* Ulrich and Bassler, upper view, ×30, USGS colln. 12082–SD (fig. 3, loc. 3), USNM 475651.

12. *Polygnathus evidens* Klapper and Lane, upper view, ×30, USGS colln. 12067–SD (fig. 3, loc. 1), USNM 475655.

13. *Polygnathus pacificus* Savage and Funai, upper view, ×30, USGS colln. 12065–SD (fig. 3, loc. 2), USNM 475656.

14. *Polygnathus samueli* Klapper and Lane, upper view, ×30, USGS colln. 12065–SD (fig. 3, loc. 2), USNM 475657.

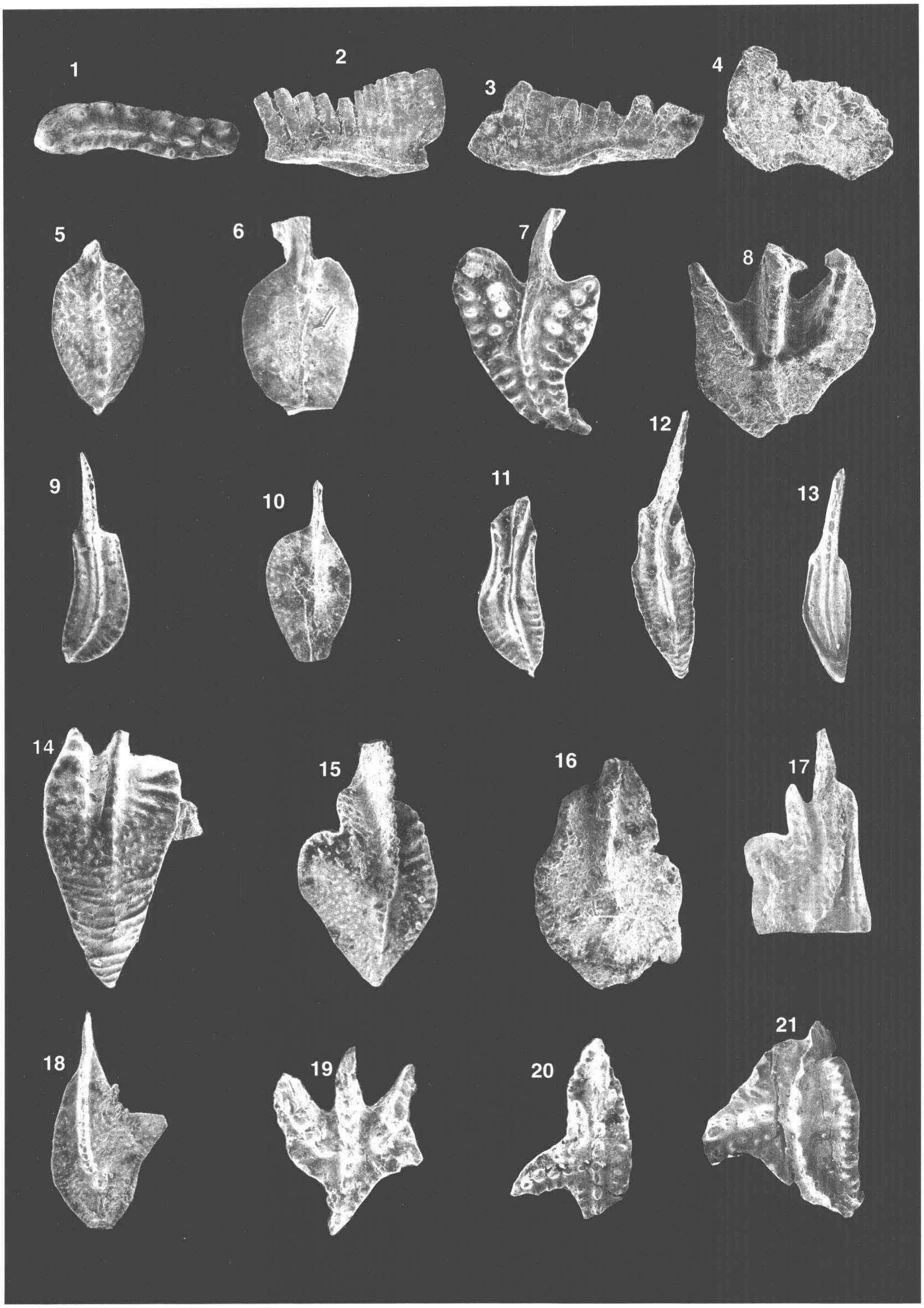
15, 16. *Palmatolepis plana* Ziegler and Sandberg, upper views, ×30, USGS colln. 12084–SD (sample listed at end of app. 1), 12076–SD (fig. 3, loc. 5), USNM 475658, 475659.

17, 18. *Palmatolepis proversa* Ziegler, upper views, ×30, USGS colln. 12076–SD (fig. 3, loc. 5), USNM 475660, 475661.

19. *Ancyrodella lobata* Branson and Mehl, upper view, ×30, USGS colln. 11083–SD (fig. 3, loc. 4), USNM 475662.

20. *Ancyrognathus* cf. *A. coeni* Klapper, upper view, ×30, USGS colln. 12076–SD (fig. 3, loc. 5), USNM 475663.

21. *Ancyrognathus* aff. *A. triangularis* Youngquist, upper view, ×30, USGS colln. 11083–SD (fig. 3, loc. 4), USNM 475664.



LATEST GIVETIAN AND FRASNIAN CONODONTS FROM THE BEAUCOUP FORMATION, HUNT FORK SHALE, AND NUTIRWIK CREEK UNIT