



Preliminary Bedrock Geologic Map of the Seward Peninsula, Alaska, and Accompanying Conodont Data

By Alison B. Till¹, Julie A. Dumoulin¹, Melanie B. Werdon², and Heather A. Bleick¹

¹U.S. Geological Survey, Anchorage, Alaska

²Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska

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Figure 1. Map of northern Alaska showing major geographic area, geological provinces, and the outline of the map area.48

Conversion Factors

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
Area		
square meter (m ²)	0.0002471	acre
square kilometer (km ²)	247.1	acre
square meter (m ²)	10.76	square foot (ft ²)
square kilometer (km ²)	0.3861	square mile (mi ²)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27)

Introduction

This 1:500,000-scale geologic map depicts the bedrock geology of Seward Peninsula, western Alaska, on the North American side of the Bering Strait. The map encompasses all of the Teller, Nome, Solomon, and Bendeleben 1:250,000-scale quadrangles, and parts of the Shishmaref, Kotzebue, Candle, and Norton Bay 1:250,000-scale quadrangles (sh. 1; sh. 2).

Rolling, tundra-covered hills cover most of Seward Peninsula; trees and shrubs are present only in limited areas in the southern and eastern parts of the peninsula. Broad lowlands underlie large areas in central and northern Seward Peninsula. Part of the central area and large areas in northernmost and easternmost Seward Peninsula are an extensive, unvegetated lava field. Four glacially carved mountain ranges, the York, Kigluaik, Bendeleben, and Darby Mountains, reach heights of 1,000-1,300 m (sh. 2); the highest point on the Peninsula, Mount Osborn, is in the Kigluaik Mountains. The York Mountains of western Seward Peninsula and hills adjacent to them on the east are underlain by bare, unvegetated carbonate rocks.

The map area covers 74,000 km², an area slightly larger than West Virginia or Ireland.

Sources of Data

This geologic map is a compilation of published and unpublished geologic mapping and information derived from other published and unpublished sources. Published geologic maps at scales of 1:250,000, 1:63,360, and 1:50,000 were major sources and range in publication date from 1972 to 2005. More detailed studies, including theses, papers, and unpublished mapping, represent work done between 1980 and 2008.

The amount of geologic detail available varies significantly across the area of the map, because of variations both in degree of study and in quality of bedrock exposure. Bedrock exposure, outside of the mountain ranges, is generally poor in the northern peninsula, and better in southern parts of the peninsula. The most detailed geologic mapping on the peninsula has been concentrated in the York and Kigluaik Mountains, and the central Solomon quadrangle. The distribution of some metamorphic indicator minerals and conodont color alteration index (CAI) values presented on sheet 2 is limited by quality of exposure and amount of study in a given area.

Components of the Map and Accompanying Materials

The geologic map and related supplemental information are presented in two oversized sheets, this text, three tables, and an appendix. The appendix includes an explanatory text and two tables.

The geologic map, Correlation of Map Units, List of Map Units, and sources of data are shown on sheet 1. The geographic names referenced in the text, metamorphic/tectonic subdivisions of the map area, and selected metamorphic and thermal history data are shown on sheet 2. Metamorphic and thermal history data are largely from the collections of the authors, but include all available information from government, industry, and academic sources.

Table 1 shows the distribution of the map units on the nine 1:250,000-scale quadrangle maps of the map area, and augments geographic information provided in the Description of Map Units.

Geochronologic data in tables 2 and 3 were compiled from the literature; a few unpublished ages were included. Results that were shown by researchers to be analytically sound and geologically meaningful have been included in the tables, while less sound results (for example, ⁴⁰Ar/³⁹Ar age spectra lacking plateaus, K-Ar analyses with poor radiogenic yield) have been excluded. In a few cases, results that did not meet these criteria have been included; statements in the "comments" column of the table indicate when and why this was done. All ages mentioned in this report are listed in the tables.

The appendix includes discussion of sources and distribution of conodont data and geologic implications of the data. Table A-1 lists the conodont data by 1:250,000-scale quadrangle. Table A-2 summarizes the temperature ranges thought to correspond to color-alteration index (CAI) values of conodonts.

Geologic time-scale age boundaries used are those of Gradstein and Ogg (2005).

Geologic Summary

Major Geologic Components

Most of Seward Peninsula is underlain by rocks that were part of a Late Proterozoic to early Paleozoic continental margin; remnants of that margin are also present in the Brooks Range. Rocks of the Chukotsk Peninsula, 85 km west of the Seward Peninsula, across Bering Strait (sh. 1, 2), probably were part of the same continental margin as well (Dumoulin and others, 2002). The extensive high-pressure metamorphic rocks exposed in central Seward Peninsula (Nome Complex), the southern Brooks Range, and the Ruby geanticline are thought to record subduction of that continental margin during the Jurassic (Patton and Box, 1989; Christiansen and Snee, 1994; Roeske and others, 1995; Gottschalk and Snee, 1998) (fig. 1).

During the Early Cretaceous, contractional deformation ceased within the subduction zone, moved into the subjacent continental crust, and propagated to shallower levels. As a result, the continental margin was involved in a mountain-building episode, which involved thickening of the continental crust and movement of thrust sheets northward. We refer to this post-subduction contractional deformation of continental crust as the Brooks Range orogeny. Some exhumation of the Nome Complex blueschists by thrust faulting may have been part of this episode. Rocks in the York Mountains of Seward Peninsula likely experienced thrust faulting and shallow burial at this time, based on thermal indices (conodont color alteration indices; table A-2) from carbonate rocks and outcrop-scale structures in siliciclastic rocks.

Metamorphic fabrics in the Nome Complex have been related to subduction zone deformational processes (Thurston, 1985; Patrick, 1988) and extensional collapse of the Brooks Range orogen after the mountain building and crustal thickening episode (Hannula and others, 1995; Amato and others, 2002). $^{40}\text{Ar}/^{39}\text{Ar}$ and fission-track data indicate that significant cooling of the high-pressure metamorphic rocks now exposed on Seward Peninsula occurred in the period 120-70 Ma (Hannula and McWilliams, 1995; Dumitru and others, 1995); extensional deformation is thought to have occurred during that time span.

Amphibolite to granulite facies metamorphism overprinted the Nome Complex and other rocks during the mid-Cretaceous; at about the same time, a protracted period of magmatism began on Seward Peninsula and lasted until the end of the Cretaceous (fig. 2). At least one suite of plutonic rocks formed in an island arc setting (Amato and Wright, 1997). During the Cenozoic, normal faulting created small mountain ranges and adjacent sedimentary basins, and mafic volcanic rocks accumulated in the central and northern parts of the peninsula.

In this text the term “metabasite” refers to metamorphosed mafic rocks of any nature, including originally intrusive and extrusive varieties.

Based on lithology, age, tectonic affinity, and metamorphic history, rocks of Seward Peninsula are divided into several tectonic subdivisions, illustrated on sheet 2.

York Terrane

Rocks of western Seward Peninsula are mostly lower Paleozoic and possibly older carbonate and siliciclastic rocks that retain primary sedimentary features except where they occur near granitic intrusions or where they are mica rich. We divide the York terrane into two parts: the “York Mountains succession”, a relatively well-studied stratigraphic sequence found mainly in the central York Mountains, and “Units of uncertain affinities”, a group of relatively poorly understood rocks (sh. 1).

Thermal indicators, based on conodont color alteration index (CAI) values, show that the York terrane contains several provinces with different thermal histories, and therefore, different burial and tectonic histories (sh. 2, appendix 1). Some York terrane rocks are unmetamorphosed (most of the York Mountains succession), and some may have reached low greenschist facies conditions (Units with uncertain affinities). Siliciclastic rocks in units with higher thermal indices (units OEt, OEI) and a related unit (OEp) display open folds with a sub-horizontal axial plane cleavage; finer-grained rocks are slates or phyllites and are crenulated. These units probably experienced burial and deformation during the Brooks Range orogeny. Carbonate rocks with lower thermal indices, in the central York Mountains, were much more shallowly buried (sh. 2). Structures that separate different thermal provinces have yet to be delineated, but are important for defining the deformation history of the York terrane.

Carbonate strata of the York terrane correlate well with carbonate successions in three regions: the Brooks Range (northeast of the Seward Peninsula), the Farewell terrane of interior Alaska (southeast of Seward Peninsula), and the peri-Siberian terranes of northeastern Russia (Dumoulin and Harris, 1994; Dumoulin and others, 2002). Lithofacies and biofacies of York terrane carbonate rocks are especially similar to those of coeval strata in the western Brooks Range

(Baird Mountains) and the Farewell terrane. Rocks in all three regions contain a distinctive biota characterized by both Siberian and Laurentian (North American) endemic forms, including many identical species. Detailed lithologic similarities between the three successions are also numerous (Dumoulin and others, 2002).

Grantley Harbor Fault Zone and Contact Between the York Terrane and the Nome Complex

Several lenses of low-grade metasedimentary rocks, probably fault bounded, sit on the structural contact between the York terrane and the Nome Group. This zone is distinguished on the map because the rocks are more penetratively deformed than similar lithologies in the York terrane, and less penetratively deformed than similar lithologies in the Nome Complex. Hannula and others (1995) considered these rocks part of a structurally coherent section that decreases in metamorphic grade from the Kigluaik Mountains northwest to the coast. However, there is a metamorphic discontinuity within the section. Metamorphic grade of the Nome Complex does decrease from the Kigluaik Mountains to the northwest; metabasites nearer the Kigluaik Mountains are blue amphibole-bearing, and those farther away contain lower grade pumpellyite-actinolite assemblages (Hannula and others, 1995) (see unit P_{2np}). However, a sliver of Nome Complex rocks that contain lawsonite and glaucophane pseudomorphs sits between the pumpellyite-actinolite grade rocks of unit P_{2np} and the subgreenschist facies unit of the Grantley Harbor Fault Zone (sh. 2). The sliver of schists that contain glaucophane and lawsonite pseudomorphs must have been structurally imbricated with the adjacent rocks.

Faults within the Grantley Harbor Fault Zone are part of the regionally important structural contact between the Nome Complex and the York terrane. The contact was interpreted as a thrust fault by Till and Dumoulin (1994), based on possible correlation with east-vergent structures on the Lisburne Peninsula, western Brooks Range (Patton and Tailleir, 1977; Moore and others, 2002). However, models for mid-Cretaceous crustal extension (Miller and Hudson, 1991) and evidence for extensional faulting within the York terrane (Toro and others, 2006) are consistent with an extensional detachment between the York terrane and the Nome Complex. The contact between the York terrane and the Nome Complex, which is very poorly exposed, may have been a thrust fault during the contractional mountain-building phase of the Brooks Range orogeny, and been reactivated multiple times as a thrust and(or) extensional surface.

Nome Complex

The low, rolling hills of central and eastern Seward Peninsula are underlain by lithologically varied rocks that have well-developed blueschist and greenschist metamorphic fabrics. These rocks underlie most of the peninsula, including the highly productive gold districts that have attracted geologists' attentions since the 1899 Nome gold rush.

The metamorphic rocks consist of several thick mappable lithologic sequences, scattered carbonate rocks with an uncertain relation to those sequences, and small bodies of orthogneiss. Mesozoic ductile and penetrative deformation largely obliterated primary sedimentary and igneous textures. Sparse conodont and other fossil collections and zircon ages from orthogneisses provide limited age control, and were interpreted to indicate Neoproterozoic and Paleozoic protolith ages for the unit overall (Till and others, 1986).

In 1900, U.S. Geological Survey geologists created the first topographic and geologic maps of the newly discovered Nome gold fields. They first applied the name "Nome series" to the lithologically complex metamorphic rocks that underlie the placer deposits of southern Seward Peninsula (Brooks and others, 1901). Initially, the approach to differentiation of units was stratigraphic, and was based upon apparent superposition of lithologic units and a small number of megafossil collections. Within a few years, as additional megafossil ages conflicted with the perceived relations within the series, the name "Nome group" was proposed (Collier and others, 1908). In proposing the change, Collier and others (1908) noted that the unit was not a stratigraphic one, but rather was heterogeneous and metamorphic; no type section was proposed, and lithologic descriptions were very simple. In modern stratigraphic nomenclature the term "group" is for a set of related lithostratigraphic units; the term "complex" is for highly deformed rocks such as those exposed in central Seward Peninsula (North American Commission of Stratigraphic Nomenclature, 2005).

We include all rocks on Seward Peninsula that exhibit a common set of structural and (or) metamorphic features, likely formed in the same deformational event, in the Nome Complex. Although the bulk of the Nome Complex shows evidence of high-pressure metamorphism, rocks along the eastern, western, and northern boundaries of the complex crystallized at slightly different peak metamorphic conditions (sh. 2). In these cases, similarities in structural fabric elements and lithologic characteristics suggest that they were part of the same metamorphic event, and are therefore included in the complex. A number of the lithologies in central Seward Peninsula do not produce mineral assemblages diagnostic of metamorphic grade; in those cases, a structural style consistent with lithologies that do contain high-pressure minerals is used for inclusion in the complex. A few lithologies, such as fine-grained dolostones, do not

manifest the structures common in most of the Nome Complex, and are exposed in isolated outcrops. Where available, color alteration index values (CAIs) of conodonts that are consistent with the conditions of high-pressure metamorphism were used to include these rocks.

We divide the Nome Complex into three parts (sh. 1). The “Layered sequence” consists of mappable lithologic units that occur in a consistent, layer-cake structural relation to one another over much of central Seward Peninsula. “Scattered metacarbonate rocks” consists of volumetrically minor dolostones and marbles that are widely distributed. Units that are exposed only on the north and southeast coasts of the peninsula (DO_{bm}, D_€bm, D_€ks) are included in “Metaturbidites”.

The character of the lithologies in the Nome Complex is consistent with formation on a continental shelf and slope. Some carbonate rocks (units €d, Od, Sd, Ddm of Scattered metacarbonate rocks) contain sedimentary features, megafauna, and (or) microfauna typical of shallow water conditions. Other rocks show features that indicate they formed in slope and basinal environments (Metaturbidites units DO_{bm}, D_€bm). Metasedimentary rocks that formed from combined carbonate, siliciclastic, and graphitic components are common; metasedimentary rocks composed of intermixed mafic, carbonate, and siliciclastic components are also widespread. Chemical characteristics of the mafic rocks in the Nome Complex indicate that they formed during rifting of a continental margin (Werdon and others, 2005a; Ayuso and Till, 2007).

The age of the Nome Complex protolith is known from microfossils, megafossils, U-Pb zircon analyses, and detrital zircon analyses. Cambrian, Ordovician, Silurian, and Devonian fossils were collected from carbonate rocks (Till and others, 1986). Small, Late Proterozoic orthogneiss bodies have been identified (Patrick and McClelland, 1995; Amato and Wright, 1998; Till and others, 2006), as well as several Middle Devonian metagranitic bodies (Till and others, 2006; Gottlieb and Amato, 2008; Amato and others, 2009). Detrital zircon analyses reveal that very little of the protolith of the complex was deposited before 600 Ma, and some metamorphosed siliciclastic rocks are likely Devonian or younger (Amato and others, 2003c; Amato, 2004; Till and others, 2006, 2007). Mafic rocks that formed during rifting of the continental margin have not been directly dated in the Nome Complex, but are thought to be Ordovician (see description of unit Ocs).

Penetrative ductile deformation and recrystallization of the sequence make geologic mapping and identification of the nature and precise age of the protolith extremely difficult. The presence of mafic boudins that contain blueschist-facies minerals in the Nome Complex was first noted by Sainsbury and others (1970); Thurston (1985) documented blueschist-facies minerals in a variety of lithologies, showing that high pressure/low temperature metamorphism affected the entire Nome Complex. The Nome Complex, therefore, is a metamorphic complex initially formed during subduction of a continental margin. This indicates that lithologic units within the Nome Complex were removed from the surface of the subducting continental crust - but not necessarily in a way that retains their original stratigraphic relations. Based on available detrital zircon data, the structurally lowest parts of the Nome Complex are the youngest parts of its protolith (Till and others, 2006).

The metamorphic history of the Nome Complex is imperfectly known, especially its history after peak high-pressure/low-temperature metamorphism. As is the case with many blueschist-facies metamorphic terranes, many lithologies in the Nome Complex do not contain mineral assemblages diagnostic of metamorphic grade. The same mineral assemblages may form, for example, at both high pressure (blueschist-facies) and low pressure (greenschist-facies) conditions. Further, greenschist- and blueschist-facies mineral assemblages can form at the same conditions in mafic rocks of slightly different compositions (Evans, 1990). Finally, in the Nome Complex greenschist-facies assemblages do overprint blueschist-facies minerals locally, but establishing the relation of greenschist assemblages to deformational events and the age of those events are challenging. Distinguishing the metamorphic history of the Nome Complex – especially the history after peak high-pressure metamorphism – has shown to be particularly difficult.

Based on thermobarometry and petrography, the metamorphic pressure-temperature path of the Nome Complex traversed the lawsonite-stable part of blueschist facies and reached peak pressure in the epidote-stable part of blueschist facies/eclogite facies (Forbes and others, 1984; Thurston, 1985). Conditions of peak pressure were estimated at 460°C, 12 kb (Patrick and Evans, 1989). Temperature peaked during exhumation in albite-epidote-amphibolite-facies. This pressure-temperature path is identical to that documented in the Schist belt in the southern Brooks Range (Till and others, 1988; Gottschalk, 1998) and is similar to that in the Ruby geanticline (Roeske and others, 1995) (fig. 1); the Nome Complex, Schist belt, and schists in the core of the Ruby geanticline probably formed during the same subduction episode.

Geochronologic studies to date have not clearly documented the timing of the high-pressure event on Seward Peninsula. Although Rb-Sr and K-Ar ages indicated a Jurassic age of metamorphism (Armstrong and others, 1986), ⁴⁰Ar/³⁹Ar plateau ages from white mica in the Nome Complex typically span the ages from 109 to 125 Ma (table 2); these ages are thought to represent minimum ages for blueschist-facies metamorphism (Hannula and McWilliams, 1995). The Rb-Sr ages are from essentially 2-point isochrons; therefore, their value is also limited. Sodic-calcic amphibole from a

vein thought to have formed during decompression and heating of the Nome Complex yielded a $^{40}\text{Ar}/^{39}\text{Ar}$ plateau age of 138.6 ± 1.0 Ma (Layer and Newberry, 2005; table 2); this age approximates the timing of peak temperature for the Nome Complex, and is a minimum age for peak pressure. White mica $^{40}\text{Ar}/^{39}\text{Ar}$ ages from metamorphically correlative rocks in the Ruby geanticline place a minimum age of 144 Ma on the blueschist-facies event (Roeske and others, 1995), and blueschist-facies rocks of the southern Brooks Range are thought to have reached peak pressure during the Middle Jurassic (Christiansen and Snee, 1994; Gottschalk and Snee, 1998). Based on the age of the vein-filling sodic-calcic amphibole and correlative nature of high-pressure/low-temperature metamorphic events in the Brooks Range and Ruby geanticline, we believe that the Nome Complex reached peak pressure during the Jurassic.

The degree to which the dominant structural fabric in the Nome Complex is a product of exhumation processes, rather than subduction processes, is a matter of some controversy. Thurston (1985) and Patrick (1988) suggested that the parallelism of glaucophane and pseudomorphs after glaucophane with the dominant fabric indicates that the fabric was formed during high-pressure metamorphism. Miller and Hudson (1991) postulated that Seward Peninsula was part of a vast region that underwent crustal extension in the mid-Cretaceous in response to crustal thickening during the Brooks Range orogenic episode. Based on structural and metamorphic analysis, Hannula and others (1995) contended that the dominant fabric in the Nome Complex was related to the extensional episode, and the blueschist fabric was largely overprinted. Because many of the lithologies in the Nome Complex display the same metamorphic assemblages at blueschist or greenschist facies, this is a challenging problem to unravel.

Sheet 2 shows subdivisions of the Nome Complex that highlight small differences in metamorphic and (or) deformational history. In central Seward Peninsula, the greater part of the Nome Complex displays consistent metamorphic and deformational features. These rocks possess a penetrative fabric formed in a ductile setting and, in appropriate lithologies, contain minerals diagnostic of blueschist-facies conditions. Glaucophane and fine intergrowths of chlorite and albite that pseudomorph glaucophane are widespread in mafic, pelitic, and calcareous lithologies. One metabasite contains the eclogite-facies diagnostic minerals jadeitic pyroxene (omphacite) and garnet (Nome Complex-central; sh. 2). Exposures of the Nome Complex margins (west, north, and east) show slight variations in deformational and structural style. Descriptions of these variations are on sheet 2 and in the Description of Map Units.

High-grade Metamorphic and Associated Igneous Rocks

Amphibolite and granulite-facies metamorphic rocks are exposed in the Kigluaik, Bendeleben, and Darby Mountains and in a small area north of the Oonatut Granite Complex in the northwestern Bendeleben quadrangle (fig. 2). These high-grade metamorphic rocks formed during the Cretaceous and have no identified direct counterparts in the Brooks Range, although potentially metamorphically correlative rocks are known in the Ruby geanticline (Roeske and others, 1995). On Seward Peninsula, some lithologic units in the high-grade metamorphic rocks are identical to lithologic units recognized in the Nome Complex (Till and others, 1986; Till and Dumoulin, 1994), and other lithologies are not known in the Nome Complex (for example, ultramafic and associated rocks that are exposed at the core of the Kigluaik Mountains). The oldest dated rock on Seward Peninsula (870 Ma), a foliated metarhyolite, is exposed in the southwestern Bendeleben Mountains (Gottlieb and Amato, 2007; Amato and others, 2009). No rocks of that age have been identified in the Nome Complex.

High-grade metamorphic assemblages record a polyfacial metamorphic history that has not been studied in detail. In some areas, high-grade metamorphic assemblages demonstrably overprint blueschist and greenschist-facies assemblages that formed during metamorphism of the Nome Complex (Thurston, 1985; Till and others, 1986; Hannula and others, 1995). Kyanite is present in pelitic rocks in all three mountain ranges; kyanite-bearing assemblages are typically overprinted by sillimanite-bearing assemblages, and therefore represent an early part of the metamorphic history. Evidence for decompression is recorded in some of the high-grade metamorphic rocks. In rare lithologies high in aluminum and iron, earlier, higher-pressure assemblages (orthoamphibole plus aluminosilicate) are overprinted by lower-pressure assemblages (cordierite plus staurolite or garnet) (sh. 2).

The metamorphic history of rocks in the two east-west trending ranges (Kigluaik, Bendeleben) is broadly similar. Metamorphic grade in the Kigluaik Mountains increases towards the core of an antiform, or dome, defined by foliation and gneissic layering. Two-pyroxene gneisses, definitive of granulite facies, are present in the core of the antiform near Mount Osborn (Till, 1980; Lieberman, 1988; sh. 2). Peak metamorphic grade in the Kigluaik Mountains is thought to have occurred at about 91 Ma, immediately before or coincident with intrusion of the Kigluaik pluton (Amato and others, 1994; Amato and Wright, 1998). Metamorphic isograds in the Kigluaik Mountains are closely spaced, a feature likely related to exhumation processes (Patrick and Lieberman, 1988; Miller and others, 1992; Calvert and others, 1999). In the central Bendeleben Mountains, foliation is also domed (Gottlieb and Amato, 2008). However, metamorphic zonation is less well known and apparently more complex than in the Kigluaik Mountains; the timing and conditions of peak

metamorphism have yet to be directly documented. Also the relations of the two plutons in the Bendeleben Mountains to high-grade metamorphism is unknown; part of the Bendeleben pluton is older (104 Ma) and the Pargon is younger (86 Ma) than the Kigluaik pluton (Gottlieb and Amato, 2008). Rapid cooling (to <200°C) of the Kigluaik gneisses and schists occurred between 87 and 78 Ma (Calvert and others, 1999). U-Pb ages on zircon rims in cordierite schist and on zircon grains in igneous rocks in the Bendeleben Mountains seem to indicate that decompression occurred at about 88 to 85 Ma (Gottlieb and Amato, 2008); biotite and monazite cooling ages from the Bendeleben Mountains range from 87 to 81 Ma (Turner and Swanson, 1981; Gottlieb and Amato, 2007).

The high-grade metamorphic rocks of the Kigluaik and Bendeleben Mountains are structurally coherent and domed, whereas distribution of high-grade metamorphic rocks in the north-south oriented Darby Mountains is more complex. Metamorphic grade increases along the axis of the Darby range from north to south, culminating in the area around Mount Arathlatuluk (sh. 2). In the northern part of the range, Nome Complex rocks are present and have biotite-grade metamorphic overprints. The central part of the range contains staurolite- and kyanite-bearing assemblages; kyanite may be relict from an early metamorphic event. At Mount Arathlatuluk, small, biotite-granite stocks occur with granulite-facies (2 pyroxene) metamorphic assemblages (sh. 2); sillimanite is common. Zircon from a granite stock yielded a U-Pb age of 108 Ma, an age that broadly approximates the time of peak temperature (R. Friedman, written commun., 2009). The low-grade rocks in the northern Darby Mountains are juxtaposed with a slice of high-grade metamorphic rocks (on the west flank of the mountains) along a high-angle reverse fault; the age of the fault is not known. At the time of intrusion of the Darby pluton, the metamorphic rocks were in shallow (<5 kb) crustal settings; the Darby pluton has andalusite in its contact zone (sh. 2). The Darby pluton yielded two U-Pb zircon crystallization ages of 100 Ma (Amato, written commun., 2008; R. Friedman, written commun., 2009).

Although the three mountain ranges (Kigluaik, Bendeleben, and Darby Mountains) appear to describe a small orocline, the ranges do not have the same exhumation history. The apparent orocline is due to the intersection of structures of different ages. Biotite cooling ages from the Kigluaik and Bendeleben Mountains range from 87 to 81 Ma; biotite cooling ages are older in the Darby Mountains, ranging from 102 to 90 Ma. Apatite fission-track analysis indicates that the Kigluaik and (by inference) Bendeleben Mountains were cooled and uplifted during the Tertiary (Eocene-Oligocene; Dumitru and others, 1995), whereas rocks in the northern Darby Mountains were at the surface during the early Eocene, as the Darby pluton (unit Kd) is basement to a small sedimentary basin of early Eocene age (Dickinson and others, 1987).

Yukon-Koyukuk Basin, Angayucham Terrane, and the Kugruk Fault Zone

The Yukon-Koyukuk basin sits along the eastern side of Seward Peninsula and contains Early Cretaceous subduction-related volcanic rocks and related marine sedimentary rocks. The basin is flanked on three sides by terranes with continental affinity: Seward Peninsula on the west, Brooks Range on the north, and Ruby geanticline on the east (fig. 1). The basin is bordered by marine to non-marine conglomerates that are younger than the marine volcanic and sedimentary rocks within the basin and were derived from adjacent continental rocks (Patton and Box, 1989).

Along its eastern and northern boundaries, the Yukon-Koyukuk basin is separated from flanking continental rocks by a belt of mafic and ultramafic rocks and minor sedimentary rocks, the Angayucham terrane (Box and Patton, 1989). The Angayucham is thought to represent imbricated Devonian through Jurassic oceanic crust (Pallister and others, 1989). On the eastern and northern boundaries of the Yukon-Koyukuk basin, from the basin to its flanks, major units have the same structural stacking: marine volcanic and sedimentary rocks sit above younger, continentally derived conglomerates, which sit above oceanic rocks of the Angayucham terrane, which sit above schists with continental protoliths and high-pressure/low-temperature metamorphic assemblages.

Eastern Seward Peninsula lacks this simple structural stacking. Instead, the marine volcanic and sedimentary rocks of the basin are directly juxtaposed with schists of the Nome Complex, with no intervening oceanic rocks (sh. 2). The oceanic rocks sit west of the Yukon-Koyukuk basin as isolated slivers within a fault zone flanked by the Nome Complex. The fault zone spans eastern Seward Peninsula from north to south, and was named the Kugruk Fault Zone by Sainsbury (1974). Nome Complex rocks are within the fault zone and flank the fault zone on both sides. Sedimentary rocks related to the Yukon-Koyukuk basin (the older part of unit TKs) are also caught as slivers within the fault zone.

The oceanic rocks of eastern Seward Peninsula are considered part of the Angayucham terrane and consist of metabasalt, Jurassic tonalite, and minor serpentinite. Mafic rocks throughout the belt are metamorphosed to blueschist or greenschist facies; fabrics in these rocks are weak to mylonitic. Mafic rocks in the northern part of the Kugruk Fault Zone also retain minerals from an earlier metamorphic event that predated the blueschist-greenschist facies event, while mafic rocks in the southern part of the fault zone contain a single blueschist or greenschist metamorphic assemblage and relict igneous phases. The age of blueschist-facies metamorphism is unknown, and it differs in style and conditions from

the blueschist-facies event in the Nome Complex. Although the metamorphic grade of basaltic rocks in the Angayucham terrane elsewhere is generally prehnite-pumpellyite to low greenschist, blue amphiboles are known in correlative oceanic rocks on the flank of the Ruby geanticline (Dusel-Bacon and others, 1989; Roeske and McClelland, 1997).

Two sequences of sedimentary rocks, one likely mid-Cretaceous, the other Late Cretaceous and Tertiary in age, are present within the fault zone. One sequence is dominated by coarse conglomerate rich in locally-derived clasts, including Paleozoic marbles and dolostones (most from the Nome Complex) and mylonitic metabasites from the Angayucham terrane (Till and others, 1986). Mid-Cretaceous sedimentary rocks of the adjacent parts of the Yukon-Koyukuk basin are also carbonate-rich (Nilsen, 1989; Patton and others, 2005), and are likely part of the same depositional sequence. Generally finer grained sedimentary sequences that have thick coal seams yielded Late Cretaceous and Tertiary pollen (Till and others, 1986; Dickinson and others, 1987).

Movement on the Kugruk Fault Zone may have recurred over a long time interval. The 100-Ma Darby pluton retains its intrusive contacts and is elongate parallel to the fault zone, suggesting that a structural control to the pluton's shape existed during the Cretaceous. Results from a coal drilling program in the northern part of the Kugruk Fault Zone show that Nome Complex schists sit structurally above Tertiary sedimentary rocks, where the schists must have been placed by reverse faulting (Retherford and others, 1986). Therefore, the Kugruk Fault Zone also was active during the Tertiary.

Igneous Rocks

Granitoid rocks intruded the Nome Complex during the Cretaceous (fig. 2). Based on early reconnaissance work and K-Ar ages, three suites of plutons were recognized: an early alkalic group, 110 to 96 Ma; a calc-alkaline group, 95 to 80 Ma; and a tin granite group, 80 to 69 Ma (Till and others, 1986). These characterizations are in flux.

The alkalic rocks are part of a belt that extends east of Seward Peninsula into the Yukon-Koyukuk basin (Miller, 1989; Arth and others, 1989; Amato and Wright, 1998). The calc-alkalic plutons core the Kigluaik Mountains and are common on eastern Seward Peninsula (Till and others, 1986; Amato and Wright, 1998). Magmatism continued with intrusion of plutons and alkalic dike swarms (Amato and others, 2003c; Gottlieb and Amato, 2008). During latest Cretaceous time, a suite of tin-bearing granites intruded both the Nome Complex and adjacent rocks in western Seward Peninsula (Hudson and Arth, 1983).

Magmatic events on Seward Peninsula are coeval with similar events on Saint Lawrence Island, Alaska, approximately 250 km southwest of Seward Peninsula, and in the Okhotsk-Chukotsk volcanic belt on the Russian side of Bering Strait, and formed in the same general tectonic regime (Amato and Wright, 1998; Miller and others, 2002; Amato and others, 2003b).

Better delineation of crystallization ages using U-Pb zircon geochronology and a deeper understanding of petrogenetic events using modern geochemical tools was initiated by Arth and others (1989) and Amato and others (1994). Continued study of the age and nature of petrogenetic events on Seward Peninsula is underway (for example, Amato and Wright, 1997; Gottlieb and Amato, 2008); the earlier delineation of plutonic suites is in the process of being revised.

In central, eastern, and northern Seward Peninsula, extensive plateau basalts, cinder cones, and very large maars formed during several episodes of volcanism as old as the Oligocene, and as young as the Holocene (Hopkins and others, 1971; Turner and Swanson, 1981).

Tertiary and Active Deformation

Geomorphologic, structural, and thermal data indicate active deformation on Seward Peninsula occurred in Tertiary to Recent times. Along the coastline south of the York Mountains, terraces were uplifted during the late Pleistocene (Sainsbury, 1967). Active normal faults, which are marked by sag ponds, offset streams, scarps and other features, bound the Kigluaik and Bendeleben Mountains (Kaufman, 1985; Plafker and others, 1994), and expose the high-grade metamorphic rocks. Apatite fission-track data show that significant slip on these faults started in the Eocene (Dumitru and others, 1995). A transition from Nome Complex detritus to detritus that also includes high-grade minerals was recognized in wells drilled in Tertiary (Paleogene) offshore basins (Forbes and others, 1984; Tolson, 1987). Based on gravity data, basins sit below McCarthy Marsh, south of the Bendeleben Mountains, and the Imuruk basin, north of the Kigluaik Mountains (Barnes and Hudson, 1977; Barnes and Morin, 1988); these basins are likely the same age as those offshore.

Tertiary activity along the Kugruk Fault Zone included reverse faulting (Retherford and others, 1986) as well as early Eocene graben formation (Dickinson and others, 1987). Death Valley, in the northern Darby Mountains, is likely a Tertiary feature.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

- Qs** **Surficial deposits, undivided (Quaternary)**—Frost-rived rubble on slopes and broad low ridges; glacial moraine; glacially deposited sand, gravel, and boulders; fluvial gravel and sand; marine and fluvial terrace deposits; wetlands

MESOZOIC AND CENOZOIC IGNEOUS ROCKS

- Qlj** **Lost Jim Basalt (Holocene)**—A single basaltic lava flow and associated vent deposits, undisturbed by frost brecciation, located in central Bendeleben quadrangle (fig. 2). The dark gray-black vesicular olivine basalt in eastern part of the unit exhibits pahoehoe flow features and lava tubes. Maximum age is constrained to be less than 0.8 Ma based on stratigraphic position above unit QTv (Turner and Swanson, 1981)
- QTv** **Weathered volcanic rocks, undivided (Quaternary and Tertiary)**—Basalt lava flows, vent deposits, maar volcanoes and associated pyroclastic rocks exposed in northern, central, eastern, and to a minor extent, southern Seward Peninsula (fig. 2).
- Less weathered rocks are slightly to strongly fragmented by frost riving and locally overlain by windblown silt. These rocks include alkali olivine basalt and olivine tholeiite. Alkalic rocks contain phenocrysts of olivine with plagioclase, augite, and spinel in the groundmass. Tholeiitic rocks contain plagioclase, phenocrysts with augite, hypersthene, olivine, and spinel in the groundmass (Swanson and others, 1981). These less weathered volcanic rocks underlie portions of the Lost Jim Basalt in central Bendeleben quadrangle, and include the Camille Basalt and Gosling Volcanics of Hopkins (1963), as well as small flows in valley centers on the south flank and south of the Bendeleben Mountains. Potassium-argon (K-Ar) determinations on basalt from Kugruk River canyon (Turner and Swanson, 1981) and from the northwest flank of the Bendeleben Mountains (Kaufman and Hopkins, 1985) indicate that the Gosling Volcanics were in part extruded between 0.9 and 0.8 Ma. The Camille Basalt is younger by an unknown amount of time. Equivalent to unit “Qv” of Till and others (1986). In southern Seward Peninsula, a small basaltic vent and associated flows yielded a $^{40}\text{Ar}/^{39}\text{Ar}$ whole rock age of approximately 0.8 Ma (Werdon and others, 2006).

Other volcanic rocks are thoroughly fragmented by frost action. These are the most widely distributed and voluminous volcanic rocks on the peninsula; they underlie most of the Imuruk Lake lava plateau but are mapped only where exposed through an otherwise 1- to 6-m thick mantle of windblown silt. The rocks are mostly alkali olivine basalt with phenocrysts of olivine with plagioclase, augite, and spinel in the groundmass. Lesser olivine tholeiite contains plagioclase phenocrysts with augite, hypersthene,

olivine, and spinel in the groundmass (Swanson and others, 1981). This part of the unit includes the Imuruk Volcanics of Hopkins (1963), which are between 2 and 5 Ma (Hopkins and others, 1971; Turner and Swanson, 1981). Flows of the Imuruk Volcanics were confined by modern valley systems that drained north from Imuruk Lake area and, as a result of subsequent stream incision, are exposed as bench remnants high on valley walls. South and east of Imuruk Lake, older volcanic rocks cap ridge tops. These older flows are between 26 and 29 Ma (Turner and Swanson, 1981). In southeastern Bendeleben quadrangle, basalt flows are interlayered with sedimentary rocks that have yielded early Eocene pollen (Dickinson and others, 1987). Equivalent to unit “QTV” of Till and others (1986).

The older volcanic units contain xenoliths of dunite, harzburgite, chromite, granite, and schist (Hopkins, 1963). Dunite xenoliths are most common, and reached 7-8 cm across. Granite and schist xenoliths are smaller (less than 2 cm across) and occur only where the volcanics erupted through granitic or metamorphic bedrock. Similar xenoliths in correlative volcanic rocks in western Alaska and on Saint Lawrence Island have had more detailed study (for example, Wirth and others, 2002).

The Late Quaternary Espenberg Maars, 30-50 km southwest of Cape Espenberg on northern Seward Peninsula, consist of four large craters ranging from 4 to 8 km in diameter surrounded by coeval tephra layers. These craters, known as Devil Mountain, Whitefish, North Killeak, and South Killeak Maars (fig. 2), are each separate eruption craters excavating 100 to 300 m into Pleistocene sediments and lavas (Hopkins, 1988). The maars are surrounded by a thick blanket of pyroclastic surge and airfall tephra deposits. Cliffs around Devil Mountain Maar expose sequences of bedded surge deposits, airfall lapilli beds, scoria, massive pyroclastic flows and explosion breccia (Bégét and others, 1996). This volcanoclastic sediment is evidence that the Espenberg Maars were formed by highly explosive hydromagmatic eruptions through permafrost, which ultimately created the unusually large maar craters. Devil Mountain Maar is 8 km long by 6 km wide, as much as 200 m deep, and covers over 30 km². It is the largest known maar on earth; the three other maars on Seward Peninsula are also larger than any previously described maar.

Mafic volcanic rocks of this unit are one of several Cenozoic volcanic fields in western Alaska that extend from northern Seward Peninsula to Saint Lawrence Island and the Pribilof Islands on the Bering Sea shelf (Moll-Stalcup, 1994); the Pribilof Islands are about 840 km south-southwest of Nome

- TKv **Felsic volcanic rocks (Tertiary and Cretaceous)**—Rubble crop of volcanic rocks in northeastern part of the map area, in Bendeleben D-1 quadrangle (fig. 2). Unit consists of two varieties of volcanic rock, both moderately to strongly limonite stained. One is a volcanic flow or tuff that contains up to 4% phenocrysts in an aphanitic, devitrified groundmass. Phenocrysts are predominately sanidine with rare quartz and plagioclase. No mafic minerals are present, but morphology of rare aggregates of sericite, opaques and limonite suggest the former presence of biotite. The second type of volcanic rock is fragmental and contains schist, devitrified volcanics, and angular quartz fragments in a felsic(?), sericite-bearing matrix. It may be a volcanic flow breccia or vent breccia rock. Age of unit is unknown. Felsic tuffs on Saint Lawrence Island have yielded a K-Ar age of 39.3 Ma (Patton and Csejtey, 1980)
- Ktg **Tin-bearing granitic stocks (Late Cretaceous)**—Stocks of biotite granite exposed in outcrop, rubble, and float in northwestern Seward Peninsula. Includes stocks at Cape Mountain, Brooks Mountain, Black Mountain, Ear Mountain, and the Oonatut Granite Complex (fig. 2). The belt also includes bodies not exposed at the surface at Lost River Mines and Kougarok Mountain (fig. 2). Stocks are dominantly biotite granite with lesser aplitic and pegmatitic phases (Hudson and Arth, 1983). Larger stocks, such as the Oonatut, are texturally zoned. Contacts with country rocks are sharply crosscutting, and contact aureoles are narrow. Epizonal stocks have high ⁸⁷Sr/⁸⁶Sr initial ratios and elevated Th, U, Hf, and Ta (Hudson and Arth, 1983). Potassium-argon (K-Ar) biotite ages range from 69.2±2 to 80.2±3 Ma (Hudson and Arth, 1983). Tin lodes and placers are associated with

- the stocks (Reed and others, 1989). Tin and tungsten were commercially mined in Lost River area, western Teller quadrangle (Sainsbury, 1969b)
- Kds Dikes and stocks (Cretaceous)**—Dikes and rare stocks of a variety of compositions and ages mapped extensively in the York, Kigluaik, and Bendeleben Mountains, and near the Darby Mountains, but also present in the Nome Complex. Some, but not all, are shown on the map as small pink lines.
- The oldest dike known is an analcime-biotite-nepheline syenite that intruded the Nome Complex in central Solomon quadrangle and yielded a biotite $^{40}\text{Ar}/^{39}\text{Ar}$ age of 107 Ma (Werdon and others, 2005a). A group of alkalic dikes, nepheline syenite and pseudoleucite porphyries, are exposed as frost-riven rubble in Solomon C-2, C-3 and D-3 quadrangles and intruded portions of the Kachauik pluton and adjacent marble. The dikes are up to 10 m wide and have strike lengths up to 900 m. They strike mostly to the northeast and are vertical. Syenite of the Kachauik pluton is highly radioactive adjacent to the dikes, containing up to 0.15% U_3O_8 , 1.05% ThO_2 and 2% rare earth elements (Miller and Bunker, 1976). Dikes yielded a K-Ar biotite age of 96.3 ± 3 Ma (Berry and others, 1976).
- Alkali feldspar granite to quartz monzodiorite pegmatite dikes and sills are common at the core of the Kigluaik Mountains, in the western Bendeleben Mountains, and in the Darby Mountains, but are not found in rocks of lower metamorphic grade. A foliated pegmatite dike that cut high-grade metamorphic rocks in the Bendeleben Mountains yielded a U-Pb zircon age of 99 ± 2 Ma (Gottlieb and Amato, 2008).
- Dark-brown- to orange-weathering alkalic diabase dikes are widespread on Seward Peninsula, but best documented in high-grade metamorphic rocks that underlie mountain ranges. Alkalic diabase dikes cut high-grade rocks and Cretaceous plutons in the Kigluaik and Bendeleben Mountains; dikes are up to 5 m across and yield $^{40}\text{Ar}/^{39}\text{Ar}$ ages of approximately 83 Ma (Calvert and others, 1999; Amato and others, 2003c). Similar brown- to orange-weathering alkalic mafic dikes in the Nome Complex are exposed in scattered locations on southern Seward Peninsula; in Solomon quadrangle, mafic dikes yielded $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 80 to 84 Ma (Werdon and others, 2005a; Newberry and others, 2005; Werdon and others, 2006).
- In the Bendeleben Mountains, light-tan- to orange-weathering, altered, porphyritic dikes, sills and small plugs of quartz latite are about the same age as the regionally widespread diabase dikes. In Bendeleben A-4 quadrangle, dikes are up to 12 m across and have aphanitic groundmass, feldspar and quartz phenocrysts, and altered mafic phenocrysts. Textures in dikes, sills and plugs indicate crystallization at shallower levels than the nearby granite bodies and pegmatite dikes. Gottlieb and Amato (2008) reported a U-Pb zircon age of 82 ± 1 Ma for a hypabyssal porphyritic dike, likely from this group of dikes. Dikes may be, in part, equivalent to unit “Kql” (quartz latite porphyry) and unit “Khi” (hypabyssal intrusive rocks) mapped by Miller and others (1972), and the “rhyolites of the western Bendeleben Mountains” of Turner and Swanson (1981). Similar intermediate to felsic dikes are exposed in the southern Darby Mountains, but their age is unknown.
- In western Nome quadrangle, biotite- and hornblende-bearing granitic dikes and lesser tourmaline-bearing pegmatite dikes cut folded and coarsely recrystallized marble (unit Pzmm). K-Ar ages of 80.5 ± 0.8 Ma (biotite) and 84.2 ± 0.9 Ma (hornblende) from the dikes are cooling ages (N. Shew, written commun., 1993); the hornblende age more closely approximates the intrusive age
- Kp Pargon pluton (Cretaceous)**—Fine grained equigranular, fine to medium grained seriate granodiorite, monzodiorite, and locally monzogranite exposed in the western Bendeleben Mountains along the upper reaches of the Pargon River (fig. 2). Granodiorite and quartz monzonite are the dominant lithologies. Upper contact of the pluton is preserved locally. Pargon pluton yielded a U-Pb zircon age of 86 ± 1 Ma (Gottlieb and Amato, 2008)
- Kdi Kigluaik diorite (Cretaceous)**—Fine- to medium-grained potassic mafic rocks of the lower part of the Kigluaik pluton, including biotite hornblende diorite, quartz diorite, granodiorite, tonalite, and gabbro, exposed in the western Kigluaik Mountains (fig. 2; Amato and

others, 1994; Amato and Miller, 2004). Geochemical and isotopic data indicate these mafic rocks are genetically related to the Kigluaik granite (unit Kg), the upper, more voluminous part of the pluton (Amato and Wright, 1997). Mineral thermometry indicates intrusion at pressures of 3-5 kb; together, units Kdi and Kg are thought to have formed in a subduction zone setting (Amato and Wright, 1997). Crystallization age of 90 ± 1 Ma (Amato and Wright, 1998)

- Kg Kigluaik granite (Cretaceous)**—Fine- to medium-grained felsic rocks of the upper part of the Kigluaik pluton (fig. 2), including leucocratic biotite granite and granodiorite (Amato and Miller, 2004). Unit is more extensively exposed than the mafic root, the Kigluaik diorite (unit Kdi), and contains minor amounts of alkali feldspar granite and quartz syenite (Amato and others, 1994; Amato and Wright, 1997). Contact with the underlying mafic root (Kdi) is a 10 to 20-m thick “mixing/mingling” zone characterized by mafic enclaves in a granitic matrix; textures suggest that unit is the same age as unit Kdi (Amato and Wright, 1997). The upper contact of unit with the overlying metamorphic rocks of the Kigluaik Group is locally exposed (Amato and Wright, 1997). Geochemical characteristics of units Kg and Kdi indicate formation in a subduction zone setting (Amato and Wright, 1997)
- Ks Stocks, undifferentiated (Cretaceous)**—Frost-riven outcrops, rubble fields, and float of felsic intrusive rocks at four localities align along a roughly north-south trend in Bendeleben C-3 and D-3 quadrangles (fig. 2). The northernmost, Crossfox Butte stock, is monzogranite to quartz monzonite with rare leucocratic syenite that contains several percent purple fluorite, muscovite, and minor scheelite. Country rock rubble around the stock consists of hornfelsed marble and calc-silicate rocks. A biotite K-Ar date of 91.5 ± 2.8 Ma is considered suspect due to chloritization of the biotite (Till and others, 1986). The Asses Ears stock is monzogranite to syenogranite and strikingly porphyritic, with alkali feldspar phenocrysts 2 to 4 cm long. The Virginia Butte stock is quartz monzonite to syenite that yielded a biotite K-Ar date of 94.8 ± 1.9 Ma (Till and others, 1986). The southernmost, Nimrod Hill stock, is monzonite, but contains rare biotite-rich diorite. Hornblende from Nimrod Hill yielded a K-Ar age of 96.3 ± 2 Ma (N. Shew, written commun., 1990). Aeromagnetic data suggest the stock extends west under Imuruk Lake and also suggest a possible connection with the Virginia Butte and Asses Ears stocks to the north (J. Cady, written commun., 1986)
- Kku Kugruk pluton (Cretaceous)**—Frost-riven rubble in northeast corner of Bendeleben C-2 quadrangle (fig. 2). Quartz monzonite to quartz monzodiorite. Green porphyritic rocks of approximately dioritic composition at the eastern margin of the pluton may be a border phase. Aeromagnetic data suggest that the pluton is larger than mapped (J. Cady, written commun., 1986). Biotite produced a K-Ar date of 94.8 ± 2.8 Ma (Till and others, 1986)
- Kwc Windy Creek pluton (Cretaceous)**—Talus and frost-riven rubble at north end of the Darby Mountains in Bendeleben A-1 and A-2 quadrangles. Rock type is quartz monzonite that is locally cut by biotite granodiorite dikes (fig. 2). Blocks or roof pendants of metamorphic rocks are locally common, especially in western portion of the pluton. A large block of marble, schist and calc-silicate hornfels is contained within eastern portion of the pluton. Miller and others (1972) found boulders of nepheline syenite in streams that drain east side of the pluton. Portions of pluton are altered and veined. Alteration consists of limonite staining, weak to strong sericitization of plagioclase, and variable chloritization and sericitization of hornblende. Two types of veins are present: (1) rare pieces of quartz vein material up to 15 cm across containing several percent fluorite, 1 to 2 percent molybdenite, and galena and sphalerite; and (2) thin, mostly <3 mm but up to 1 cm, veinlets containing quartz and pyrite±fluorite, molybdenite, scheelite and minor galena and sphalerite. Although these veinlets crosscut each other, they do not constitute a stockwork system. Yielded a hornblende K-Ar age of 93.8 ± 2.1 Ma (N. Shew, written commun., 1987)
- Kd Darby pluton (Cretaceous)**—Elongate monzogranite, locally granodiorite pluton 80 km long and 3 to 8 km wide that extends along crest of the Darby Mountains in southeast part of the peninsula (fig. 2). Outcrops are common in northern part of the pluton; frost-riven

rubble predominates elsewhere. Pluton is characterized by phenocrysts of alkali feldspar up to 5 cm long. Some gradual zonation of mineralogy: hornblende content decreases slightly to north; plagioclase content decreases slightly to north with a corresponding increase in alkali feldspar and quartz contents. Rounded or ellipsoidal inclusions of a mafic igneous rock are common. K-Ar ages range from 96.4±3 Ma to 90.5±1.5 (Miller and Bunker, 1976)

- Kkd Diorite (Cretaceous)**—Hybrid diorite of the Kachauik pluton; exposed in Solomon B-2 quadrangle (fig. 2). Unit is coarse grained and characterized by abundant biotite and may be a border phase of the monzonite-syenite (unit Kkms) of the Kachauik pluton (Miller and others, 1972)
- Kkg Granodiorite (Cretaceous)**—Granodiorite-quartz monzonite phase of the Kachauik pluton, exposed in frost-riven rubble, talus and outcrop in Solomon C-2 and D-2 quadrangles (fig. 2). Unit is cut by aplite, quartz latite porphyry, lamprophyre and alkaline dikes (Miller and others, 1972)
- Kkms Monzonite-syenite (Cretaceous)**—Monzonite-syenite phase of the Kachauik pluton; exposed as frost-riven rubble, talus and outcrop in Solomon B-2, C-2 and D-2 quadrangles (fig. 2). This phase is the most voluminous phase of the pluton, and is cut by aplite, quartz latite porphyry, lamprophyre, and alkaline dikes. K-Ar hornblende cooling age of 99.9±3 Ma (Miller and others, 1972; Miller and Bunker, 1976)
- Kkgm Gneissic monzonite (Cretaceous)**—Gneissic monzonite of the Kachauik pluton; exposed in Solomon C-2 quadrangle (fig. 2). Unit has a gneissic to trachytoid texture, and may be a border phase of the monzonite-syenite (unit Kkms) of the Kachauik pluton (Miller and others, 1972)
- Kbk Bendeleben and Kuzitrin plutons (Cretaceous)**—Monzogranite and granodiorite; outcrop, talus, rubble, and some cirque headwall exposures in eastern Bendeleben Mountains in Bendeleben A-2, A-3, B-2 and B-3 quadrangles, and small rubble fields north of the range in Bendeleben C-3 quadrangle (fig. 2). Known as two separate plutons, aeromagnetic data show that they are connected at depth, and they have similar chemistry, mineralogy, and cooling histories; they are lobes of the same large body. Contacts of both Bendeleben and Kuzitrin lobes with surrounding metamorphic rocks are not sharp, but rather are broad, several-kilometer-thick zones of mixed metamorphic and granitic rocks. Percentage of granitic rocks in contact zone decreases with distance from the two lobes. The Bendeleben lobe is monzogranite to quartz monzodiorite; contacts between these two phases do not appear to be gradational. Inclusions of plagioclase-biotite-pyroxene-quartz schist are locally common, and spectacular exposures of large inclusions or blocks of schist are present on northeast side of ridge in sec. 7, T. 3 S., R. 19 W. (Bendeleben A-2 quadrangle). Varying degrees of assimilation of this schist may account for the mineralogical and lithological variations. The Kuzitrin lobe is predominantly monzogranite and less well exposed. A U-Pb zircon crystallization age of 104±1 Ma was obtained from a foliated part of western Bendeleben pluton (Gottlieb and Amato, 2008). Biotite from Bendeleben lobe yielded a K-Ar age of 81.1±2 (Miller and Bunker, 1976; location 61 on sh. 2); a biotite sample from Kuzitrin lobe (location 62 on sh. 2) yielded a K-Ar age of 83.0±1.4 Ma. The biotite ages record pluton cooling
- Kdc Dry Canyon stock (Early Cretaceous)**—Frost-riven rubble of nepheline syenite on west side of Darby Mountains in Solomon D-2 quadrangle (fig. 2). Unit has a trachytoid fabric and yielded a K-Ar hornblende age of 108±3 Ma (Miller, 1972)
- Kgr Granite and granodiorite (Early Cretaceous)**—Equigranular biotite-hornblende quartz monzonite exposed along eastern boundary of map area in Candle quadrangle, at Granite Mountain and in the “J” shaped Quartz Creek pluton (fig. 2). Quartz monzonite at the core of the zoned Granite Mountain body grades into adjacent rocks of unit Ksy; the two rock types are thought to be comagmatic. Monzonite of adjacent unit Ksy yielded a hornblende K-Ar age of 108.6±3 Ma (Miller, 1972). Both bodies of quartz monzonite are part of the “western Yukon-Koyukuk plutonic suite” of Miller (1989), a potassic and ultrapotassic belt that extends from Seward Peninsula eastward into the Yukon-Koyukuk basin. Equivalent to unit “Kgr” of Patton and others (2005)

- Ksy Syenite, monzonite, and nepheline syenite (Early Cretaceous)**—Syenite, monzonite, and subordinate quartz monzonite, monzodiorite, quartz syenite, nepheline syenite and related mafic alkaline rocks of Patton and others (2005); exposed along eastern boundary of map area, in Candle quadrangle (fig. 2). Part of the “western Yukon-Koyukuk plutonic suite” of Miller (1989), a potassic and ultrapotassic belt that extends from Seward Peninsula eastward into Yukon-Koyukuk basin. Hornblende K-Ar age of 108.6 ± 3 Ma was obtained from the monzonite phase of Granite Mountain pluton (Miller, 1972). Equivalent to units “Ksy” and “Knsy” of Patton and others (2005)
- Kv Andesite and basalt flows and volcanoclastic rocks (Early Cretaceous)**—Andesite and basalt flows interbedded with volcanoclastic rocks and volcanic greywacke; exposed along eastern boundary of the map in Candle quadrangle (fig. 2). Calcareous tuffs in upper part of the unit contain abundant shelly material, including abundant early Early Cretaceous (Berriasian and Valanginian) marine mollusks; unit yielded K-Ar ages ranging from 137 to 120 Ma (Patton and others, 2005). Equivalent to unit “Kv” of Patton and others (2005)
- Kgu Granitic rocks, undifferentiated (Cretaceous)**—Granitic dikes, sills and small plugs at widely scattered localities (fig. 2). Most commonly these bodies occur within exposures of high-grade metamorphic rocks (unit PzPh), but unit is also present in the Nome Complex and on islands off the south and west coasts of the peninsula. Unit includes small bodies of anatectic biotite granite in southern Darby Mountains at Mount Arathlatuluk (107.8 ± 0.2 U-Pb zircon age), thought to be melts of the surrounding high-grade metamorphic rocks. Several bodies in western and easternmost Bendeleben Mountains intruded high-grade metamorphic rocks; small granitic bodies intruded the Nome Complex north of Death Valley, just south of the east end of the Bendeleben Mountains, and in the northeast Bendeleben quadrangle, near the boundary between the Bendeleben and Candle quadrangles. Fairway Rock, a small island directly west of the peninsula near Little Diomed Island, is a porphyritic hypersthene-bearing granite, with orthoclase crystals up to 10 cm long that are locally aligned in a fabric (Shumway and Moore, 1964). Biotite from Fairway Rock yielded a K-Ar biotite age of 110.7 ± 3 Ma, similar to ages to alkalic intrusives on Seward Peninsula (tables 2 and 3). Little Diomed Island, King Island, and Sledge Island are biotite-hornblende quartz monzonites or granites of unknown age (Sainsbury, 1972; Sainsbury and others, 1972). Extremely variable accessory mineralogy. Undated bodies are assumed also to be Cretaceous in age

YORK TERRANE

YORK MOUNTAINS SUCCESSION

- DSI Limestone (Devonian and (or) Silurian)**—Light-gray-weathering, medium-dark-gray limestone exposed in a small, fault-bounded area in central Teller quadrangle. Lithofacies include cherty lime mudstone, peloidal wackestone, and lesser coralline packstone. Lower beds produced relatively long-ranging conodonts but upper beds yielded conodonts of middle Silurian (middle Wenlock) age and Silurian (probably middle to late Silurian) corals; the fauna indicates a warm, relatively shallow water, normal-marine depositional setting (table A-1; W. Oliver, unpub. fossil report, 1974; Till and Dumoulin, 1994). DSI has also yielded corals thought to be of probable Middle or Late Devonian age (Oliver and others, 1975); the age of this collection was later revised to late Silurian (late Ludlow)-early Late Devonian (Frasnian), probably late Silurian to Early Devonian, by A. Pedder (Dumoulin and Harris, 1994; Till and Dumoulin, 1994). This revised age is younger than that of any other definitively dated lower Paleozoic rocks in the York terrane. Lithology and age of unit broadly correlate with all or parts of units SOdl and SOul of the York terrane and units Sd, DOx (overlay), and Ddm of the Nome Complex. Equivalent to unit “DI” of Sainsbury (1972)
- SOdl Dark limestone (Silurian and Upper Ordovician)**—Medium- to thick-bedded, light-brown to dark-gray limestone, dolomitic limestone, and dolostone, locally cherty, commonly very fossiliferous, exposed in a fault-bounded area in northeastern York Mountains (Teller quadrangle; “section on Don River” of Sainsbury and others, 1971).

Ordovician rocks, at least 120 m thick, consist of wackestones and packstones, with peloids and skeletal grains in a micritic matrix. Fossils are Late Ordovician and include conodonts (table A-1; Dumoulin and Harris, 1994), corals (Oliver and others, 1975; R.J. Elias *in* Blodgett and others, 2002, p. 283), trilobites (Ormiston, 1978; Ormiston and Ross, 1979), and brachiopods, cephalopods, gastropods, ostracodes, pelecypods, and stromatoporoids (Sainsbury, 1969a; Sainsbury and others, 1971; Rohr, 1979, 1988; Potter, 1984; Rohr and Potter, 1987; Rohr and others, 2003). Rugose corals (*Bighornia*) indicate a possibly Richmondian age (Dumoulin and Harris, 1994).

The Silurian section, at least 220 m thick, consists mainly of mudstone and bioclastic wackestone and packstone and contains more dolostone than the Ordovician part of the unit. Shallowing-upward cycles, 5 to 8 m thick, occur throughout. Megafossils form local buildups and include corals (Oliver and others, 1975), stromatoporoids, bryozoans, and brachiopods of middle and late Silurian age (Sainsbury and others, 1971). Biostratigraphically diagnostic conodonts are of early and earliest late Silurian ages (table A-1; Dumoulin and Harris, 1994; Till and Dumoulin, 1994).

Features such as fenestral fabric, micritized bioclasts, algal lamination, conodont biofacies, and the abundance and diversity of corals and stromatoporoids all indicate that SOdl was deposited in warm, shallow to very shallow water in a locally restricted platform setting. Ordovician conodonts and megafossils include both Siberian and Laurentian (North American) endemic forms (Dumoulin and Harris, 1994; Blodgett and others, 2002; Dumoulin and others, 2002). Silurian fossils are mainly cosmopolitan.

SOdl is at least partly correlative with unit SOul; it is also partly correlative with, but much more fossiliferous than, Silurian metacarbonate rocks in units Sd and DOx (overlay) of this map. Faunas and lithofacies of SOdl correlate well with those from age-equivalent strata in the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) and related units in western and central Brooks Range (units “DOb” and “DOc” of Till and others, 2008b) and of the Telsitna Formation and related rocks in the Farewell terrane of interior Alaska (Dumoulin and Harris, 1994; Dumoulin and others, 2002). SOdl is equivalent to units “SOdl” and “SI” of Sainsbury (1969a, 1972)

- SOul **Limestone and dolostone, undifferentiated (Silurian and Ordovician)**—Carbonate rocks equivalent to unit Ols and (or) unit SOdl, but less well studied than those units; exposed in three small fault-bounded areas in central part of the Teller quadrangle. The western and central exposures are limestone with corals of Late Ordovician (Sainsbury, 1969a, b; Sainsbury and others, 1971) or late Middle to early Late Ordovician (Oliver and others, 1975) age. The eastern exposure is near the eastern boundary of the York terrane and consists of very fine-grained, locally cherty, gray dolostone that contains long-ranging conodonts, domal to laminar stromatoporoids, and diverse tabulate and rugose corals of Silurian, probably late Llandovery-Wenlock age (table A-1). Conodonts from this locality have a CAI value of 5, one of the highest known from the York terrane (table A-1). Equivalent to unit “Oum” of Sainsbury (1969a, 1969b, 1972)
- Ols **Limestone and shale (Ordovician)**—Thin- to medium-bedded, pale-orange- to pale-yellow-brown-weathering, medium-gray to dark-gray limestone, dolomitic limestone, and dolostone with local shale and chert nodules. Ols forms subdued slopes within, north of, and east of the York Mountains; the unit is generally fault bounded, but locally depositionally overlies unit Ol. The lower 7 to 30 m of Ols is fissile black shale and lesser interbedded black limestone and dolomitic limestone that contains calcified and pyritized radiolarians and sponge spicules (T. Carr and T. Hudson, written commun, 1982; Dumoulin and Harris, 1994). Lower strata grade upward into flaggy, thin-bedded black limestone with shaly partings and soft-sediment deformation features, and then into thin-bedded, sparsely bioclastic limestone and dolostone that is graded, crossbedded, and bioturbated. Ols is at least 300 m thick (Dumoulin and Harris, 1994), and it appears to contain the Early-Middle Ordovician boundary near its base (Dutro *in* Ross and others, 1982). The unit produced pandemic, cool-water conodonts of earliest Middle Ordovician (latest Arenig and earliest Llanvirn) age (table A-1; Dumoulin and Harris, 1994), as well as cephalopods, graptolites, gastropods, and trilobites (Ross, 1967; Sainsbury, 1969b;

Dutro *in* Ross and others, 1982). The youngest beds in Ols occur in a small klippe, 0.5 km in diameter, west of the Mint River in the northwestern York Mountains (unit “Odl” of Sainsbury, 1969b) and consist of medium-bedded, mottled to laminated, gray to brown lime mudstone and dolostone that contain conodonts, corals, and cephalopods of late Llanvirn age (Flower, 1968; Sainsbury, 1969b; Dumoulin and Harris, 1994). Bedforms, sedimentary structures, and faunas indicate that Ols was deposited in a shallowing-upward, basin to peri-platform environment; the youngest strata accumulated in a mid- to outer-platform setting (Dumoulin and Harris, 1994). Lithofacies and biofacies of Ols correlate well with those of deeper water Middle Ordovician strata in the western and central Brooks Range (unit “O<c” of Till and others, 2008b; Dumoulin and Harris, 1994). Equivalent to units “Os” and “Oshd” of Sainsbury (1969a), “Olsh” and “Odl” of Sainsbury (1969b), and “Oshl” and “Oshd” of Sainsbury (1972)

OI Limestone (Ordovician)—Mainly massive to thick-bedded, light-brownish-gray to medium-gray, fine-grained limestone with local chert nodules and lesser interbeds of argillaceous limestone and shale, widely exposed in and adjacent to the York Mountains in western and central Teller quadrangle. OI is at least 450 m thick (Dumoulin and Harris, 1994); it resembles unit Oal in containing 8- to 15-m-thick shallowing-upward cycles (Vandervoort, 1985) and locally abundant trace fossils, but differs in containing more megafossils and lacking quartzose grainstone and ripple marks. Common rock types include lime mudstone, bioclastic wackestone, and fine to very fine grained peloid and intraclast grainstone. The upper 70 m of the unit is a distinctive blue-gray-weathering, white to pinkish-gray lime mudstone with rare trilobite fragments. Most exposures of OI are bounded by faults, but at a few localities it appears to grade upward into unit Olsh. Sainsbury (1969b) suggested that OI conformably overlies unit Oal, but megafossil and conodont data suggest that the lower part of OI may be coeval with much of unit Oal. OI is chiefly of Early Ordovician (early and middle Arenig) age. The tightest ages are based on conodonts and include collections restricted to the *Mac. diana*, *Ac. deltatus-On costatus*, lower *Oe. communis*, and *Re. andinus-T. laevis* Zones (table A-1); the two youngest of these collections are from near the top of OI and are definitively younger than any faunas recovered from unit Oal. Megafossils in OI include brachiopods, cephalopods, echinoderm debris, gastropods, and trilobites (Ross, 1965; Flower, 1968; Sainsbury, 1969b). Graptolitic shale of early Arenig age (*T. fruticosus* Zone; C. Carter, 1994, unpub. fossil report) forms local lenses in OI.

Lithofacies and biofacies indicate that OI accumulated in a range of subtidal to supratidal environments within a deepening-upward regime (Dumoulin and Harris, 1994); overall, OI appears to have formed in somewhat deeper water than unit Oal. Conodont assemblages in OI include both Siberian and Laurentian (North American) endemic forms (Dumoulin and Harris, 1994; Dumoulin and others, 2002); trilobites have Siberian affinities (Ormiston and Ross, 1979). OI correlates well with older parts of unit Od in the Nome Complex and the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) in the western Brooks Range (unit “DOb” of Till and others, 2008b), and with the Novi Mountain Formation, lower Telsitna Formation, and related rocks in the Farewell terrane of interior Alaska (Dumoulin and Harris, 1994; Dumoulin and others, 2002). Equivalent to units “OI” and “Olu” of Sainsbury (1969a, 1969b, 1972)

Oal Argillaceous limestone and limestone (Ordovician)—Thin-bedded, argillaceous, silty and (or) dolomitic limestone, lesser massive micritic limestone, and local chert; rocks are light gray to medium gray and weather light gray to orange to tan. The unit is widely exposed in and adjacent to the York Mountains in western and central Teller quadrangle, and is at least 350 m thick (Dumoulin and Harris, 1994). Like unit OI, it contains 8- to 15-m-thick shallowing-upward cycles (Vandervoort, 1985) and locally abundant trace fossils, but Oal is less fossiliferous than unit OI and includes quartzose grainstone and ripple marks not seen in unit OI. Common rock types in Oal are dolomitic, locally argillaceous lime mudstone and grainstone made up mainly of peloids and intraclasts with lesser bioclasts and ooids. Mud-supported strata are bioturbated, with bedding-plane feeding trails and subvertical burrows. Grain-supported rocks are planar- to crossbedded with locally well

developed oscillation and current ripples. Some grainstones contain 10 to 40 percent fine-sand- to silt-size non-carbonate grains, mainly quartz and lesser feldspar, with trace amounts of pyroxene, zircon, and leucoxene (Sainsbury, 1969b).

Most exposures of Oal are fault-bounded, and its original depositional relations with other units in the York Mountains are uncertain. Sainsbury (1969b) reported that Oal conformably underlies unit Ol, but megafossil and conodont data suggest that the upper part of Oal is coeval with much of unit Ol. Oal is chiefly of Early Ordovician (Tremadoc-early Arenig) age; the tightest ages are based on conodonts (table A-1). The oldest conodonts represent the *Ro. manitouensis* Zone, and are older than any definitively dated faunas known from unit Ol. Younger collections in Oal, however, include those of *Mac. diana* Zone age and overlap ages determined for unit Ol. Sparse megafossils in Oal include brachiopods, gastropods, and trilobite fragments (Sainsbury, 1969b); echinoderm debris, calcareous sponge spicules, and possible calcispheres were noted in thin sections. Various types of stromatolites occur locally and form biostromes as much as 5 m thick (Sainsbury, 1969b; Vandervoort, 1985).

Lithologic and fossil data indicate that Oal was deposited in a range of subtidal to supratidal settings within a deepening-upward regime (Dumoulin and Harris, 1994); overall, Oal appears to have formed in somewhat shallower and more agitated water than unit Ol. Conodonts in Oal are scarcer and less diverse than in unit Ol, likely because Oal accumulated more rapidly and (or) suffered more terrigenous input. Conodont assemblages in Oal are mainly cosmopolitan but include a few Laurentian (North American) and Siberian endemic forms (Dumoulin and Harris, 1994; Dumoulin and others, 2002; J.E. Repetski, written commun., 2008).

Some rocks presently included in unit OPl are similar in lithofacies, biofacies, and age to Oal (Vandervoort, 1985; Till and Dumoulin, 1994). Oal also correlates well with parts of unit Od in the Nome Complex, the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) in the western Brooks Range (unit “DOb” of Till and others, 2008b), and the Novi Mountain Formation, lower Telsitna Formation, and related rocks in the Farewell terrane of interior Alaska (Dumoulin and Harris, 1994; Dumoulin and others, 2002). Equivalent to unit “Oal” of Sainsbury (1969a, 1969b, 1972)

UNITS WITH UNCERTAIN AFFINITIES

- Pzl Limestone (Paleozoic)**—Intensely deformed limestone that has yielded no fossils but is presumed to be of Paleozoic age (Sainsbury, 1972), exposed in several small outcrops in central Teller quadrangle, northeast of the York Mountains. Equivalent to western part of unit “Pzl” of Sainsbury (1972)
- MI Limestone, dolomitic limestone, and marble (Mississippian)**—Intensely deformed and recrystallized medium-dark-gray carbonate rocks, locally cherty and intercalated with subordinate fine-grained siliciclastic strata, exposed on westernmost tip of Seward Peninsula (Teller quadrangle; Sainsbury, 1972). Unit has been intruded and locally highly altered by the Cape Mountain granite (unit Ktg) and associated tin-bearing fluids (Steidtmann and Cathcart, 1922). A poorly preserved coral fauna of probable Late Mississippian age was obtained from these rocks; it resembles that found in parts of the Lisburne Group (Schrader, 1902; Bowsher and Dutro, 1957) of northern Alaska (Steidtmann and Cathcart, 1922; W. Sando, unpub. fossil report, 1984). Some authors have correlated rocks of this unit with the Lisburne Group that is exposed north of Seward Peninsula at Cape Lisburne; Grantz and others (1991), for example, included both successions in their Tigara subterrane of the Arctic Alaska terrane. Sainsbury (1972) interpreted these rocks as having been thrust above the slate of the York region (unit OPl of this map). Equivalent to unit “MI” of Sainsbury (1972)
- Pzgb Metagabbro (Paleozoic)**—Dark-green- to black-weathering massive bodies of metagabbro exposed in rubble crop and small blocky cliffs associated with units OPl, OEp and OPl (Sainsbury, 1969b). Throughout the unit, igneous textures are retained in thin section. In central Teller quadrangle, east of the York Mountains, relict clinopyroxene grains are partially recrystallized to actinolite, but other igneous minerals are completely

recrystallized to a metamorphic assemblage of epidote, albite, chlorite, and small amounts of calcite, titanite, opaque, and stilpnomelane. In western Teller quadrangle, igneous minerals are more completely retained but show undulatory extinction and are cut by brittle cracks; metamorphic actinolite and chlorite occur on cracks and grain boundaries on or near clinopyroxene; small amounts of brown hornblende are considered late magmatic. Plagioclase is partially recrystallized to a very fine mat of brownish material, including sericite. Veins and veinlets of sericite and calcite are present in some samples. A U-Pb zircon crystallization age from one of these less recrystallized bodies, northwest of the York Mountains, is 539 ± 11 Ma (table 3; Amato and others, 2009). A detrital zircon sample collected from unit OPl near the U-Pb zircon sample contains a probability distribution peak near this age (J. Toro, written commun., 2006, 2007), and may represent reworking of gabbroic or related volcanic material. Another sample of unit OPl, collected from one of its southernmost exposures along the shoreline, contained a single Ordovician conodont. Metagabbro bodies are mapped near that locality, which raises the possibility that there might be two ages of gabbro in unit OPl: the dated gabbros (earliest Cambrian), and a younger set (Ordovician or younger)

OPl Limestone and dolomitic limestone (Ordovician to Proterozoic)—Light-gray- to grayish-orange-weathering, medium-light-gray to medium-dark-gray limestone and dolomitic limestone that occurs widely in western, central, and northern parts of the Teller quadrangle. The unit forms low outcrops and extensive areas of rubble and is locally intruded by gabbro (unit Pzgb of this map; Sainsbury, 1972). Most exposures of OPl are fault-bounded, but in western Teller quadrangle, it may depositionally overlies unit OPl (Sainsbury, 1969b, 1972). Beds are even to irregular and mostly 2 to 30 cm thick. Much of the unit is parallel laminated, but crossbedding occurs locally and some intervals are bioturbated. Other sedimentary features include fenestral fabric and intraclast conglomerate with clasts as much as 5 cm long. Lime mudstone, in part dolomitic and (or) argillaceous, is the main lithology in OPl; quartz silt to very fine sand makes up as much as 20 percent of some samples. Minor to trace amounts of chert, zircon, pyroxene, and antigorite(?) also occur in silty lime mudstone, suggesting that mafic rocks contributed detritus to this unit (Sainsbury, 1969b). Grainstone, composed mainly of intraclasts, peloids and rare bioclasts, is a notable subordinate lithology.

OPl contains rocks of more than one age. Sainsbury (1972) considered much of this unit to be Precambrian, but subsequent paleontological studies indicated that at least some strata are Ordovician. OPl has produced dated fossil assemblages (mostly conodonts) at >10 localities (table A-1; T. Carr and T. Hudson, written commun., 1982; Vandervoort, 1985; Till and Dumoulin, 1994; Toro and others, 2006). A few collections consist only of poorly preserved conodonts, chitinozoans, or acrotretid brachiopods that merely indicate broad, mainly Paleozoic age ranges, but several conodont assemblages are tightly dated as early-middle Early Ordovician (table A-1) and correlate well with faunas from units Oal and Ol. Three other collections are early Middle Ordovician (table A-1), slightly younger than any definitively dated faunas in units Oal and Ol but coeval with parts of unit Ols in the York terrane and unit Od in the Nome Complex. The gabbro that intruded OPl, however, is earliest Cambrian (unit Pzgb; Amato and others, 2009), which constrains the age of at least part of the unit to Early Cambrian or older.

Metamorphic grade and degree of deformation vary within OPl. Some samples appear unmetamorphosed and undeformed in thin section, whereas other samples contain layers rich in metamorphic white mica, are recrystallized, and have a phyllitic or schistose fabric. CAI values of conodont collections from this unit are mostly 4-4.5, but are 5 and 6 at several localities (table A-1); these values indicate that host rocks reached temperatures of 190 to >360°C (table A-2). Relations between variations in CAI values, metamorphic textures, and structural level have not been documented.

Lithofacies and biofacies of Ordovician strata in OPl match particularly well with those of unit Oal. OPl also correlates with parts of unit Ol, the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) in the western Brooks Range (unit “DOB” of Till and others, 2008b), and the Novi Mountain Formation, lower Telsitna Formation, and

related rocks in the Farewell terrane (Dumoulin and Harris, 1994; Dumoulin and others, 2002). Equivalent to units “pOt” and “pOl” of Sainsbury (1969a), “pOal”, “pOa”, “pOl”, and “pOlu” of Sainsbury (1969b), and “OpCl”, “pCt”, “pCld”, and part of unit “pCl” of Sainsbury (1972)

OPt Sandstone, siltstone, and limestone (Ordovician to Proterozoic)—Gray- to orange-weathering, gray to brown, locally calcareous sandstone to siltstone, interbedded with gray to black mudstone and local limestone, exposed in western Teller quadrangle. Beds are typically ≤5 cm thick (20 cm maximum). Outcrop features, which include climbing ripples, cross beds, parallel and convolute laminae, and graded beds, suggest a turbidite origin. Sandstone is very fine to coarse grained; some beds contain black shale fragments 1 to 2 mm long. Sand and silt clasts are angular to subrounded and consist of quartz, feldspar, sedimentary and metamorphic lithic grains, mica, chlorite, and minor tourmaline and zircon. Limestone is fine grained, ferroan, and contains as much as 10 percent silt- to medium-sand-size grains of quartz and feldspar. In thin section, samples of OPt appear recrystallized but only mildly deformed. Sainsbury (1969b, 1972) suggested that OPt depositionally underlies unit OEI; its contact with unit MI is a fault.

OPt likely includes rocks of more than one age. The unit was intruded by gabbro (unit Pzgb of this map; Sainsbury, 1972) that at one locality in the northeastern part of the outcrop belt of OPt has been dated as earliest Cambrian (Amato and others, 2009). However, southern exposures of OPt produced a single conodont of middle Early-Late Ordovician age at one site (table A-1; Till and Dumoulin, 1994) and conodont fragments of indeterminate Cambrian-Triassic age at two other sites (table A-1; T. Carr and T. Hudson, written commun., 1982). A detrital zircon sample of sandstone from eastern exposures has a major peak in cumulative probability distribution at 550 Ma and several other notable peaks between 640 and 720 Ma (J. Toro, written commun., 2006, 2007). The 550 Ma peak may include zircons derived from the gabbros (unit Pzgb) or their volcanic equivalents. OPt, therefore, is in part Proterozoic (pre-intrusion of gabbros), and in part Ordovician or younger (based on fossil data).

OPt could correlate, at least in part, with Middle Ordovician-Lower Silurian graptolitic argillite and turbidites (Iviagik Group of Martin, 1970) exposed south of Cape Lisburne (Grantz and others, 1983; Moore and others, 1994, 2002; Harris and others, 1995). Metasandstone in the Iviagik Group has a range of compositions (Dumoulin, 2001; Moore and others, 2002) that are broadly similar to those observed in OPt but the metasandstone differs in containing more chert, including grains of radiolarian chert not seen in OPt. Equivalent to parts of “pOs” of Sainsbury (1969b) and “pCs” of Sainsbury (1972)

OPp Phyllite (Ordovician to Proterozoic)—Fine-grained, mainly pelitic and (or) calcareous phyllite exposed in west-central Teller quadrangle. Unit crops out on creeks, weathers gray to grayish-brown, and is layered and locally finely laminated. The phyllitic foliation surface is crenulated. Gray-weathering material is sericite-rich; brown-weathering rocks are calcareous. In thin section, grain size, composition, and oriented lenses of sericite and opaques define foliation. Thin sericitic layers alternate with layers that contain interlocking crystals of calcite that are matrix to disseminated rounded to subrounded plagioclase and quartz grains. Locally, carbonate grains are stained with iron oxide. No fossils have been found, but OPp was intruded by gabbro (unit Pzgb of this map) that crystallized in the earliest Cambrian (Amato and others, 2009). Unit PzEt may be a more deformed and metamorphosed relative of OPt. Equivalent to parts of units “pOs” of Sainsbury (1969a, b) and “pCs” of Sainsbury (1972)

GRANTLEY HARBOR FAULT ZONE

Pzp Phyllite and argillite (Paleozoic)—Phyllite, argillite, and lesser metasiltstone and fine-grained metacarbonate rocks exposed south and north of Grantley Harbor in central Teller quadrangle. Outcrops consist of brownish-orange- to black-weathering, silvery-gray to black, locally carbonaceous phyllite to argillite, with interlayers and lenses of tan to green metasiltstone to semischist and dark gray to black, locally tannish-orange metacarbonate.

Lithologies are interlayered on a scale of centimeters, with metacarbonate layers as thick as 1.5 m. These rocks have yielded sparse conodont fragments of indeterminate Ordovician-Triassic age (table A-1; T. Carr and T. Hudson, written commun., 1982, 1984) and contain rare relict bioclasts, including probable recrystallized radiolarians and siliceous sponge spicules, observed in thin section. **Pzp** in part resembles carbonaceous radiolarian-bearing rocks found in eastern exposures of unit DOx. Equivalent to part of unit “Pzb” of Hannula and others (1995) and parts of unit “pCs” and “pCnc” of Sainsbury (1972)

PzEt **Metalimestone (Paleozoic and Proterozoic?)**—Thinly layered to laminated, orange- and gray-weathering, color-banded, white to dark-gray metalimestone exposed in a small area south of Grantley Harbor in south-central Teller quadrangle. Layers range from a few millimeters to 6 cm thick and reflect differences in composition and grain size. Darker layers are finer grained, more impure, and contain abundant organic material and white mica, whereas lighter layers are coarser grained and consist mostly of calcite and lesser silt-size quartz grains. The unit has a well-developed cleavage which is axial planar to tight to isoclinal folds, formed at low- or sub-greenschist facies conditions, and a second, lower temperature dissolution cleavage with associated tight folds (Hannula and others, 1995). Calcite-filled tension gashes are common (Hannula and others, 1995). No fossils have been positively identified, although a few forms noted in thin section could be relict bioclasts. Locally, this unit includes interlayers of red-weathering, green phyllite and appears to grade into unit **PzEt**. Thinly interbedded lime mudstone and argillaceous limestone is the most likely protolith for **PzEt**, which may be a more deformed and (or) metamorphosed correlative of unit Oal and (or) unit OPl. Equivalent to unit “Pzsl” of Hannula and others (1995) and a small part of unit “pCl” of Sainsbury (1972)

PzEt **Metasiltstone and phyllite (Paleozoic and Proterozoic?)**—Metasiltstone, metasandstone, and phyllite that form a small exposure south of Grantley Harbor in central Teller quadrangle. The unit consists of intercalated grayish-green metasiltstone to medium-grained metasandstone, in layers 1 cm to 1 m thick, grayish-green to silver phyllite and silty phyllite, and dark gray to black phyllitic shale. Percentage of these lithologies varies throughout the outcrop belt but metasiltstone and (or) metasandstone generally predominate. Some coarser grained layers appear to be graded, contain parallel laminae, and (or) show local cut-and-fill structures; shaly rip-up clasts as much as 4 cm long occur at several localities. Metasandstone and metasiltstone layers have a semischistose texture and consist mainly of quartz, calcite, and quartz-white mica aggregates (metamorphic lithic clasts?) in a matrix of white mica and chlorite; lesser clast types include feldspar, dolomite, and allanite(?). No fossils constrain the age of the unit, but lithofacies suggest they may be a more deformed equivalent of unit OEt. Equivalent to part of unit “Pzb” of Hannula and others (1995) and a small part of unit “pCs” of Sainsbury (1972)

NOME COMPLEX

LAYERED SEQUENCE

Pznp **Metagabbro and metasediments (Paleozoic?)**—Massive tors and rubble piles of metagabbro and poorly exposed metasedimentary rocks on west side of the Kigluaik Mountains. Metagabbro bodies form flat-topped hills generally less than a kilometer across; one body exposed along sea cliffs is 9 km long. Metasedimentary rocks are poorly exposed and include metagraywacke and tuffaceous metasediments. Original igneous and sedimentary features are preserved. In thin section, metagabbro is coarse grained and partially to completely recrystallized to actinolite, epidote, chlorite, titanite, albite and quartz (Hannula and others, 1995; Till, unpub. data). The metagabbros are geochemically similar to metabasites from units Ocs and DOx (Ayuso and Till, 2007). The geometries of outcrop-scale structures are similar to those in the more completely recrystallized and deformed part of the Nome Complex. Hannula reported three pumpellyite and actinolite bearing samples from northern parts of the unit and one crossite-bearing sample from the central part, which indicates that metamorphic grade

increases from northwest to southeast within the unit. The contact between units P_{zn}p and Ocs to the southwest corresponds to the garnet isograd of Hannula and others (1995). P_{zn}p may be equivalent to unit Ocs. Equivalent to unit “P_{zmvu}” of Hannula and others (1995)

Ds Pelitic schist (Devonian?)—Tors of resistant, well-foliated quartz-rich schist. Pelitic rocks are the dominant lithology; calcareous schist is a minor component. Outcrop appearance of the pelitic schist is diagnostic of the unit, and shows 1- to 2-cm-thick bands of granular interlocking quartz grains interlayered with micaceous minerals. In thin section, major minerals include quartz, muscovite, chlorite, chloritoid, and locally graphite, glaucophane and garnet. Quartz-segregation layers parallel foliation and trace intrafolial isoclinal and chevron-style folds axial planar to the foliation. Minor lithologic variation may occur at outcrop scale, typically with relatively thin calc-schist layers in quartz-rich schist.

Four detrital zircon samples were collected; only one yielded sufficient zircons for analysis. The youngest zircon population contains Early to Middle Devonian grains (Till and others, 2006). At least part of the protolith of the unit is Devonian or younger.

Unit thickness is unknown. Typical examples of the unit crop out in northeast Solomon D-5 quadrangle. First described by Smith (1910). Equivalent to unit “pCst” of Sainsbury (1974) and unit “CpCs” of Till and others (1986), and unit “Ds” of Werdon and others (2005a,b) and Newberry and others (2005)

Dcs Pelitic, calcareous, and graphitic schist (Devonian)—Pelitic, calcareous, and graphitic lithologies interlayered on a scale of centimeters to meters, exposed in central Nome and Solomon quadrangles. Interlayering is gradational and intimate. The unit is composed predominantly of pale brown and gray weakly foliated to well-foliated schists dominated by plagioclase, calcite, quartz, white mica, and graphite. In the central Solomon quadrangle, where calcareous lithologies are subordinate to pelitic lithologies, the unit forms smooth rounded hills, or more commonly, is present in valleys and areas of subdued topography. Rarely forms outcrops; usually forms loose rubble on hills or in stream cuts; in low areas unit is covered by tundra. Ridge-top outcrops and ridge-flanking tors are more common in the Nome quadrangle, but not abundant. The unit may be present but unrecognized in exposures of the Nome Complex north of Kigluaik and Bendeleben Mountains.

Pelitic rocks are light to dark gray weathering and contain pale-colored chloritoid, glaucophane or pseudomorphs of chlorite and albite after glaucophane, and in rare cases, garnet; at some localities, micaceous laminae alternate with quartz-rich laminae. Accessory minerals include epidote, clinozoisite, apatite, tourmaline, sphene, graphite, ilmenite, pyrite, rutile, and zircon. Calcareous schist is light to dark brownish-gray and commonly contains plagioclase, chloritoid, calcite, some dolomite, and rare garnet. Plagioclase commonly occurs as syn- and post-penetrative deformation metamorphic porphyroblasts. Accessory minerals include apatite, tourmaline, graphite, pyrite, rutile, and zircon. Gray-weathering, plagioclase-rich lithologies are interlayered with orange- or brown-weathering impure marble or calcareous schist in some localities, mica- and graphite-rich schists in other localities. Layers rich in chlorite and albite, with and without white mica and calcite, are generally less than 0.5 m thick.

The unit includes relatively thin, but widely distributed, layers of light to dark gray or pale orange weathering millimeter-scale color laminated marble. Marbles are slightly impure, most commonly with small concentrations or disseminations of quartz, white mica, and graphite; marbles also can include iron carbonate, iron oxide, and rare sulfide minerals. Less common, but also broadly distributed, are layers typically less than 20 cm thick of pale tan- to white-weathering metaquartzite with fine laminations defined by minor iron carbonate, iron oxide, and white mica.

Dark-gray- to black-weathering, graphitic metasiliceous rock, locally micaceous, contains millimeter-scale laminae enriched in graphite, white mica, and iron oxide, and occurs in layers meters to tens of meters thick; exposures are generally thinner than the graphitic metasiliceous layers in unit DO_x.

In the Nome quadrangle, a dark-gray- to black-weathering rock with white

millimeter- to centimeter-thick lenses, layers, and irregular blobs of polycrystalline quartz forms layers a meter to several meters thick. Matrix to the quartz concentrations is typically rich in white mica, graphite, chlorite, and albite in varying abundances. Many exposures are resistant. Some of the polycrystalline quartz lenses and blobs trace intrafolial isoclinal folds; blobs on fold hinges are more equant. These features and other deformational characteristics of the Nome Complex are consistent with a protolith for Dcs that had quartz-rich alternating with mica-rich layers, although its present appearance is suggestive of a conglomerate. Dcs is equivalent to the “lumpy schist” or unit “pCPzspm” of Bundtzen and others (1994).

A distinctive group of lithologies along the western margin of the unit in the Nome quadrangle coincides with a long, linear resistivity low and magnetic high (Burns and others, 2005a,b). Pale green and pale gray weathering, locally brown-weathering schists locally display millimeter- to centimeter-thick layers of sugary white quartz. Rocks typically are interlayered concentrations of quartz with lesser iron carbonate and epidote versus white mica, medium-dark colored chloritoid, and locally epidote, iron carbonate, and chlorite. Chloritoid grains may occur in polycrystalline lenses within white mica laminae. Epidote grains contain brown (allanite?) cores. Brown-weathering layers are calcareous. This group of lithologies locally contains Zn-Pb mineralization. A lens of carbonate clast conglomerate, 10 to 15 m thick and ≥ 15 to 20 m long, sits between this group of distinctive lithologies and the thick pure marbles of unit DOx. The conglomerate is poorly sorted, matrix supported, interlayered with schist; its matrix is calcareous schist that contains abundant quartz and white mica. Clasts are rounded to angular, elongate to disc-shaped, and as much as 75 cm in maximum diameter. Most are light gray to beige dolostone and medium gray marble.

Many detrital zircon samples contain small populations of Middle and Late Devonian zircons and large populations of early-middle Silurian zircons as well as older populations (Till and others, 2006; Till and others, 2008a). Therefore, much or all of the unit is Devonian or younger.

Thickness of unit is greater than 1.2 km.

A distinctive marble forms a small lens within or adjacent to Dcs in the Nome quadrangle. The marble is white to light gray, generally impure (5 to 15 percent quartz, 1 to 5 percent white mica), and typically contains sand- to pebble-size clasts of dark gray to black, organic-rich marble. Most clast-bearing intervals appear to be clast supported and some may be graded. Clasts are rounded to angular in shape, commonly laminated, and generally ≤ 2 cm in diameter; a few clasts may be as much as 12 cm long. The clast-bearing marble produced conodonts with CAI values of 5 at two localities (table A-1). One collection yielded a single element of Silurian(?) through Triassic age. The other collection, also a single conodont, is an Sb element of late Permian through Triassic (likely Triassic) age. Three possible scenarios that explain the presence of a Triassic marble in the otherwise Devonian and older Nome Complex include: (1) contamination of the conodont sample; (2) pre-metamorphic fault juxtaposition of Triassic and older rocks; and (3) a pre-metamorphic unconformable relation between Triassic and older rocks. The CAI value of this conodont is consistent with that of other Nome Complex rocks, and no rocks that could have produced such contamination (that is, rocks of known Permian or Triassic age and high thermal level) were being processed in the laboratory at the time the Seward Peninsula sample was run (A. Harris, written commun., 2005). Thus, the clast-bearing (Triassic?) marble was juxtaposed with Dcs before or during Jurassic metamorphism or may be a rare remnant of rocks that sat unconformably atop protoliths of the Nome Complex before those protoliths were metamorphosed. Because of the uncertainties in the origin of this marble and its uniqueness, we choose not extend the protolith age of the Nome Complex to Triassic

DOx **Mixed marble, graphitic metasiliceous rock, and schist (Devonian to Ordovician)**—
Interlayered pure and impure marble, graphitic metasiliceous rock, pelitic schist, calc-schist, and mafic schist. Gray- and orange-weathering marble and dark gray-black-weathering graphitic metasiliceous rock are the most common lithologies in the unit,

which is dominated locally by one or the other. Gray-weathering pure marble forms rounded ridgelines that extend along strike for several kilometers, and rounded hills of slabby, black graphitic metasiliceous rock can be recognized from great distances. The unit is defined by its position structurally below the Casadepaga schist (unit Ocs). Good exposures are rare; minor lithologies generally do not crop out. Lithologies thicken and thin along strike on a scale of kilometers, a feature which may be depositional as well as structural.

In western Solomon quadrangle and Nome quadrangle, there is a consistent general stacking pattern of lithologies within DOx. The structurally upper part of the unit is composed of mixed schist and marble, including pelitic schist, gray marble, orange-weathering impure marble, black schistose marble, and black metasiliceous rock; these lithologies are interlayered on a scale of meters and decameters. The uppermost lithology is commonly an orange-weathering marble that varies from pure to impure on a scale of meters. Impurities include chlorite, quartz, tremolite, and albite; impure layers also include intraclasts, most 3 cm or less in diameter. One of the pure marble layers yielded Ordovician conodonts (see below). Other impure marbles in the upper part of DOx also contain intraclasts. Total thickness of the mixed schist and marble sequence varies from 250 m to over 2 km. The structurally lower parts of the unit are dominated by gray marble or black metasiliceous rock. Where the gray marble is dominant, it reaches thicknesses of 1-2 km and contains minor thin (less than 50 m) layers of metaquartzite, pelitic schist, and chlorite-albite schist. Where the black metasiliceous rock is dominant, it reaches thicknesses of around 500 m and is underlain by 10-30 m of gray marble interlayered with thin bands of pelitic schist.

Metabasites are found in both the mixed schist and marble sequence and within the thick, unit-dominating gray marble and black metasiliceous rock. These mafic rocks are boudins or layers of glaucophane-, epidote-, and garnet-bearing metabasite, or chlorite-, albite-, actinolite-bearing metabasite similar to those found in the Casadepaga schist. Within DOx, they occur in greatest volume south of Salmon Lake near the boundary between the Nome and Solomon quadrangles.

The gray-weathering pure marble is pale gray to white on the fresh surface, and composed of coarse crystalline calcite. The graphitic metasiliceous rock is generally homogeneous, dark-gray or black, and compositionally limited to quartz, graphite, and very small amounts of white mica, albite, and chlorite. Graphite may be present in sufficient quantities to rub off on the hands. Locally a centimeter-thick banding of dark gray-black quartz-graphite schist and gray-black quartz-graphite-calcite schist are found.

In Nome quadrangle, DOx contains several small rubble patches of carbonate conglomerate, as well as rubble and outcrops of light gray dolostone, locally mottled with orange, pink, or light brown, that retains relict sedimentary features. Conglomerate is matrix supported and contains rounded to angular clasts, as much as 8 cm long, of pale-orange to medium-gray dolostone; at one locality, the unit contains subordinate clasts of marble and quartz-white mica schist. The matrix is beige to orange pink or light brown dolomite with lesser quartz and white mica. Relict textures, seen in conglomerate clasts and in mottled dolostone rubble, include coated grains, crinoid ossicles, and possible brachiopod fragments.

In northwestern Solomon quadrangle, DOx contains an interval of dolostone-clast conglomerate as much as 100 to 200 m thick and 480 m in lateral extent. The conglomerate ranges from matrix-supported (1 to 10 percent clasts) to clast-supported (>80 percent clasts) and contains interlayers and (or) lenses of clast-free schist and dolostone. Clasts are rounded to irregular; most have a flattened, ovoidal shape but some are rod-like. Sorting is poor; clasts range from a few millimeters to 70 cm in maximum dimension. Some clasts are finely laminated. Most clasts consist of light-gray- to rusty-weathering, very light gray, fine-grained ferric dolostone with minor amounts of quartz, white mica, and calcite. About 1 to 5 percent of clasts are medium light gray marble. The conglomerate matrix is quartz schist that also contains white mica, dolomite, chlorite, epidote, and chloritoid. A less extensive (several meters thick by 10 m long) but

otherwise similar lens of dolostone-clast conglomerate occurs in unit Ocs in the Nome quadrangle. The dolostone clasts at both localities resemble, and may have been derived from, dolostone equivalent to that in unit €d.

The age range of DOx is not strictly known. Conodonts of Ordovician age were obtained from a pure layer in the impure marble at the structural top of DOx (in the Solomon quadrangle). Marble in the Nome quadrangle produced conodonts of early Paleozoic age (table A-1, T. Carr and T. Hudson, written commun., 1982, 1984). Recrystallized radiolarians collected in northern Darby Mountains in banded calcite-bearing graphitic metasiliceous rock are of probable pre-Devonian age (B.K. Holdsworth, written commun., 1985).

In the Teller quadrangle, part of the unit (shown with the diagonal line overlay) is distinct in age and lithology. Dolostone, dolomitic marble, and marble form an elongate belt, extending for almost 40 km, in the westernmost part of DOx in eastern Teller quadrangle; only the southern half of the belt has been examined. The unit forms rubble-covered hills; outcrops are rare. Dolostone is medium gray to dark gray and weathers light to medium gray, very pale orange, or dark yellow brown. Sedimentary structures include millimeter- to centimeter-scale parallel lamination and lesser color mottling that likely reflects bioturbation. Intraclasts (maximum 1 cm in diameter) and millimeter-scale burrows occur locally. In thin section, dolostone is mostly finely crystalline and non-ferroan; some samples contain minor amounts of fine-grained quartz and white mica, or rare clasts (bioclasts?). Marble is white to grayish black and has few relict sedimentary features other than locally well-developed parallel lamination. Conodonts of late Silurian-Devonian age have been recovered from two localities; a third locality produced a fauna of Silurian (late Llandovery-Ludlow) age (table A-1). Sedimentary structures and conodont biofacies suggest a warm, shallow-water depositional setting. Faunal and lithofacies data indicate that these rocks may correlate, at least in part, with unit Sd in the Nome Complex. Correlation with units Ddm and SOdl and SOul (York terrane) is also possible, although these units contain more abundant megafossils than DOx with diagonal line overlay. Shallow-water Silurian rocks also occur widely in the Brooks Range. Units that contain such strata and could correlate, at least in part, with DOx (overlay) include units “DOb” (Baird Group), “DOc”, and “DSc” of Till and others (2008b); Silurian lithofacies in unit “DSc” are an especially good match. DOx with overlay is equivalent to parts of units “Pzm” and “pCn” of Sainsbury (1972).

Three detrital zircon samples have been collected from DOx in southern Seward Peninsula. One yielded largely Neoproterozoic zircons, another yielded zircon populations as young as Silurian, and the third yielded a robust population of Middle and Early Devonian zircons (Amato, written commun., 2008). Apparently, at least part of DOx must be Devonian or younger.

On the eastern edge of the map area, on the boundary of Norton Bay and Candle quadrangles, exposures of metasedimentary rocks include calcareous, pelitic, and quartz-rich lithologies. These rocks have not been studied in detail; some may ultimately prove to have histories separate from the Nome Complex. These rocks are equivalent to units “PzPus”¹ and “MzPzq” of Patton and others (2005).

DOx is between 0.8 to 1.5 km thick, and best exposed in eastern Solomon D-5 quadrangle and in east-central Solomon D-6 quadrangle. The unit includes parts of units “pCs” and “slate of the York region” of Sainsbury (1974)

Dg **Granitic orthogneiss (Devonian)**—Fine-grained, very light gray to orange-weathering, well-foliated, white to light tan schist of granitic to tonalitic composition that forms the rounded, frost-riven slopes of Kiwalik Mountain and one small body in northern Darby Mountains. Commonly forms weathered boulders 0.5-1 m across. Crops out rarely; where foliation can be measured, it is parallel to the foliation in the surrounding schist. Contact crosses lithologic layering in surrounding schist. Layers and boudins of the orthogneiss which have chilled margins are commonly found in country rock close to the

¹ Symbol P indicates Proterozoic age.

contact. Quartz, albite, K-feldspar, and white mica are the most common constituents. Accessory minerals include biotite, epidote, fluorite, magnetite and calcite. The unit yielded a U-Pb zircon age of 391 ± 3 Ma (J. Aleinikoff, written commun., 2005; Till and others, 2006). A small body associated with unit DOx in the northern Darby Mountains yielded an age of 390 ± 4 Ma (Toro, written commun., 2006); a foliated body with a similar age was found in the high-grade metamorphic rocks of Bendeleben Mountains (Gottlieb and Amato, 2008). Middle Devonian granitic orthogneiss (also approximately 390 Ma) is known in eastern Brooks Range in a metamorphic belt with a similar history to the Nome Complex (Aleinikoff and others, 1993; Moore and others, 1997). Granitic orthogneiss with similar, but less well-defined age, is present in central Brooks Range and southern Ruby geanticline (Toro and others, 2002; Patton and others, 1987; Roeske and others, 1995)

Df Felsic schist (Devonian)—Light-orange- to light-green-weathering, fine- to coarse-grained quartz-feldspar-white mica schist. Crops out on the southwest flank of Kiwalik Mountain as platy rubble-crop of millimeter-scale laminated, very fine grained schist. Rarely, accessory black tourmaline lies in plane of foliation. Stream gravels along strike to the northwest of the rubble crop include a rock which has the appearance of a flattened matrix-supported conglomerate or fragmental volcanic, composed of clasts and matrix of the major minerals listed above. Clasts show greatly varying grain size and internal textures. U-Pb zircon age from laminated schist on the flank of Kiwalik Mountain is 391 ± 5 Ma (J. Aleinikoff, written commun., 2005; Till and others, 2006); the fact that the schist contains a single zircon population supports an igneous protolith for the unit. The contact between Df and other parts of the Nome Complex may be a fault. Two metafelsites of essentially identical age were identified in eastern Brooks Range, where metafelsites occur in sections of rocks less metamorphosed than the Nome Complex (Aleinikoff and others, 1993; Moore and others, 1997)

Ocs Casadepaga Schist (Ordovician)—Light-green, silvery green and greenish-brown mafic, feldspathic, and calcareous schist. Typically occurs as frost-riven slabs and flakes that underlie rounded hills and dark-greenish-black tors and rubble piles several meters across. Tors of metabasite, abundant plagioclase porphyroblasts in dark-green, chlorite-rich schist, and the quartz-poor nature of the rocks are characteristic of this unit. The most common lithologies are dominated by components of mafic, feldspathic, and calcareous composition that are intermixed and interlayered on a scale of tens of centimeters; the layering may occur in repetitive couplets.

Medium- to pale-grayish-green-weathering pelitic schists are common. Plagioclase, chlorite, white mica, and quartz in subequal amounts dominate; epidote, carbonate, and glaucophane (or pseudomorphs of chlorite and plagioclase after glaucophane) are typical. Titanite (sphene), rutile, and sulfides are present in minor amounts. Based on major element chemistry, the protoliths were shales and graywackes (Werdon and others, 2005a). Carbonate-rich schists or layers are typically buff or pale brown weathering and tend to be more recessive in outcrop than other lithologies. Pure carbonate layers are rare and thin but include both pure and impure varieties; they weather pale brown, black, or gray. Dark-green-weathering schists are rich in chlorite, epidote, actinolite, and plagioclase, and represent metamorphosed mafic material. Dark-green-weathering chlorite-rich schists spotted with white equant plagioclase grains typically contain few to no calcium-bearing phases. These are probably mafic rocks that were altered or weathered previous to metamorphism.

Boudins, lenses and layers of fine- to coarse-grained, massive metabasite comprise the greenish-black tors. In thin section these rocks are found to be composed of glaucophane, actinolite, chlorite, epidote, garnet, albite, white mica, titanite, and locally quartz, Fe-carbonate, pyroxene, and barrosite. Coarser grained varieties have textures suggestive of a coarse-grained gabbroic protolith. Mafic schist layers in the surrounding rocks have mineral assemblages similar to the metabasite pods. The metabasites comprise two compositional groups (Werdon and others, 2005a,c). One group has weakly developed arc-like signatures (for example, slight Nb depletion in spidergrams)

reflecting crustal contamination; the second group exhibits features associated with enriched mantle (E-MORB) and alkaline intercontinental rifts (no Nb depletion, small positive Ti anomalies in spidergrams) (Ayuso and Till, 2007). Metabasites from unit DOx fall into the same two compositional groups. The chemical characteristics are thought to indicate a tectonic setting related to the early stages of continental, rift-related magmatism (Ayuso and Till, 2007); crustal contamination during rifting is thought to have produced the weak arc-like signatures.

In western Solomon quadrangle, the contact between Ocs and the overlying impure marble unit (Oim) is exposed. Near the contact, on all sides of a synform cored by Oim, a thin (few meters – tens of meters) layer of black weathering, platy, fine grained and finely laminated quartz-graphite schist is present. The amount of graphite in the rock is variable, though it is always black-weathering; thin laminae of lenses (mm- to cm-scale) that are more quartz-rich are common. Graphite is present as fine disseminated material in the quartz-rich matrix, as well as in lozenges several mm across. White mica is disseminated and minor. Semi-quantitative spectrographic analyses of a few samples from this layer show elevated values of Mo, V, Ag, and Zn (B. Gamble, written commun., 1985). Thin layers of mafic schist separate the graphitic layer from the overlying impure marble.

No direct evidence for the depositional age of Ocs exists. Seven detrital zircon samples collected from widely distributed parts of the unit contain very similar grain populations. Most grains fall into the range of 600-700 Ma; several samples contain small populations of Ordovician or Cambrian grains (Amato and others, 2003a; Till and others, 2006; 2008a). Depositional age of the unit must be younger than 600 Ma (latter part of the Neoproterozoic), and is likely Ordovician or younger. Werdon and others (2005a) considered the unit to be Cambrian in age, based on an Rb-Sr isochron. The samples included in the isochron are a mix of mafic and pelitic rocks, so their assumption that the samples shared the same initial strontium isotopic composition is likely not correct; the isochron represents a mixing line between mafic and sedimentary protoliths.

Ocs is assigned an Ordovician age based on detrital zircon geochronology and on the occurrence in both this and the impure marble unit (Oim) of both metabasite schist layers and unfoliated metabasite pods. The protoliths of both units apparently contained pyroclastic or redeposited mafic material as well as intrusive mafic rocks. Metabasite layers indicate that production of mafic material was at latest syn-depositional – not simply post-depositional. We postulate that units Oim and Ocs were formed in the same basin. Because the impure marble unit yielded Early through Middle Ordovician conodonts, we believe that basin was formed during the Ordovician.

The unit is 0.6 to 1.6 km thick and is best exposed in southeastern Solomon D-5 quadrangle, north of the Nome-Council road; in central Solomon D-5 quadrangle; and in east-central Solomon D-6 quadrangle. The Casadepaga schist was named and first described by Smith (1910). Partially equivalent to the “slate of the York region” of Sainsbury (1974), and unit “pCqms” of Miller and others (1972); equivalent to unit “Ocs” of Till and others (1986)

Oim **Impure chlorite marble (Ordovician)**—Buff- to orange-weathering chlorite-, white mica-, and albite-bearing calcite marble that underlies rounded hills. Rare outcrops show well-foliated impure marble to calcareous schist. Impurities are most commonly chlorite and albite. Lenses (up to a meter across) and fine layers of chlorite and albite are diagnostic of the unit, and trace foliation and folds. Chlorite-albite lenses and layers are more abundant near the base of the unit; pods of fine-grained metabasite are also more common in the lower part of the unit. The pods can be recognized in the field as piles of massive, medium-gray rubble several meters across; one is 0.5 km across. Intraclasts occur in some exposures and are typically composed of black calcite and no more than 4 cm in diameter. Most commonly they are a minor component of the rock, but locally are concentrated in centimeters-thick layers. In rare instances the unit may include layers of pure marble or orange-weathering dark-gray dolostone. The unit is a minimum of 1.2 km thick. Conodonts of Early through Middle Ordovician age have been obtained from a

dolostone lens in the upper part of the unit in Solomon D-6 quadrangle (84ATi281, table A-1). Excellent exposures of the unit can be found in central Solomon D-6 quadrangle. Equivalent to units “pCsm” of Miller and others (1972); “pCl” of Sainsbury (1974); and “Oim” and “Pzim” of Till and others (1986). In western Solomon quadrangle, the contact of Oim with underlying unit Ocs is marked by a lens of graphitic siliceous rock a few meters thick. Outcrops are black. Quartz and graphite vary in relative concentration, and yield a finely laminated appearance. Fine white mica and sulfide minerals are present in minor amounts. Semi-quantitative spectrographic analysis of these rocks shows they contain elevated amounts of Mo, Ag, Zn, and V

En Metagranitic rocks (Late Proterozoic)—Pale-gray to pale-greenish-tan, locally green-weathering rubble crop and outcrop of small granitic, granodioritic, and tonalitic orthogneiss bodies. Weakly-foliated to well-foliated, fine- to coarse-grained, with foliation defined by weak to strong alignment of micas. Coarsest grained varieties may contain lozenge-shaped feldspar grains and thin, millimeter-thick lenses of quartz that also parallel foliation. Plagioclase, quartz, ± microcline are dominant phases; chlorite, biotite, and white mica are minor phases, and are associated with epidote, garnet, and calcite at some localities. Accessory phases include opaque oxides, zircon, apatite, allanite, and titanite. Phengitic white mica compositions in microcline-bearing orthogneiss bodies are consistent with crystallization at blueschist-facies conditions (Evans and Patrick, 1987). In outcrop, foliation parallels surrounding schists of the Nome Complex; the metagranitic rocks were apparently folded in with metasedimentary rocks of the Nome Complex during the Mesozoic. Detrital zircons from metasedimentary rocks of unit Ocs collected immediately adjacent to a body of En in east-central Nome quadrangle include a significant 600-Ma population, younger than the metagranitic rock (669±5 Ma, table 3; locality 3, sh. 2) (Till and others, 2006). Late Proterozoic intrusive age based on several U-Pb zircon analyses that range from approximately 665 to 685 Ma (including errors) (table 3; Patrick and McClelland, 1995; Amato and Wright, 1998; Till and others, 2006). Equivalent to parts of unit “pCPzg” of Bundtzen and others (1994) and unit “pCdog” and parts of unit “pCPzuog” of Amato and Miller (2004)

SCATTERED METACARBONATE ROCKS

Pzm Marble, undivided (Paleozoic)—Generally light-gray-weathering, white to medium-gray, medium to coarsely crystalline marble that forms rubble-covered hills and small outcrops that are widely but sparsely distributed through the map area. Marble is dominantly pure, but locally contains as much as 10 percent quartz, white mica, and (or) albite. At several localities in the western Bendeleben and Solomon quadrangles, Pzm contains conodonts, stromatoporoids and (or) colonial and rugose corals of Ordovician through Devonian or Silurian to Devonian age; combined age constraints from megafossils and microfossils at one locality suggest an age of Middle Devonian (table A-1; Till and others, 1986). Pzm likely includes rocks of several different ages. It correlates at least in part with Ddm but lacks the lithologic features diagnostic of that unit; some parts of Pzm may be as old as Ordovician (table A-1). Occurrences that have yielded no fossils are assumed to be Paleozoic based on physical proximity to strata of known Paleozoic age. The relation of Pzm to rocks of the Nome Complex is uncertain; it is most commonly spatially associated with unit Ds. Equivalent to unit “Pzm” of Till and others (1986)

Pzd Dolostone, undivided (Paleozoic)—Generally light-colored, fine-grained, featureless dolostone that forms rubble-covered hills sparsely distributed through the map area. This unit likely includes rocks of several ages. Conodont faunas, obtained at seven localities, are mostly long ranging but one collection, in eastern Bendeleben quadrangle, may be Early Mississippian; another, in northwestern Solomon quadrangle, is middle Silurian-Early Devonian; and a third, in western Candle quadrangle, could be Ordovician (table A-1; Till and others, 1986). Occurrences that lack fossils are assumed to be Paleozoic based on physical proximity to strata of known Paleozoic age. Some rocks mapped as Pzd at Cape Deceit in the Kotzebue quadrangle may be part of unit DObm (T. Ryherd, written

commun., 1985; Ryherd and Paris, 1985). **Pzd** may also include strata correlative with units **Ed**, **Od**, **Sd**, and (or) **Ddm** that lack lithologic or faunal features diagnostic of these units. The relation of **Pzd** to rocks of the Nome Complex is uncertain. Equivalent to unit “**Pzd**” of Till and others (1986), and, in Candle and Norton Bay quadrangles, to part of “**Pzcs**” of Patton and others (2005)

- Pzmm** **Marble of the Moon Mountains (Paleozoic)**—Pale-gray- to white-weathering, coarsely crystalline calcite marble exposed only in western Nome quadrangle, in an area informally called the Moon Mountains (sh. 2) due to lack of vegetation. The marble has a layered appearance due to variations in grain size; layering is folded. Folds are cut by biotite-hornblende granitic dikes and lesser tourmaline-bearing pegmatites (see unit **Kds** for ages); gossan is spatially associated with the dikes. Overall large grain size of calcite in the marble is larger than typically found in unit **Pzm**
- Ddm** **Dolostone, metalimestone, and marble (Devonian)**—Medium- to dark-gray-weathering, dark-gray to black dolostone, metalimestone and marble, with minor associated chert, that typically weathers to fist-sized rubble but forms outcrops along river banks or sea cliffs. **Ddm** is widely but sparsely distributed through the map area; it crops out in the northwestern and eastern Bendeleben quadrangle and the central and eastern Solomon quadrangle; it is best exposed in sea cliffs in the Solomon C-1 quadrangle. Outcrops are not foliated, but are strongly fractured, commonly brecciated, and may be veined with coarse-crystalline calcite or dolomite. **Ddm** consists of fine-grained, mostly non-ferroan or slightly ferroan dolomite and subordinate fine- to coarse-crystalline calcite. Dolostone is the dominant lithology in eastern exposures; metalimestone and marble predominate in western and central exposures. Relict sedimentary structures include zebra dolomite, fenestral fabric, and millimeter-scale (algal?) laminations. Thin section textures, where not obscured by recrystallization and dolomitization, are bioclastic and peloidal packstones and wackestones. Early to earliest Late Devonian conodonts have been found in 20 collections; tightest ages are earliest Emsian and latest Emsian-earliest Eifelian (table A-1). A megafauna of late Early, Middle, and early Late Devonian age consists of tabular and rugose corals, stromatoporoids, brachiopods, and rare bryozoans. Megafauna, microfauna, and sedimentary features all denote a warm, relatively shallow water depositional setting. Age and spatial relations suggest that **Ddm** may have been unconformably deposited on older parts of the Nome Complex, specifically units **DOx** and **D~~C~~bm**. Lithofacies and faunal data indicate that **Ddm** correlates well with the youngest strata in the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) and related rocks in western and central Brooks Range (units “**DOb**” and “**DOc**” of Till and others, 2008b) and may also correlate with the Beaucoup Formation (Dutro and others, 1979) and related rocks found throughout the Brooks Range (units “**DI**” and “**Dmu**” of Till and others, 2008b). Equivalent to unit “**Ddm**” of Till and others (1986) and partly equivalent to unit “**Ddl**” of Miller and others (1972)
- Sd** **Dolostone (Silurian)**—Light-gray- to tan-weathering, light- to dark-gray, fine-grained, ferroan dolostone that forms two small rubble-covered hills, one in southeastern Bendeleben quadrangle and the other in southeastern Solomon quadrangle. At the northern locality, the main lithology occurs with lesser amounts of black dolostone and black marble. Color mottling, likely due to bioturbation, is notable at the southern occurrence. Other features of unit include possible fenestral fabric and relict bioclasts. Gray dolostone at both localities yielded conodont faunas of middle-late Silurian age (table A-1). Sedimentary structures and conodont biofacies indicate a shallow, warm-water depositional environment. Several other lithologically similar dolostones in southeastern Bendeleben and northeastern Solomon quadrangles contain Silurian-Early Devonian conodonts; these occurrences are presently mapped as unit **Pzd** but may, at least in part, belong to **Sd**. Shallow-water Silurian strata that correlate, at least in part, with **Sd** include units **DOx** (overlay) in the Nome Complex, **SOdl** and **SOul** in the York terrane, and the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) and related units in the western and central Brooks Range (units “**DOb**” and “**DOc**” of Till and others, 2008b). Equivalent to unit “**Sd**” (northern locality) and part of unit “**Pzd**” (southern

- locality) of Till and others (1986)
- Od Dolostone (Ordovician)**—Light-gray- to pink- to tan-weathering, gray to tan dolostone that forms small areas of rubble crop in tundra and local cliffs along river banks. Unit is best exposed along several rivers in northeastern Bendeleben quadrangle, but also crops out at isolated localities in northwestern and southeastern Bendeleben quadrangle and northwestern Solomon quadrangle. Depositional relations between Od and other units are nowhere preserved, but map patterns suggest possible associations with units Oim and Ddm. Od consists of fine-grained, mostly non-ferroan dolomite. Relict sedimentary features include: distinct color-mottling, reflecting an original partly bioturbated fabric; zebra dolomite, suggestive of evaporitic supratidal conditions; fenestral fabric, which generally occurs in tidal flat or shallow subtidal environments; and probable oncolites, which also indicate a shallow-water depositional environment. Conodont faunas represent at least three distinct ages: two discrete intervals in the Early Ordovician, and early to middle Middle Ordovician (table A-1). Most of the assemblages represent shallow to very shallow, warm-water biofacies, but one collection of middle to late Early Ordovician age from the Bendeleben D-2 quadrangle denotes a cooler and (or) deeper water setting (table A-1). A single collection of poorly preserved corals has also been obtained (Till and others, 1986). Most conodonts in Od are cosmopolitan forms, but Siberian and Laurentian (North American) endemics occur in a few collections (Dumoulin and others, 2002). The older (Early Ordovician) part of Od correlates with much of units Oal, Ol, and OPl in the York terrane; Middle Ordovician strata in Od are coeval with, but represent shallower water facies than, unit Ols in the York terrane. Od also correlates well in age and lithology with Early and Middle Ordovician rocks of the Baird Group (Tailleur and others, 1967; Dumoulin and Harris, 1994) in the western Brooks Range (unit “DOb” of Till and others, 2008b). Od strata that contain cooler and (or) deeper water biofacies resemble coeval deeper water rocks in unit “OPc” (Till and others, 2008b) in the Baird Mountains quadrangle. Equivalent to unit “Od” of Till and others (1986)
- €d Dolostone (Cambrian)**—Gray- to orange-weathering, light-gray or medium-gray to pinkish-orange dolostone that forms hilltop rubble patches and subcrop on several small knobs in the northwestern Solomon quadrangle. The dolostone is non-ferroan to moderately ferroan and locally contains a few percent quartz and white mica. Structurally underlying the dolostone is a section of schist and marble several tens of meters thick. The upper third consists of quartz-white mica schist and chloritic marble; the lower two thirds is mostly marble containing about 10 percent quartz, white mica, and chlorite. The orange-weathering dolostone contains lapworthellids (table A-1), a phosphatic microfossil indicative of Early (to possible early Middle) Cambrian age and a shallow-water depositional environment. €d correlates precisely with the oldest part of unit D€bm, which also contains lapworthellids, and may correlate with part of unit “OPc” (Till and others, 2008b) in the western Brooks Range. Equivalent to unit “Cd” of Till and others (1986)

METATURBIDITES

- D€bm Black marble (Devonian to Cambrian)**—Dark-gray to black marble and subordinate fissile impure marble, calcareous schist, and mafic schist that crops out in eastern Solomon and western Norton Bay quadrangles. Unit is best exposed in sea cliffs along Norton Bay and forms rubble covered hills inland. Marble layers are 1 to 20 cm thick, with rhythmic alternations of purer, coarse-crystalline and more impure, fine-crystalline layers. Common green-weathering mafic dikes, sills, and plugs, 0.5 to 2 m across, intrude the carbonate strata; preserved contact metamorphic effects include bleached carbonate rocks and albite-, chlorite-, epidote- and tourmaline-bearing skarn assemblages. Mafic rocks consist of fine-grained chlorite, actinolite, albite, and white mica; glaucophane inclusions are found in the albite. Commonly, mafic minerals form layers and are disseminated in the fine crystalline carbonate rock, suggesting that some mafic volcanism accompanied deposition of the carbonate strata. All of the mafic volcanic rocks were affected by

regional metamorphism, as were the carbonate rocks. Marble protoliths were likely carbonate turbidites and periplatform ooze.

Seven conodont faunas were obtained from six localities in DЄbm (table A-1). Two faunas are middle to early late Silurian (Wenlock-Ludlow), one is middle Early Devonian (Siegenian), and one is late Silurian to Early Devonian. Two faunas from westernmost exposures of DЄbm are considerably older: one middle Early through Late Ordovician and the other Early Cambrian. Thus, there is a gap of over 100 million years between the oldest and youngest faunas. At least three explanations can be invoked for this faunal distribution. If all conodont collections represent depositional ages, then the unit may represent two episodes of deposition of lithologically similar material—one Early Cambrian, one Late Ordovician-Early Devonian, separated by a long interval of non-deposition. Or, deposition may have extended more or less continuously from Cambrian into Devonian time—present fossil collections from DЄbm are few and future collections may eliminate the apparent hiatus. Alternately, some or all of the conodont collections could be reworked, and the depositional age of the entire unit could be late Silurian-Early Devonian or younger. In this case, the western faunas would represent material eroded from an older (Cambrian and Ordovician) carbonate platform source; the eastern faunas could represent erosion from a younger source or faunas contemporaneous with deposition.

DЄbm may be a more deformed equivalent of unit DObm, and it is intercalated with, and possibly a facies equivalent of, unit DЄks. It is lithologically similar to, and may be partly coeval with, Silurian carbonate and siliciclastic turbidites in the west-central Brooks Range (unit “Spl” of Till and others, 2008b). The easternmost exposures of DЄbm include some outcrops of unit Ddm that are too small to be mapped separately. Equivalent to unit “DCbm” of Till and others (1986), and partly equivalent to unit “Dld” of Miller and others (1972) and units “Pzcs”, “PzPus”, and “PzPss” of Patton and others (2005)

DЄks **Calcareous schist of Kwiniuk Mountain (Devonian to Cambrian)**—Dark-brownish-gray, rust-spotted, well-foliated, medium-grained schist composed predominantly of quartz, calcite, white mica, chlorite, plagioclase, and graphite. Locally shows millimeter-scale dark/light layering. Rusty spots (weathered iron carbonate?) up to 0.5 cm across are locally abundant. Fresh surfaces are gray. Interlayered on a meter to kilometer scale with units DObm and DЄbm; age assigned to this unit based on that intimate relation. On Kotzebue Sound, unit is exposed in beach cliffs at Sullivan Bluffs (15 km west of Cape Deceit), where it shows relict crossbedding and graded bedding, and contains abundant pyrite. Equivalent to unit “DCKs” of Till and others (1986)

DObm **Black metalimestone and marble (Devonian to Ordovician)**—Dark-gray to black metalimestone and marble and subordinate dolostone exposed on sea cliffs on Kotzebue Sound. Rocks weather gray to yellowish-brown, commonly have fissile partings, and are well layered. Layers range from 2 to 50 cm thick, with rhythmic alternation of thicker, coarse-crystalline and thinner, fine-crystalline layers. Relict sedimentary structures include graded bedding, flame structures, loaded bed bottoms, channelized beds, and imbricated rip-up clasts. Three kilometers west of Cape Deceit, a 15- to 20-m-thick interval of dominantly matrix-supported carbonate breccia, with rounded and angular clasts as much as 5 m in diameter, occurs in the section, as well as thinner (≤ 1 m thick) intervals of carbonate-clast breccia. Local solution collapse features occur, and dedolomitization textures were seen in thin sections. Subordinate argillite, phyllite, and radiolarian chert are found about 2.4 km west of Cape Deceit; quartz-graphite schist and impure marble (containing as much as 20% graphite, quartz, albite, and white mica) are abundant in the western exposures.

DObm has yielded tightly dated fossil collections of Middle Ordovician through late Silurian age and some longer ranging collections that could be as young as Devonian (table A-1; Ryherd and Paris, 1987). The argillite-dominated interval west of Cape Deceit contains abundant Middle and Late Ordovician graptolite assemblages as well as Ordovician conodonts (Ryherd and Paris, 1987; Harris and others, 1995; Ryherd and

others, 1995; Dumoulin and others, 2002). Higher in the unit, a continuous section of allodapic carbonate rocks, at least several hundred meters thick, produced a middle to late Silurian (Wenlock to Ludlow) conodont succession (table A-1; Dumoulin and others, 2002). Several conodont collections from eastern exposures of the unit could be as young as Devonian (table A-1). Well-layered metalimestone containing redeposited(?) rugose and colonial corals of Middle to Late Devonian age have been described from Willow Bay, 20 km east of Cape Deceit (Kotzebue A-1 quadrangle); these rocks may be part of DObm (T. Ryherd, written commun., 1985).

Two small gabbroic plugs intrude DObm west of Cape Deceit. The plugs show relict ophitic textures and are partially recrystallized to a low-grade metamorphic assemblage of actinolite, epidote, and garnet. CAI values of conodont assemblages in this unit range from 5.5-7 (table A-1) and may reflect the presence of hydrothermal fluids.

DObm represents periplatform ooze, turbidites, and debris flow deposits derived from a carbonate platform that accumulated in slope and basinal environments (Dumoulin and Till, 1985; Ryherd and Paris, 1985, 1987; Harris and others, 1995; Dumoulin and others, 2002). It correlates, at least in part, with unit DЄbm and is intercalated with, and possibly a facies equivalent of, unit DЄks. DObm is lithologically similar to, and at least partly coeval with, Silurian carbonate and siliciclastic turbidites in the west-central Brooks Range (unit “Spl” of Till and others, 2008b). It also correlates in part with Middle Ordovician-lower Silurian graptolitic argillite and quartz-rich turbidites of the Iviagik Group of Martin (1970) that are exposed south of Cape Lisburne (Grantz and others, 1983; Moore and others, 1994, 2002; Harris and others, 1995). Equivalent to unit “DObm” of Till and others (1986), and partly equivalent to units “MI?”, “pCl”, and “Pzm” of Hudson (1977) and the Deceit Formation of Ryherd and Paris (1987)

HIGH-GRADE METAMORPHIC AND ASSOCIATED IGNEOUS ROCKS

PzPh High-grade metasedimentary and metaigneous rocks (Paleozoic and Proterozoic)—Brown, light-brown, reddish-brown, black, and gray-weathering schist and gneiss exposed in the Kigluaik, Bendeleben, and Darby Mountains. Highest grade metamorphic assemblages are upper amphibolite to granulite grade; assemblages in all three ranges record multiple metamorphic events. Metamorphic foliations range from gneissic to schistose; locally, foliation is lacking and crystallization of metamorphic minerals appears to be static (Till and others, 1986; Lieberman, 1988; Calvert and others, 1999). Lithologically variable on a scale of centimeters and meters, the unit includes pelitic, semi-pelitic, quartzose, calcareous, aluminous, mafic, ultramafic, and graphitic schist and gneiss. Dominant lithologies vary within each mountain range. Till and others (1986) recognized sequences of rocks lithologically similar to those mapped within the Nome Complex in western Bendeleben and northern Darby Mountains. Thurston (1985), Patrick and Lieberman (1988), Hannula and others (1995) and Calvert and others (1999) showed that the high-grade metamorphic event in the Kigluaik Mountains overprinted blueschist-facies assemblages in the Nome Complex. At least part of PzPh, perhaps a significant part, was originally blueschist-facies rocks of the Nome Complex.

Metamorphic foliations and lithologic layering in the Kigluaik Mountains define a dome, with highest-grade rocks in its core. The earliest-formed metamorphic assemblages known in the range are found at the base of the section, below Mount Osborn. There, garnets in pelitic rocks locally contain kyanite inclusions (Lieberman, 1988); garnet lherzolite occurs as large, meter-scale xenoliths in pegmatite and is present in abundance in glacial moraine (Till, 1980, 1981; Lieberman and Till, 1987). Garnet lherzolite is stable at eclogite facies (Evans, 1977; Spear, 1993). The dominant metamorphic fabric in the Kigluaiks post-dates this high-pressure event and contains peak granulite-facies assemblages. Garnets in lherzolite are partially overprinted by spinel-bearing assemblages stable at granulite facies. Two-pyroxene semipelitic and mafic gneiss, diagnostic of the facies, are also found in the core of the range (Till and Dumoulin, 1994). Most of the rocks in the range crystallized at temperatures above the

second sillimanite isograd (above the temperature stability of muscovite; sh. 2; Amato and Miller, 2004). Metamorphic grade decreases towards the flanks of the dome, where biotite-grade metamorphic assemblages overprint low-grade metamorphic assemblages of the Nome Complex (Thurston, 1985; Hannula and others, 1995; Amato and Miller, 2004). Metamorphic isograds along the flanks of the dome are closely spaced (Till, 1980; Patrick and Lieberman, 1988; Miller and others, 1992; Amato and Miller, 2004).

Metamorphic foliations in the Bendeleben Mountains define a dome that spans the area between the large, ovoid pluton in the eastern part of the range and the smaller, irregularly shaped pluton in the west part of the range; the dome coincides with sillimanite-bearing peak thermal assemblages (Gottlieb and Amato, 2008). West of the dome, southwest of Mount Bendeleben, kyanite-bearing assemblages predate sillimanite-bearing assemblages in pelitic rocks (sh. 2; Till and Dumoulin, 1994; Till, unpub. data). Kyanite-bearing assemblages are apparently the oldest in the range.

Metamorphic rocks in the Darby Mountains lack any domal structure; instead, map-scale folds of lithologic sequences with near-vertical axial planes are present where rocks exhibit higher-grade assemblages (Till and others, 1986). In the northern Darby Mountains, units of the low-grade Nome Complex are shallowly-dipping and partially overprinted by biotite-grade metamorphic assemblages (Till and others, 1986). Southward along the crest of the range, kyanite- and staurolite-bearing assemblages occur. Kyanite is texturally older and may be relict of an earlier metamorphic event. Farther south, the appearance of sillimanite and locally sillimanite plus K-feldspar in pelitic schists indicates an increase in metamorphic grade. Metamorphic grade culminates near Mount Arathlatuluk. There, rare two pyroxene schists are diagnostic of granulite facies, and small granitic bodies appear to be anatectic melts (sh. 2). The anatectic granites were formed around 102 Ma (Till and Dumoulin, 1994). A fault-bounded block of high-grade rocks on the western flank of the Darby range contains similar high-grade metamorphic assemblages (formed above the second-sillimanite isograd) (sh. 2).

In all three mountain ranges, decompression post-dated the thermal peak, and is recorded in aluminum- and iron-rich metasedimentary rocks. In these volumetrically minor but significant rocks, assemblages containing sillimanite or kyanite (\pm hercynite spinel) and orthoamphibole were overprinted by assemblages containing cordierite and staurolite or garnet (sh. 2). Corona or symplectite textures are common in these rocks. The aluminosilicate plus orthoamphibole assemblage is stable at moderate to high pressures, above about 5 kb, and the cordierite-bearing assemblage is stable at low pressures, below about 5 kb (Spear, 1993). While decompression assemblages apparently formed at about 82 Ma in the Bendeleben range (Gottlieb and Amato, 2008), similar assemblages in the Darby range are probably older: the 100-Ma Darby pluton cross-cuts the metamorphic gradient in the Darby range; andalusite formed in its contact aureole (sh. 2). Andalusite forms at pressures lower than 4 kb.

These high-grade metamorphic rocks are equivalent to generalized units “PzpCh”, “PzpCg”, “PzpCg” and units representing upgraded Nome Complex “Oimh”, “Ocsh”, “OCxh” and “CpCsh” of Till and others (1986)

- PzEm** **Marble (Paleozoic to Proterozoic?)**—Light-gray-weathering, coarse-grained pure and impure marble interlayered with unit **PzPh**. Commonly massive, though locally meter-thick layers are separated by thin (centimeter-scale) layers of fine-grained impurities. Thin sections show equilibrium metamorphic textures involving calcite, dolomite, phlogopite, tremolite, quartz, scapolite, diopside, and graphite. Equivalent to unit “PzpCm” of Till and others (1986)
- PzPg** **Gneiss and orthogneiss (Paleozoic? and Proterozoic?)**—Light-brownish-gray, light-orange to gray biotite-plagioclase-quartz gneiss and granitic orthogneiss and minor metasedimentary rocks exposed in rubble crop north of the Oonatut Granite Complex, northwest Bendeleben quadrangle (Hudson, 1979). Fabric in the gneiss is defined by discontinuous layers and lenses of plagioclase and quartz and discontinuous concentrations of biotite. Orthogneiss is fine grained, homogeneous in texture, with

foliation defined by aligned and segregated muscovite and minor biotite. Calcite marble layers, less than 10 cm thick, are folded in with the orthogneiss at one locality. Minor hornblende-plagioclase-titanite amphibolite and pelitic metasedimentary rocks are found in southern part of the unit, and close to the Oonatut Granite Complex the metasedimentary rocks contain porphyroblasts of andalusite (Till, unpub. data). Contacts with the Nome Complex are thought to be structural (Hudson, 1979). Equivalent to units “pCgn” and “pCgog” of Hudson (1979)

- Eo Orthogneiss (Proterozoic)**—Pale-gray-, tan- and orangish-tan-weathering outcrops and rubble fields of foliated and unfoliated metagranitic rocks that form a large, tabular, concordant body within high-grade rocks of the Kigluaik Mountains. Called the “Thompson Creek orthogneiss” after exposures in Nome D-1 quadrangle (Till, 1980; Amato and Miller, 2004), the rock is syenogranite to monzogranite in composition (Streckeisen, 1976). Potassium-feldspar, plagioclase, and biotite are locally aligned in foliation; quartz and biotite lenses or layers up to a centimeter thick also parallel foliation. Allanite is locally 1 to 2 percent of the rock and is zoned with brown cores and orange rims; accessory zircon is also present. Quartz amphibolite layers that are parallel to metamorphic foliation in the orthogneiss are 1-2 m thick. Amato and Miller (2004) show the Thompson Creek orthogneiss on both the north and south flank of the antiform in the core of the Kigluaik Mountains (their unit “pCtog”). Orthogneiss yielded U-Pb zircon ages of 555±15 Ma (TIMS; Amato and Wright, 1998) and 565±6 Ma (SHRIMP; Amato, 2004)
- Ev Metavolcanic rocks (Proterozoic)**—Foliated lens- to sill-shaped bodies in western Bendeleben Mountains exposed in outcrop and rubble fields. Unit is up to 50 m thick. Very fine grain size and variation in abundance and relative proportion of biotite and hornblende suggest a volcanic protolith (Amato and others, 2009). Foliation is defined by the parallel alignment of biotite and feldspar. Grain size varies from layer to layer locally. Contacts and internal foliation are conformable to the foliation of the enclosing metamorphic rocks where exposed. These are the oldest dated rocks on Seward Peninsula, having yielded a U-Pb zircon age of 870 Ma (Gottlieb and Amato, 2007, 2008; Amato and others, 2009)

KUGRUK FAULT ZONE

- TKs Carbonate-rich conglomerate and sandstone; mudstone, siltstone and coal (Tertiary and Cretaceous)**—Two separate sedimentary sequences, of broadly different age: tan to light-gray siltstone, sandstone, and pebbly sandstone, and light-gray-weathering conglomerate composed mostly of marble, metalimestone, and dolostone clasts, probably of mid-Cretaceous age; and a separate sequence of gray and brown siltstone, mudstone, sandstone, coal, and minor conglomerate of Late Cretaceous and Tertiary age. Both sequences are exposed in narrow slices along the Kugruk Fault Zone. Mid-Cretaceous carbonate-rich sandstone and siltstone are found in southeastern and east-central parts of the Bendeleben quadrangle; conglomerate is found in these areas as well but also forms scattered outcrops in southeastern Solomon and southwestern Norton Bay quadrangles, where it is the dominant lithology. The younger sequence is poorly exposed in northeastern and southeastern Bendeleben quadrangle; it has been explored for coal and uranium (Retherford and others, 1986; Dickinson and others, 1987).

The older sequence, carbonate-rich sedimentary rocks, is better exposed. Carbonate-rich sandstone and siltstone typically occur as rubble-covered hills but are best exposed in river-cliff outcrops in Bendeleben C-2 quadrangle. Rocks are friable to well indurated, calcite cemented, and form beds 5 to 60 cm thick; sedimentary structures include graded bedding, channels, small scale ripples, and crossbeds. Some fine-grained layers are rich in carbonaceous plant debris and coal seams are locally well developed. Most samples consist of poorly to moderately well sorted, angular to rounded grains. Clasts appear to have been derived primarily from adjacent metamorphic rocks; clast lithologies include marble, dolostone, plagioclase, monocrystalline and polycrystalline quartz, volcanic rocks (with felsitic and lathwork textures), blueschist-facies metabasite,

radiolarian chert, phyllite, quartz-mica schist, and amphibolite. Carbonate clasts predominate at most localities.

Conglomerate, associated with minor sandstone and pebbly sandstone, forms rounded knobs up to 25 m high and more extensive areas of rubble crop. Bedding is rarely evident, but sandy interbeds and crude grading are locally present. Rocks are very poorly sorted and have a matrix of calcite cement and carbonate sand. Cobbles are sub-rounded to rounded; maximum clast diameter at outcrops studied ranges from 52 to 72 cm. Pebble counts indicate that carbonate clast content varies from a low of 81 percent in Bendeleben C-2 quadrangle to a high of 98 percent in Bendeleben A-1 quadrangle. Marble and metalimestone versus dolostone ratios range from 1:2 in Bendeleben A-1 quadrangle to 3:1 in Bendeleben C-2 quadrangle. Non-carbonate clasts include chert, monocrystalline and polycrystalline quartz, quartz-mica schist, chlorite schist, and various greenstone lithologies that were likely derived from the adjacent unit $MzPzr$.

Two small outcrops of mafic clast conglomerate underlie carbonate conglomerate in Bendeleben C-2 quadrangle. Sorting in these rocks is poor; clasts are rounded to angular and as much as 30 cm in diameter. Clasts are mainly metavolcanic rocks, some of which contain blue amphibole; subordinate clast lithologies include radiolarian chert, marble, quartz, and quartz-mica schist.

The calcareous sediments are locally intruded by sills (too small to show on this map) of probable Tertiary or Cretaceous age; the sediments are unmetamorphosed but deformed and vertical beds occur locally. No fossils constrain the depositional age of the conglomerates, but ages of some clasts have been determined. Carbonate clasts from six localities yielded 21 conodont collections, 19 of which have CAI values of 5-6 (table A-1). Relatively well-constrained clast ages are mainly Silurian and Devonian; the tightest ages are Middle to Late Ordovician, early to middle Silurian, middle to late Silurian (Wenlock-Ludlow), late Early Devonian (late Emsian), and Middle Devonian. Conodont biofacies of several of the Silurian clasts indicate a high-energy, shallow-water depositional setting (Till and others, 1986). The lithofacies, thermal level, age, and biofacies of the carbonate clasts correlate well with those of units Od, Sd, and Ddm; thus, carbonate cobbles in TKs most likely were derived largely from these units. Carbonate clasts of Silurian age and shallow-water biofacies appear to be volumetrically over-represented relative to the present areal distribution of such rocks. The carbonate-rich clastic rocks of TKs may have been deposited in a series of small alluvial fans.

The mid-Cretaceous carbonate-rich sedimentary sequences exposed east of Seward Peninsula in the Yukon-Koyukuk basin (Nilsen, 1989; Patton and others, 2005) are thought to be correlative with the carbonate-rich sedimentary rocks of unit TKs.

The younger sequence in TKs is exposed in creek bottoms in Bendeleben D-1 quadrangle and in a small area south of Death Valley, in Bendeleben A-1 quadrangle. In the northern locality, lignite, up to 30 m thick, is interbedded with siltstone, mudstone, and sandstone along a strike length of almost three-quarters of a mile, based on drilling results; bedding is steeply dipping (Retherford and others, 1986). Pollen assemblages of Late Cretaceous and Tertiary (Eocene to early Miocene?) ages have been found in finer grained parts of the sequence (Till and others, 1986; Haga, in Retherford and others, 1986). Drilling results show that schists of the Nome Complex sit structurally above parts of the sequence (Retherford and others, 1986).

In southeastern Bendeleben quadrangle, the younger sequence is also exposed in a small area south of Death Valley. Early Eocene and younger sedimentary and basaltic rocks accumulated in a small graben and are interleaved with basaltic rocks (Dickinson and others, 1987). Sandstone, mudstone, conglomerate and coal beds up to 55 m thick were documented in drill core. Sandstones in the core host an epigenetic and supergene uranium deposit (Dickinson and others, 1987). A similar sequence of sedimentary and volcanic rocks probably underlies Death Valley.

Unit is equivalent to units "Kc" of Miller and others (1972), "Kl_{cg}" of Sainsbury (1974), "TKs" and "TKc" of Till and others (1986), and "Kcc" of Patton and others (2005); also partly equivalent to units "Kss", "Kls", and "TKs" of Sainsbury (1974)

Jt Spruce Creek tonalite (Jurassic)—Tan-weathering, recessive, quartz-poor, plagioclase-rich intrusive rock. Rubble along middle to upper portions of Spruce Creek, in the headwaters of the Kugruk River in Bendeleben B-2 and B-3 quadrangles, is 50 to 70 percent plagioclase, 5 percent hornblende, and 25 to 45 percent quartz. Alkali feldspar is absent. A more hornblende-rich (30 percent), quartz-free dioritic variety is locally present. Hornblende is preserved only in northernmost exposures of the stock, along west banks of the creek. Elsewhere, no primary mafic minerals are present; hornblende is altered to mixtures of chlorite, opaque minerals, and epidote. An odd textural variety of the stock was found in one locality. Approximately 70 percent of this rock consists of concentrically radiating, spherulite-like intergrowths of plagioclase and quartz, often surrounding cores or nucleus grains of quartz or plagioclase, 0.7 to 1.7 mm in diameter. Several small exposures of an intrusive similar to the tonalite, thought to be fault slivers, are found along an unnamed stream that flows into the Kugruk River in the northwest corner of Bendeleben C-1 quadrangle. Tonalite yielded a U-Pb zircon age of 163 ± 3 Ma (J. Aleinikoff, written commun., 1987; Till and Dumoulin, 1994). Equivalent to unit “MzPzt” of Till and others (1986)

MzPzm Metamorphosed mafic rocks and serpentinite (Mesozoic and Paleozoic?)— Tectonic assemblage of metagabbro, metabasalt, amphibolite, serpentinite, and minor chert, exposed in rubble fields and poor outcrops along the trend of the Kugruk Fault Zone. Mafic rocks include minor unmetamorphosed (but altered) rocks, rocks with relict igneous textures and a single metamorphic overprint, and rocks that have experienced more than one metamorphic event. Pumpellyite- and prehnite-bearing veins that cross foliation are common in many lithologies.

In outcrop, singly metamorphosed mafic rocks are light to medium green, medium and grayish green, massive to finely color laminated. The degree of deformation varies within the unit. In thin section, metamorphic minerals statically overprint igneous textures, are weakly to well-aligned in a foliation, or the rock texture is mylonitic, with undulose extinction, grain size reduction, and microboudinage. Metagabbros and metabasalts typically retain porphyroclasts of igneous clinopyroxene that have rims of actinolite or blue amphibole. Mineral assemblages reflect a variety of metamorphic facies: actinolite-epidote-chlorite-plagioclase, blue amphibole-lawsonite(?)—chlorite, blue amphibole-epidote-chlorite, and blue amphibole-pumpellyite-chlorite. These greenschist-, lawsonite-blueschist-, epidote blueschist-, and transitional blueschist-pumpellyite-actinolite-facies rocks occur over the length of the fault zone and are intermixed. The presence of multiple facies may reflect compositional variation in the mafic rocks rather than significant differences in metamorphic history. The boundaries among these facies come close to intersecting at temperatures of about 275–350°C and pressures of 6–8 kb and variations in bulk rock composition shift the boundaries in pressure-temperature space (Evans, 1990). These rocks may have formed at generally similar conditions.

There are two groups of multiply metamorphosed rocks. Amphibolites composed of coarse actinolite overprinted by finer grained greenschist-facies assemblages are minor but widespread. In the northern part of the fault zone (Bendeleben D-1 and Kotzebue A-1 quadrangles) mafic rocks display evidence of an albite-epidote amphibolite facies event overprinted by a lower-grade event. Blue-green amphibole, epidote, and albite, with and without garnet, occur in equilibrium metamorphic textures. These albite-epidote-amphibolite-facies assemblages are slightly to significantly overprinted by epidote-blueschist or greenschist assemblages, largely on mineral rims or cracks. The later metamorphic event is likely the same event that affected mafic rocks in the unit farther south.

Rubble crop of light-green-weathering, dark-greenish-black serpentinite is found in two large lenses in eastern Solomon quadrangle and in smaller bodies, up to 30 m across, in beach cliffs on Kotzebue Sound. The southern lens is the largest and is closely associated with outcrops of mylonitic metabasite.

Rare subcrop of dark rusty-brown-weathering volcanoclastic rocks occurs in Bendeleben B-2 quadrangle; rocks are fine- to medium-grained and composed of

unsorted sub-rounded to angular clasts of aphanitic to porphyritic basalt. Basalt textures are variable; grain size, mineralogy, and vesicularity vary from clast to clast. Associated with these rocks are lesser light-gray- to orange-weathering, very fine grained porphyritic felsic rocks. Quartz and plagioclase phenocrysts sit in a slightly recrystallized, fine-grained matrix; disseminated iron oxides impart the orange color.

MzPzm is equivalent of unit “Pmv” of Miller and others (1972), unit “Jv” of Sainsbury (1974), and combined units “MzPzm”, “MzPzb”, and “MzPzs” of Till and others (1986)

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Appendix. Conodont data from the Seward Peninsula

By Julie A. Dumoulin, Anita G. Harris, and John E. Repetski

Introduction

Numerous conodont collections were made, mainly during the 1980's, to support geologic mapping on the Seward Peninsula. In this section we present table A-1, which lists virtually all conodont collections from this area that were examined by paleontologists of the U.S. Geological Survey as well as a few additional collections from unpublished industry reports. The table provides the location, age, geologic unit, and thermal level of these collections, as well as the sample collector and identifier (ID) and some explanatory remarks.

Sources of Data

Table A-1 contains 194 entries encompassing 234 collections. Most entries consist of a single collection, but some include two or more collections from the same location (typically, a measured section) that have identical ages and thermal levels. Fewer than half of the entries in this table have been previously published. Citations for published collections, mostly from the Bendeleben and Solomon quadrangles, are given in the remarks column. Cited references generally present faunal lists for the collections they include and may also contain more detailed age and (or) biofacies information than is given here. Transcriptions of original fossil reports (including faunal lists) for about half of the collections in table A-1 can be found online in the Alaska Paleontological Database at <http://www.alaskafossil.org>. The remarks column in table A-1 contains a note for all samples that were found in this database as of 09/10/07; the database is not yet complete, however, and more collections from the Seward Peninsula may be added later.

Conodont data are organized by quadrangle, listed from northwest (Teller) to southeast (Norton Bay). Sample locations are based on latitudes and longitudes supplied by the collector. Most samples were collected prior to common usage of GPS units by field geologists; thus, accuracies of these locations cannot be quantified. Most locations were verified using original field maps and (or) notes of the geologists who collected them. In some cases, latitudes and longitudes from the original database and (or) published references were corrected to reflect locations documented on the field maps.

The collectors' original field numbers are given for all samples. Some collections, mainly those that are relatively age-diagnostic, also have a U.S. Geological Survey collection number; this is the number under which fossil collections are generally filed in the U.S. Geological Survey repository. An Examination and Report (E&R) shipment number is provided for most samples; for the samples listed in this appendix, this is the identifying number of the unpublished U.S. Geological Survey report in which the collection was first described. The E&R number includes the year in which the report was written; for example, E&R No. A-85-23B was written in 1985. It is important to note that the composition and age of most collections listed herein have not been reevaluated since they were originally analyzed; all samples that have been reexamined more recently are identified in the remarks column. Many E&R reports can be found in the Alaska Geology technical archives unit in the Alaska Science Center, Anchorage, Alaska.

U.S. Geological Survey geologists collected most of the samples listed in this table, but students or employees of academia or industry submitted half of the samples from the Teller quadrangle. Anita G. Harris (formerly Epstein) and John E. Repetski identified the majority of the collections, but Timothy R. Carr, then with Atlantic Richfield Company, identified several collections submitted by geologists from the Anaconda Minerals Company. We thank Dr. Carr and Travis Hudson for allowing us to include these previously unpublished data in our table.

The data table contains two fields for geologic unit represented by the collection, headed "Geologic unit (this map)" and "Geologic unit (source map)." Unit designation in the current map is given for all samples. Where this name appears in brackets, it indicates an outcrop of the unit in question is too small to show at the scale of the current map. The source map unit is taken from the cited reference for previously published faunas, or was provided by the collector for unpublished collections.

Color changes in conodonts reflect the thermal history of the rocks that contain them (Epstein and others, 1977). Harris, Repetski, and their co-workers determined the conodont color alteration index (CAI) for almost all the collections in the database. Temperature ranges for CAIs were established from plots of experimental data by Epstein and others (1977) and Rejebian and others (1987); a CAI of 1 indicates a temperature range of less than 50-80°C, whereas a CAI of

6 indicates temperatures in excess of 360°C (table A-2). CAI can be equated to burial depths for a given geothermal gradient; for example, in the Appalachian basin, overburdens of ~3,600-5,500 m produced a CAI of 3 (Harris and others, 1978). Although there is a general correspondence between CAI and metamorphic history, CAI can be affected by multiple factors, some of which are not related to metamorphism. Some implications of CAIs of conodonts from the Seward Peninsula are discussed briefly below.

All samples listed herein were processed in order to obtain conodonts. In a few cases, the samples produced no conodonts but did yield other phosphatized or phosphatic fossils (such as lapworthellids) that provide age information. Such samples are noted in the remarks column.

Most collections in the database are stored at the U.S. Geological Survey in Reston, Virginia. However, faunas collected by geologists of Amoco Oil Corporation (a single sample in the Seward Peninsula database) are not part of the USGS collection but were examined by Anita Harris at the Amoco offices in Oklahoma during the 1980's. Harris determined the age and CAI of the collections; Amoco provided sample locations.

Geologic Implications

Conodont data constrain the geologic, biogeographic, and thermal histories of the Seward Peninsula. A full discussion of these topics is beyond the scope of this text, but we highlight here some implications of the conodont collections, particularly those previously unpublished and (or) used to define the ages and affinities of the geologic units in the accompanying map.

Nome Complex and Kugruk Fault Zone

Most of the conodont data from the Nome Complex and Kugruk Fault Zone included here have been previously published and interpreted (Dumoulin and Till, 1985; Till and others, 1986; Till and Dumoulin, 1994; Harris and others, 1995; Dumoulin and others, 2002); highlights of these findings are summarized here. Conodonts constrain the age, biofacies, and thermal level of parts of the Nome Complex and of carbonate clasts in the conglomerate of unit TKs in the Kugruk Fault Zone.

Dolostones of the Nome Complex produced many more identifiable conodonts than did calcitic marbles and metalimestones (Till and others, 1986). This situation, which is the opposite of that found in unmetamorphosed carbonate rocks, introduced an unavoidable bias into our conodont collections. Conodont faunas from relatively pure carbonate strata that formed in shallow to very shallow water settings and were likely dolomitized during early diagenesis are over-represented in our database relative to their areal distribution within the Nome Complex. Nevertheless, conodonts have been obtained from a variety of lithofacies in the Nome Complex that formed in both shallow- and deep-water settings.

Shallow-water carbonate rocks of Cambrian through Devonian age, included in the Nome Complex by Till and others (1986), form small, discontinuous outcrops that are widely distributed across the central and eastern Seward Peninsula (units €d, Od, Sd, and Ddm). Conodonts from these units (table A-1) provide biofacies data that strengthen depositional interpretations based on sparse sedimentary features, as well as precise age determinations that allow detailed correlations with lower Paleozoic strata of the York terrane and the Central belt of the Brooks Range (Till and others, 2008b). Conodont faunas from units Od and Sd correlate especially well with faunas from York terrane units Oal, Ol, OPl, SOdl, and DSI.

Deeper-water carbonate rocks of early Paleozoic age, also included in the Nome Complex (Till and others, 1986), crop out in the northeastern and southeastern parts of the Seward Peninsula (units DObm and D€bm, respectively). Conodonts constrain the ages of these two units (table A-1), and indicate that Silurian carbonate turbidites are a significant component of both.

Conodonts provide some age constraints for parts of the Nome Complex dominated by non-carbonate lithologies, although carbonate layers in these rocks are mainly impure calcitic marbles that yielded few fossils (see table 3 in Appendix B of Till and others, 1986). Unit Oim produced a single conodont assemblage of Early-Middle Ordovician age, and unit DOx produced several collections of early Paleozoic age (table A-1). An enigmatic single conodont of probable Triassic age from marble in the Nome quadrangle (table A-1; Till and others, 2006) may indicate the presence of a fault-bounded upper Paleozoic sequence within unit Dcs.

Conodont data also illuminate the thermal history of the Seward Peninsula. Conodont CAIs from the Nome Complex are mainly 5-6 (dominantly 5-5.5) and indicate that the rocks containing these conodonts reached temperatures of 300-360°C or greater (tables A-1, A-2; sh. 2; Rejebian and others, 1987). Temperature estimates for CAIs are derived from an Arrhenius plot of experimental data (Table A-2; Epstein and others, 1977; Rejebian and others, 1987); each CAI value

denotes a range of temperatures. For a given CAI value (for example, 5), the lower temperature (300°C) represents a longer heating duration (500 million years) and the higher temperature (480°C) corresponds to a shorter heating time (1 million years). Peak temperatures experienced by conodont-bearing rocks of the Nome Complex were likely closer to the high end of the CAI thermal range, because these temperatures were produced by blueschist and (or) greenschist metamorphic events that were, geologically speaking, relatively short-lived. This interpretation is supported by calcite-dolomite thermometry of Nome Complex samples, which indicates temperatures of 425-480°C (Patrick and others, 1985).

Twenty percent of Nome Complex conodont assemblages include specimens with CAIs as high as 6.5, 7, and 8. These higher values generally occur in collections that contain a range of CAIs, and are commonest in units Od and, most notably, DObm, where values greater than or equal to 7 occur in almost two thirds of the collections. Saline and (or) corrosive fluids involved in episodes of dolomitization or mineralization can produce anomalously high CAIs (Till and others, 1986; Rejebian and others, 1987). Textural studies of conodonts with high CAIs and the rocks that contain them suggest that most of the highest CAIs in the Nome Complex reflect hydrothermal alteration related to dolomitization and (or) faulting.

Numerous conodonts obtained from conglomerate clasts in unit TKs in the Kugruk Fault Zone suggest that these cobbles were derived largely from carbonate rocks of the Nome Complex. Age, biofacies, and thermal level of the carbonate clasts correlate particularly well with those of units Sd and Ddm. The abundance of carbonate clasts in unit TKs conglomerate that contain conodonts of Silurian age and shallow-water biofacies implies that such rocks once were more widely distributed on the Seward Peninsula.

York Terrane and Grantley Harbor Fault Zone

Most conodont data from the York terrane and Grantley Harbor Fault Zone included here have not been previously published, although preliminary summaries of some of these data are found in Dumoulin and Harris (1994), Till and Dumoulin (1994), Harris and others (1995), and Dumoulin and others (2002). Ordovician and Silurian strata of the York terrane previously were relatively well dated by megafossils (for example, Sainsbury 1969a, 1969b, 1972 and references therein), but conodonts provide tighter ages for much of this stratigraphy, particularly Early Ordovician rocks that contain few megafossils (units Oal, Ol). Conodonts also indicate that several units considered Precambrian by Sainsbury (1972) are at least partly of Ordovician age (such as rocks included in units OEl and OEt of this map). Questions that might profitably be addressed in the future using detailed conodont sampling include the age range and geographic distribution of Ordovician strata within composite units such as OEl and OEt, and the amount of age overlap between units Oal and Ol.

Most rock units in the Grantley Harbor Fault Zone that were sampled for conodonts were barren. However, unit Pzp produced a few fragmentary conodonts that indicate an Ordovician-Triassic age (table A-1; T. Carr and T. Hudson, written commun., 1982, 1984).

Conodonts contribute greatly to our understanding of the paleobiogeography of the York terrane. Conodont assemblages from several units, most notably Ol and SOdl, include both Siberian and Laurentian (North American) endemic forms, a pattern that is also seen in megafaunas from these rocks (Dumoulin and Harris, 1994; Blodgett and others, 2002; Dumoulin and others, 2002). Similar mixed biogeographic affinities characterize conodonts in unit Od of the Nome Complex, the Baird Group and related rocks in the Central belt of the Brooks Range, and lower Paleozoic strata of the Farewell terrane in interior Alaska. These faunal correlations, along with detailed lithofacies matches between coeval strata in these successions, suggest that lower Paleozoic rocks on Seward Peninsula, in the Brooks Range, and in the Farewell terrane may once have been part of a single continental fragment situated between Siberia and Laurentia (Dumoulin and others, 2002).

Conodont CAIs from the York terrane generally are lower than those from the Nome Complex and define three thermal provinces (table A-1; sh. 2). The first province consists of outcrops of units Oal, Ol, and Ols between lat 65°23.9' and 65°33' N. and long 167°14' and 167°23' W. (Teller B-5 and C-5 quadrangles) that have CAIs mainly of 2-2.5. These values indicate temperatures of 60-150°C (table A-2) and demonstrate that these York terrane rocks are still within the oil window; a CAI of 3, denoting temperatures of 120-190°C, approximates the thermal limit of oil preservation (Bird and others, 1999). The second province contains rocks with slightly higher CAIs (3-3.5); these rocks are located in the Don River area (Teller B-4 quadrangle), and consist mainly of unit SOdl. CAIs elsewhere in the York terrane are mostly 4-4.5 and delineate a third province; these values are found in units Oal, Ol, and Ols where they occur outside of the first province, as well as unit DSl and much of unit OEl.

Higher CAIs of 5-6, equivalent to those found in the Nome Complex, occur in a few conodont assemblages from the York terrane (table A-1). Some higher values likely reflect contact metamorphic effects associated with intrusion of Cretaceous dikes and plutons (for example, a few outcrops of units Oal and Ol in the Teller B-5 and C-5 quadrangles; Toro and others, written commun., 2006). Other high CAIs occur near the western edge of the York terrane (unit SOul in

the Teller C-2 quadrangle). Lastly, CAIs greater than or equal to 5 characterize all three conodont assemblages obtained from unit O_{Pt} and several assemblages from unit O_{Pl}. Recrystallization and schistose to semi-schistose fabrics characterize most of unit O_{Pt} and parts of unit O_{Pl}; these rocks may be part of a more deformed and (or) mildly metamorphosed structural plate that underlies parts of the York terrane (Toro and others, 2006).

As outlined above, CAIs from the York terrane are not simply correlated with unit age—that is, older rocks do not have consistently higher CAIs than younger rocks. Thus, these CAIs were most likely not produced by simple burial metamorphism. Instead, York terrane thermal data may reflect tectonic burial by thrust sheets, as has been proposed to explain CAI patterns in the western Brooks Range (Harris and others, 1987). Additional conodont sampling, in concert with detailed structural studies, could help define the composition and extent of discrete thrust sheets within the York terrane.

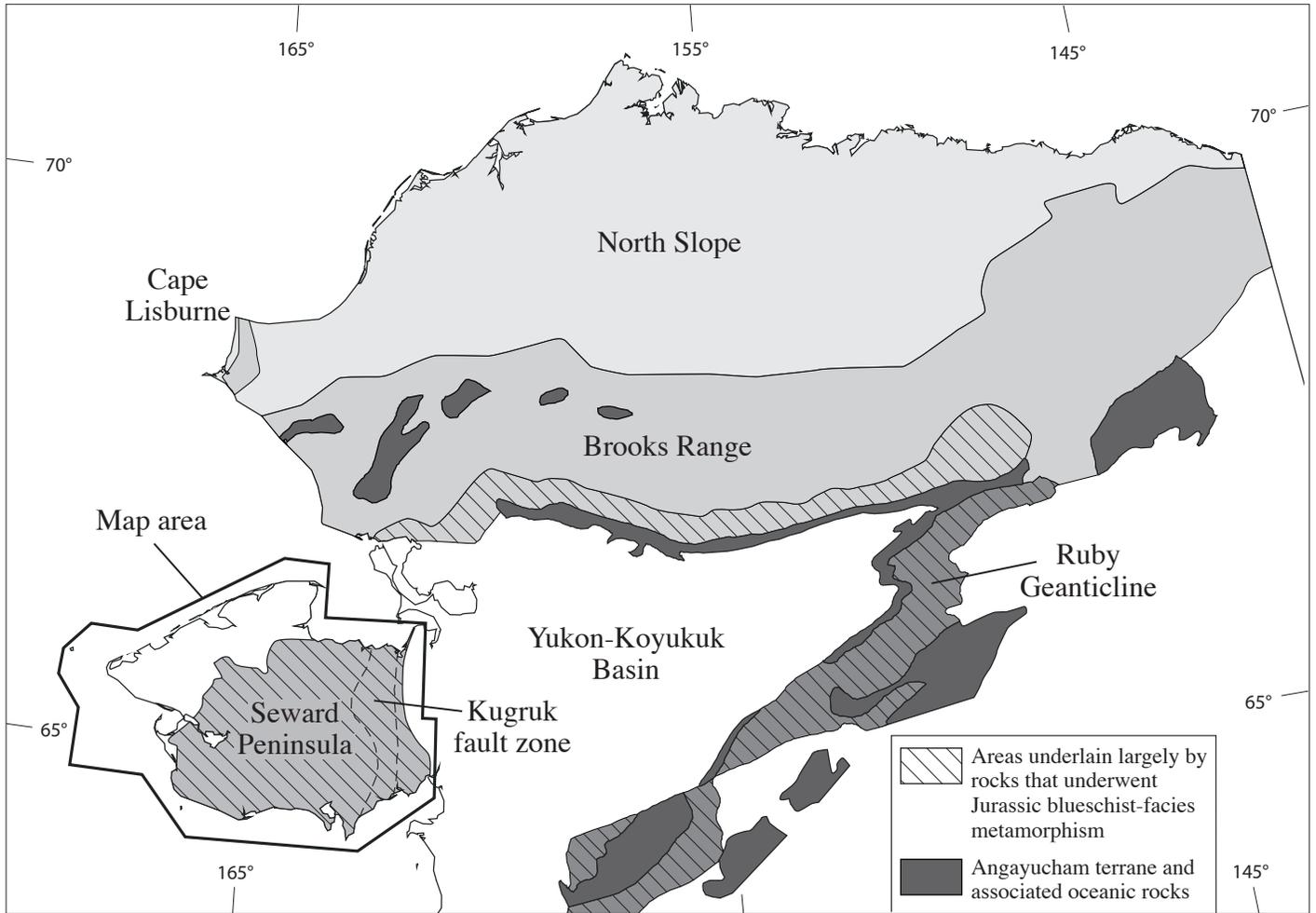


Figure 1. Map of northern Alaska showing major geographic areas, geological provinces, and the outline of the map area.