# Geologic and Fossil Locality Maps of the West-Central Part of the Howard Pass Quadrangle and Part of the Adjacent Misheguk Mountain Quadrangle, Western Brooks Range, Alaska

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# GEOLOGIC AND FOSSIL LOCALITY MAPS OF THE WEST-CENTRAL PART OF THE HOWARD PASS QUADRANGLE AND PART OF THE ADJACENT MISHEGUK MOUNTAIN QUADRANGLE, WESTERN BROOKS RANGE, ALASKA

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## INTRODUCTION

This geologic map covers an area of about 2,100 sq mi (5,500 sq km), encompassing eight 15-minute quadrangles (scale 1:63,360, or 1 in./mi) along the north flank of the west-central Brooks Range, in northern Alaska (fig. 1). These eight quadrangles correspond to the west-central part of the Howard Pass quadrangle and the eastern part of the adjacent Misheguk Mountain quadrangle (scale 1:250,000). The part of the map that corresponds to the six easternmost 15-minute quadrangles (Howard Pass quadrangle) incorporates all available field observations and data of numerous geologists over the past 50 years (fig. 2); the part of the map that corresponds to the two westernmost quadrangles (Misheguk Mountain quadrangle) utilizes the data and mapping of Mayfield and others (1984). This map attempts to integrate previous stratigraphic and structural ideas, as represented by the existing mapping of Mayfield and others, into current geologic models and the geologic perspective developed during new geologic mapping within the Howard Pass quadrangle, mainly in the 1990's.

### REGIONAL GEOLOGIC SETTING

The map area is mainly within the Arctic Mountains physiographic province of Wahrhaftig (1994), where altitudes reach 1,000–1,500 m, but the area includes the southernmost edge of the Arctic Foothills province to the north, where altitudes are generally 300–500 m or less. These provinces are the physiographic expression of the Brooks Range orogen. The map area is within a belt of complex folding and thrusting in the northern part of the Brooks Range orogen, which extends across arctic Alaska from the Bering sea on the west to the Canadian border on the east (fig. 1), where it appears to connect southeastward with the northern Cordilleran fold and thrust belt (Plafker and Berg, 1994; Dover, 1994). The belt of folding and thrusting in the Brooks Range includes the "disturbed belt" and "crestal belt" geologic provinces of Moore and others (1994), and the DeLong Mountains, Endicott Mountains, and Angayucham subterranes of their Arctic Alaska terrane.

The rocks of the Brooks Range orogen formed in carbonate platform and continental margin settings from Late Proterozoic through pre-Late Devonian time, and in a variety of continental margin settings from Late Devonian through Mesozoic and younger time (Plafker and Berg, 1994). Extensional basins associated with intermittent mafic or bimodal igneous activity formed repeatedly from Proterozoic through Mesozoic time (Plafker and Berg, 1994). Two major periods of tectonism are widely recognized in the Brooks Range fold and thrust belt—the pre-Early Mississippian Ellesmerian orogeny and the late Mesozoic to early Tertiary contractional Brookian orogeny. At least two distinct pulses of Brookian thrusting separated by Albian clastic deposition can be distinguished in the west-central part of the Brooks Range (Moore and others, 1994), and some of the key evidence for separating these pulses comes from this map area. Generally north-directed vergence is clearly indicated in the Howard Pass quadrangle for the younger of these pulses, and a similar direction of thrusting, but with vastly greater distances of tectonic transport from depositional sites far south of the present Brooks Range, has generally been interpreted for the earlier pulse as well. However, the magnitude and direction of emplacement, and original depositional sites of the early Brookian allochthonous sequences in the Howard Pass quadrangle, are poorly constrained by local evidence and regarded by two of the authors of this report (Dover and Dumoulin) as open to question.

### STRATIGRAPHIC FRAMEWORK

Seven generally time-equivalent, allochthonous stratigraphic sequences have been recognized by previous workers in the Howard Pass and adjacent Misheguk Mountain quadrangles. These sequences have been confirmed, and their map distributions refined by the mapping in the west-central Howard Pass area presented here. Major thrust faults separate these sequences from one another. The sequences are shown diagrammatically in the “Correlation of Map Units” (see sheet 1) to have a uniform direction of structural overriding relative to one another, but a consistent direction of emplacement has not been definitively demonstrated in the field, so the process of structural stacking and the actual directions of overriding may have been much more complex than the “Correlation of Map Units” implies.

In the west-central Howard Pass quadrangle, as elsewhere in the region, the map distribution of stratigraphic sequences is complicated by complex interaction of the two pulses of Brookian thrusting recognized here. The number of stratigraphic sequences that can be distinguished, and the complexity with which they are structurally juxtaposed, has complicated stratigraphic terminology in the western Brooks Range. Several different systems of terminology have been used by various workers in the region, usually with the object of clarifying or improving on the complications of prior descriptive frameworks. However, each new attempt has necessarily added its own layer of complexity by introducing new terms or new usages of old terms. The result has been a confusing mix of stratigraphic and structural terms with similar names, and the use of different terms for essentially the same rock packages (for example, see Mayfield and others, 1988, table 7.1, p. 148).

The descriptive system used on this map is no exception; it is a slightly modified version of an earlier one by Ellersieck and others (1979), judged to be the simplest and most logical of the descriptive frameworks previously used, to which some newer terminology of Mull and Werdon (1994) is added. This system recognizes seven distinct thrust-bounded stratigraphic sequences, or thrust sequences, named for the major thrust complexes they characterize. The term "sequence" is used here in the generic sense common to past usage in the western Brooks Range (see Mayfield and others, 1988), rather than in the specific sense of seismic stratigraphy. Five sequences correspond to those named by Ellersieck and others (1979), and to the equivalent allochthons designated by Mayfield and others (1988) and numerous other authors. These are, from structurally low to high, the Picnic Creek, Kelly River, Ipnavik River, Nuka Ridge, and Copter Peak sequences. A sixth, and the structurally lowest sequence, here called the Endicott sequence, corresponds to the Endicott Mountains allochthon of Mull and Werdon (1994). The Endicott sequence contains two distinct facies of Upper Devonian to Lower Mississippian rocks in the southeastern part of the map area. These are referred to herein as the Key Creek and Aniuk River facies of the Endicott sequence, and were included in the Key Creek and Aniuk River sequences, respectively, of Mull and Werdon (1994). The Key Creek and Aniuk River facies appear to be restricted to two distinctly different imbricated thurst panels representing at least moderate thrust telescoping within the Endicott sequence, but not as much telescoping as that inferred for emplacement of the overlying sequences. The seventh, and structurally highest, sequence is the Misheguk sequence, restricted to exposures at Siniktanneyak Mountain (Nelson and Nelson,1982; Bickerstaff, 1994). The term "allochthon" is not used on this map or in the stratigraphic nomenclature because of controversial structural implications that have come to be associated with it through common usage in the western Brooks Range regarding the areal extent and continuity of the allochthons, where they originated, their distance and direction of tectonic transport, and their mechanism of emplacement.

The seven stratigraphic sequences represent all or part of the age range from Devonian to Early Cretaceous (Neocomian), and most are unconformably overlain by upper Lower Cretaceous (Albian-Aptian) clastic rocks and Pleistocene surficial deposits. The two structurally highest sequences, the Copter Peak and Misheguk sequences, are predominantly igneous or igneous-derived. These two sequences are relatively poorly dated, and although previously regarded as genetically related components of an ophiolite, have uncertain plate tectonic settings and origins that are currently undergoing reassessment in areas southwest of the Howard Pass quadrangle (R.W. Saltus, T.L. Hudson, and S.M. Karl, written commun., 1999). The other five sequences, the Endicott , Picnic Creek, Kelly River, Ipnavik River, and Nuka Ridge sequences, consist predominantly of sedimentary rocks and differ most strikingly in their Devonian and Mississippian strata. However, some also have important differences in their Pennsylvanian to Jurassic sections, as, for example, the abundance of chert (Imnaitchiak Chert) in the Picnic Creek and Ipnavik sequences compared with that in the Endicott sequence. Distinctive Cretaceous lithologic components such as coquina and cannon-ball concretions, and faunal distinctions, may also characterize one sequence or another, but the data are sparse, and systematic Cretaceous variations between sequences are poorly documented; those differences known to the authors are specified in the "Description of Map Units."

Any thrust-based stratigraphic scheme is necessarily complicated where thrust sheets die out along strike and lose their structural identity, or where units pinch out or undergo lateral facies changes within a single thrust sheet. These problems are compounded on a regional scale because (1) the wider the region, the more likely individual stratigraphic sequences are to undergo lithologic changes, and (2) individual structures, including "allochthons," cannot be extended indefinitely. A local example is the decision to treat the Key Creek and Aniuk River facies on this map as lateral variations within the Endicott sequence, rather than split the Endicott into two different sequences. A regional example is that Pennsylvanian and Permian rocks in what is mapped as the Endicott sequence (or allochthon) in the De Long Mountains quadrangle, 100 mi west of the Howard Pass quadrangle, more closely resemble correlative rocks of the Picnic Creek sequence in their chert content than they do equivalent rocks in the Endicott sequence in this map area. Other examples of how the lithology of some map units within a single "allochthon" ("sequence" in our terminology) vary regionally are mentioned in the stratigraphic descriptions of Mull and Werdon (1994) and Mayfield and others (1984).

Despite the distinctive lithologic components or intervals by which they are characterized, all of the sequences mapped here, except for the Misheguk sequence, also have enough stratigraphic similarities and lithologies in common to make mapping distinctions difficult in places. These similarities suggest structural telescoping of originally connected Devonian through Early Cretaceous depositional settings for these sequences, rather than structural amalgamation of isolated and disparate depositional sites. Deposition along a rifted continent-ocean margin characterized in different places by a carbonate platform and (or) clastic wedge could produce all of the various sedimentary rock types and the mafic to bimodal igneous rocks juxtaposed in the sequences of the Howard Pass and Misheguk Mountain quadrangles, but the configuration and location of the hypothetical rift margin is uncertain. The location and precise plate tectonic setting in which the arkosic rocks of the Nuka Ridge sedimentary sequence formed is enigmatic, but they also could be derived locally from erosionally denuded crystalline basement rocks in uplifts along such a rift margin.

## STRUCTURAL DISCUSSION

This geologic map depicts the complex interaction of two fundamentally different suites and ages of contractional structures, represented on the geologic map by several types of thrust fault and fold symbols, that deform the major sequences mentioned above. Figure 3 is a simplified tectonic map showing the distribution of these thrusted sequences and the pattern of structural interaction between the two main deformational phases.

The oldest and largest of the thrust faults form the structural soles of the thrust sequences, which are shattered by a complex array of smaller, imbricate thrust faults that typically splay from the sole thrusts. The structural distribution of these sequences and their sole thrusts, but not the subsidiary faults that imbricate the sequences, is shown in figure 3. The amount of displacement represented by these sequence emplacement structures has been estimated by Mayfield and others (1988) to be 700–800 km, assuming origination of all of the sequences from south of the present Brooks Range. We (Dover and Dumoulin) believe other tectonic models that would require less cumulative shortening may be possible.

The structural sequences typically have a broad, open, upright to overturned folded form produced by the younger episode of contractional folding and thrusting that occurred after their emplacement. Only the largest of these later structures are shown in figure 3. The most prominent of the fault zones (the Makpik-Bupto zone) is interpreted to have major right-lateral displacement where it trends northeast across structural grain along Makpik Creek, and to splay eastward into several prominent east-west-trending thrusts having major north-directed movement. This zone cuts all of the structural sequences in the map area except the Kelly River and Nuka Ridge sequences, which are not exposed along the zone. The Makpik Creek part of this zone may be controlled at depth by a major basement-controlled lateral ramp. Additionally, high-angle faults of several types are also represented on the map, but these are generally much subordinate to, and far less structurally significant than, the thrusts.

### Sequence Emplacement Structures of Aptian or Older Age.

Most of the individual thrust-bounded sequences are structural duplexes. Duplexing is interpreted from the pattern by which the internal thrust faults that imbricate the stratigraphic sequences commonly curve into and merge with the major sole thrusts. The best examples in the map area are in the

Endicott, Picnic Creek, Ipnavik River, and Nuka Ridge sequences. These internal, imbricating thrusts are inferred to be essentially the same age as the sole thrust(s) they merge with, and the stacked structural panels they bound represent enormous internal thickening and shortening during emplacement of each complex. Imbrication and tectonic emplacement of the thrust complexes involved the Neocomian (lower Lower Cretaceous) and locally Upper Jurassic Okpikruak Formation, which is present at the top of several of the sequences; clasts in conglomerates of the Albian-Aptian (upper Lower Cretaceous) Fortress Mountain Formation foredeep deposits of the Colville Basin were derived from the thrust complexes during and after their emplacement and uplift. These relationships indicate a mid-Early Cretaceous age of emplacement for the structural sequences.

Amount and direction of tectonic transport is difficult to document for most individual thrust imbrications. Some are clearly related to overturned folds and have relatively small displacements of a few kilometers or less; others, including some related to large, commonly detached recumbent folds, require larger displacements based on the extent of overriding of underlying thrust imbricates or panels. Internal tectonic shortening of 200–300 percent or more seems likely from the number of imbricate splays, the degree of truncation and overriding apparent for at least some of them, and the amount of structural thickening indicated by the map pattern of imbricate stacking. Though the actual amounts of structural shortening and thickening are undocumented, and there is insufficient subsurface control for accurately constructing balanced retrodeformed structure sections for this map area, it seems clear that the component of total displacement respresented by **internal shortening** has been greatly underestimated in previous analyses of thrusting in the western Brooks Range.

The intensity of internal deformation and the degree of internal shortening mentioned above is a consideration separate from the question of the direction and extraordinary amount of transport previously inferred by Mayfield and others (1988) for emplacement of the major thrust sequences from their original depositional sites. On the basis of their work, emplacement of the structural sequences has generally been interpreted to have been toward the north and to have produced a structural stacking that places sequences formed successively farther south into progressively higher structural positions. However, independent evidence for the direction of imbricate thrusting during emplacement is not generally available from the internal fabric of the thrust sequences in this map area or in the "allochthons" elsewhere in the western Brooks Range. In the absence of such evidence, prevailing models of far-traveled allochthon emplacement may be open to question because of the possible masking effect of a later, second phase of superimposed deformation that dominates structural grain in the west-central Brooks Range. The asymmetry and north-vergence of overturned folds, and the geometry of thrust cutoffs, indicate consistently north-directed thrusting of this later, post-sequence-emplacement deformation, which produced reversals of dip and overturning of pre-existing structures. The extent to which the effects of this phase of deformation may have been mistakenly attributed to sequence emplacement is unclear, but this does appear to have happened in places, as indicated below. Therefore, in the absence of definitive evidence based on internal fabric, previously inferred models of far-traveled emplacement of sequences from the south are unconfirmed in our map area, and two of us (Dover and Dumoulin) believe that conceptional cross-sections like those of Mayfield and others (1988) and Mull and others (1987) are open to question.

A case in point is the prominent klippe of the Nuka Ridge sequence on Nuka Ridge, in the northwest corner of the map area, along the east edge of the Misheguk Mountain quadrangle (fig. 4). Here, as shown by the original mapping of Mayfield and others (1984), an imbricate stack of the Nuka sequence is folded into a large, broad, northwest-trending and northward-overturned syncline characteristic of post-emplacement, late phase structures throughout the map area. The north-south cross-section through this klippe drawn by Mayfield and others (1984) clearly shows the overturned geometry of the fold, but this is a post-emplacement structure and does not constrain the direction of original emplacement and imbrication of the Nuka sequence. Instead, the direction of emplacement thrusting should be viewed in a line of section normal to the cutoffs the imbricate thrust panels make with one another, and with the sole thrust of the klippe. As mapped by Mayfield and others (1984) at Nuka Ridge, this would require an approximately west-northwest structure section along the crest of the ridge (fig. 4). According to standard duplex geometry (Boyer and Elliott, 1982; Mitra, 1986), the pattern of flats with ramps cutting up-section seen in figure 4 suggests emplacement from the **west**, rather than the south. Whether the original mapping at Nuka Ridge is correctly portrayed by Mayfield and others (1984) or not, this geometric pattern does not support the emplacement direction they interpreted from their mapping. Similar geometric reasoning, but based on somewhat less compelling geologic patterns, raises similar questions for emplacement of the main Ipnavik River thrust sequence of the De Long Mountains in the west-central part of the map area and for other major thrust sequences in the map area. The significance of this is that critical re-examination of evidence bearing on the direction of emplacement of each of the major structural sequences in the western Brooks Range is needed before the prevailing interpretation of palinspastic restoration from the south can be evaluated. A more complex model of development of the structural sequences involving original emplacement from other directions, followed by segmentation and structural overprinting of the sequences by **later** north-directed thrusting, may be required.

### Post-Albian Deformation.

The predominantly east-west to northwest-southeast structural grain of the Howard Pass-Misheguk Mountain area is a product of the second generation of major thrusting and associated folding mentioned above (fig. 3). Second-phase structures cut and deform all of the major thrust complexes, postdate their emplacement, and involve their Aptian-Albian depositional products. The trends of many of these relatively younger faults have prominent linear or curvilinear topographic expression. This period of deformation broadly folded the Fortress Mountain Formation and Torok Shale, and the thrust sequences themselves, but tighter folding with associated small thrusts and reverse faults affected incompetent rocks, and earlier structures were probably reactivated and tightened up in many places. Map evidence for younger faults merging with the sole thrusts of older thrust complexes suggests that at least some of the younger generation of thrusts root in, were propagated from, or utilized weak zones of, reactivated older structures. Distances of transport of the largest of the younger thrusts were far less than for the emplacement of the earlier thrust complexes but may have been several kilometers or more in places and were sufficient to severely disrupt the earlier structural patterns. Some of the best examples are within the Drenchwater Creek and Cutaway Basin structural windows, the Makpik-Bupto structural zone, and the Memorial Creek fault zone (fig. 3). A key consequence of the recognition of two distinct ages of thrusting is that because the younger "out-of-sequence" thrusts cut and juxtapose different structural sequences, younger-on-older thrust relations are common in the map area where relatively younger rocks from one structural sequence are emplaced on older rocks of the same sequence, or where younger rocks of one structural sequence are thrust onto older rocks of another. Examples of this relationship involving the Endicott and Picnic Creek sequences are common in the Drenchwater and Cutaway Basin windows, and where Cretaceous rocks of the Picnic Creek sequence override older rocks of the Ipnavik River sequence on major thrusts crossing Story and Safari Creeks and the west fork of Swayback Creek. The possibility of younger-on-older displacements caused by extensional low-angle normal faulting cannot be eliminated in some places but is less consistent with the predominantly contractional relationships and patterns that can be documented throughout the map area. Second-generation thrusts consistently dip south, and related folds verge northward, indicating that the younger phase of folding and thrusting was consistently north- to north-northeast-directed. This phase of deformation, which dominates structural trends in the west-central Brooks Range, affects rocks as young as Albian (latest Early Cretaceous) and is therefore interpreted to be Late Cretaceous and (or) younger in age.

### Structural Symbols

Some thousands of bedding attitudes and other structural data and controls were used in this map compilation. However, because of the complexity and tightness of the map, and questions about how representative much of the data are for numerous areas of complex small-scale folding, only a few bedding attitudes in structurally simple areas are included on this map. Instead, bedding traces and small fold axes are included. These were mapped in the field and from high-quality aerial photographs and judged to be more representative of the deformation style, less likely to add clutter or be obscured by mapping detail, and a visually much more graphic indication of the controls on the placement of the many small faults required by structural cut-offs and truncations than would otherwise be apparent. Outcrop-scale and larger fold axes are added where they do not obscure contact relations.

## MAPPING CREDITS

Much of the current knowledge of the west-central Brooks Range stems from geologic mapping by the U.S. Geological Survey, starting mainly in the early 1950s. Instrumental in that mapping effort were the field activities of I.L. Tailleur over the course of more than four decades. His work, supported by the mapping of numerous colleagues, led to a model of western Brooks Range geologic development still widely held today. This generation of mappers included I.L. Tailleur (1950–53, 1965–66, 1968, 1975–77, 1979, 1986, 1992); R.L. Detterman, A.H. Lachenbruch, M.C. Lachenbruch, and M.D. Mangus (1949); B.H. Kent (1950–51); H.N. Reiser (1951); and Ed Sable (1953). The contributions of these early workers—I.L. Tailleur and his associates—are therefore the foundation of this map, and our compilation depends heavily on the data and ideas they generated.

The next generation of geologic mapping utilized in this compilation resulted from various Federal and State Survey activities of the 1970s. Contributers to this phase of geologic exploration within the Howard Pass quadrangle include I. Ellersieck (1976–77, 1979); C.F. Mayfield (1975–77, 1979); M. Churkin (1977–78); G.R. Winkler (1977), W.J. Nokleberg (1977–78); M.L. Miller and M. Mullen (1978); W.P. Brosge (1979); S.W. Nelson (1978–79, 1991); and W.H. Nelson and S.M. Curtis (1979). Geologic contacts and the distribution of map units within the Misheguk Mountain part of this compilation are generally shown here as mapped in 1978 and published by Mayfield and others (1984), although stratigraphic units were combined in a few places, and characterization of fault type is modified locally in accord with interpretations based on later mapping in the adjacent Howard Pass quadrangle.

The main impetus for this compilation was geologic mapping done in 1992 by the U.S. Geological Survey, in cooperation with the Alaska Division of Geological and Geophysical Surveys. Participants in the 1992 map project and contributors of mapping and (or) data to the part of this compilation within the Howard Pass quadrangle were J.H. Dover, J.A. Dumoulin, R.T. Miyaoka, J.S. Kelley, J.M. Schmidt, and S. Bie (general area); D.P. Bickerstaff and M. Miller (Siniktanneyak Mountain mafic-ultramafic complex); M.B. Werdon (Story Creek area); and C.G. Mull, T.E. Moore, and Ellie Harris (southeastern part of the map area). Gravity data collected by R.L. Morin in 1992 helped in constraining the limits and tectonic configuration of the Siniktanneyak Mountain mafic-ultramafic complex. Other recent geologic mapping utilized in the compilation is from the following sources: D.C. Bradley and D. Bohn (1990), J.A. Dumoulin and J.M. Schmidt (1990–91), C.G. Mull (1990–93), R. Harris (1991), R.R. Reifenstuhl and T.E. Moore (1992–93), K. Adams and E.E. Harris (1993), and S.M. Karl (1994).

Identifications of geologic units in numerous small, isolated exposures, and bedding traces throughout the Howard Pass part of this map compilation, rely heavily on the field observations and aerial photograph interpretations of Tailleur and others (1966), and detailed interpretation of color-infrared imagery by J.H. Dover (1992–94).

## DESCRIPTION OF MAP UNITS

### SURFICIAL MATERIALS
### (QUATERNARY)

Qa **Main stream alluvium—**Unconsolidated silt, sand, and gravel in active main stream channels

Qs **Surficial deposits, undivided—**Unconsolidated stratified and unstratified surficial deposits, including side-stream alluvium; colluvium; terrace gravels; landslide deposits; delta, fan, and talus deposits; and glacial deposits

Qg **Glacial deposits, undivided—**Mainly unstratified glacial drift in moraines along west side of Makpik Creek

### FOREDEEP DEPOSITS OF THE
### COLVILLE BASIN
### (LOWER CRETACEOUS)

Ktfm **Torok Shale and Fortress Mountain Formation, undivided (Albian and Aptian)—**Undifferentiated and regionally interfingering units of the Torok Shale, characterized by folded, thinly interbedded black clay shale and silty shale; and the Fortress Mountain Formation, consisting predominantly of greenish-gray graywacke, interbedded with dark-gray mudstone and shale, and massive beds of pebble- to cobble-conglomerate containing clasts of variegated chert and altered mafic igneous rocks. Fortress Mountain Formation contains early (and rare middle) Albian megafossils in northern and eastern parts of Howard Pass quadrangle and in the De Long Mountains quadrangle (Elder and others, 1989), and Aptian-Albian microfossils in the De Long Mountains and Chandler Lake quadrangles (C.G. Mull, written commun., 2000)

ENDICOTT SEQUENCE
(LOWER CRETACEOUS TO DEVONIAN)

KDe **Rocks of the Endicott sequence, undivided (Lower Cretaceous (Neocomian) to Devonian)—**Mapped tentatively in a few areas of limited or isolated exposure in the north-central part of the map area. Not examined in the field or identifiable by photo interpretation; assignment based on inferred but unconfirmed continuity with stratigraphic assignments by other geologists within what appears to be the same structural plate or sequence. Assignment to other sequences is possible but would require additional structural complexity for which there is presently no independent evidence

KJo **Okpikruak Formation (Lower Cretaceous (Valanginian) to Upper Jurassic (Kimmeridgian))—**Dark-gray to grayish-tan mudstone, siltstone, graywacke sandstone, and minor conglomerate; locally contains interbeds of distinctive reddish-gray coquinoid limestone (c) composed of the pelecypod *Buchia sublaevis* of early Valanginian age (table 5, locs. 167, 168, 185); also contains *Buchia* species of middle to late Valanginian and possible Kimmeridgian ages in, and just west of, the map area (table 5, locs. 182, 188; Mayfield and others, 1984, table 2, loc. 53). *Buchia* species of Berriasian and early Valanginian age are found farther west (western Misheguk Mountain and De Long Mountains quadrangles); species of early Valanginian and possible Late Jurassic age occur to the east (eastern Howard Pass and Killik River quadrangles) (Elder and others, 1989, table 1, loc. 105, USGS colln. 22509; C.G. Mull, written commun., 1990). Includes rock types assigned to the Ipewik unit to the west and considered to be of Jurassic and Early Cretaceous age (for example, Mayfield and others, 1990). Intensely deformed and base structurally detached in places. Thickness unknown

JIPe **Etivluk Group (Middle Jurassic to Pennsylvanian)—**Assemblage of variegated but mostly black, gray, or greenish-gray bedded chert containing partings and subordinate interbeds of shale and siliceous shale. Typically is intensely tectonically disrupted. Locally contains abundant radiolarians (table 2, locs. 15, 16, 31, 43, 58, 62, 107, 151, 152; and Mayfield and others, 1984, table 2, loc. 14A); ages include middle Permian, Middle Triassic (Ladinian), and Late Triassic (early to middle Norian). Late Triassic (Norian) bivalves (*Monotis* sp.) also occur in this unit (table 5, loc. 164)

JTRo **Otuk Formation (Middle Jurassic to Triassic)—**Interbedded fossiliferous black chert and shale, and thin-bedded, black and banded limestone characterized by abundant *Monotis* sp. or *Halobia* sp. pelecypods of Late Triassic age (table 5, locs. 165, 166, 173, 176, 178, 187). Mapped separately where white-weathering limestone bands and layers are exposed and are easily identified on aerial photographs and color infrared imagery. Radiolarian collections from this unit (table 2, locs. 5, 13, 18, 19, 38, 42, 117, 127, 130; table 4, loc. 117; Mayfield and others, 1984, table 2, loc. 13) are of Middle Triassic (Ladinian) and Late Triassic (Carnian? and Norian) ages; a single conodont collection (table 4, loc. 117) is Middle Triassic. The Jurassic Blankenship Member at the top is locally exposed (but not mapped separately) and consists of organic-rich black shale and thin-bedded chert; east of the map area (eastern part of the Howard Pass quadrangle) it contains pelecypods (*Otapiria tailleuri*) of Early Jurassic (Sinemurian) age (Elder and others, 1989, table 2, locs. 488–489). Formation is commonly exposed only as rubble or in structurally complicated partial sections in stream cuts. Thickness less than 100 m

PIPs **Siksikpuk Formation (Permian to Pennsylvanian)—**Predominantly nonresistant thin-bedded siltstone, shale, siliceous mudstone, and thin-bedded chert. Distinctive thin basal yellowish-orange-weathering, greenish-gray siltstone; grades upward into maroon to green mottled siltstone containing barite seams and crystals, and resistant green and greenish-gray siliceous mudstone and chert in beds 10 cm or less thick, and poorly exposed gray clay shale. Formation is commonly structurally complicated and exposed only as rubble on hillsides or recognized in streamcuts as the yellowish orange-weathering beds overlying the Lisburne Group. Mull and others (1987, p. 659) restricted the geographic extent of the Siksikpuk to "some areas of the western . . . and north-central Brooks Range" where it "consists dominantly of shale and siltstone and only minor chert." These authors noted that in the Killik River quadrangle the Siksikpuk Formation [restricted] is present only in the Endicott allochthon (our sequence), whereas other allochthons (our Picnic Creek and Ipnavik sequences) contain Imnaitchiak Chert; to the west, in the De Long Mountains, Imnaitchiak Chert occurs in all sequences, including the Endicott. The Siksikpuk as restricted by Mull and others (1987) has yielded only Permian fossils, but the basal age of the unit is poorly constrained (Murchey and others, 1988) and may gradually increase to the west, where gray chert overlying the Kuna Formation in the De Long Mountains quadrangle (probable "Imnaitchiak Chert" in the usage of Mull and others, 1987) contains Pennsylvanian radiolarians (K.M. Reed, written commun., 1998). In the Endicott sequence in the map area, most strata that lie between the Lisburne Group and the Otuk Formation are lithologically like the Siksikpuk Formation [restricted], but chert increases (gradationally?) to the west. Rocks here mapped as Siksikpuk in the eastern Misheguk Mountain quadrangle are lithologically intermediate between the Siksikpuk [restricted] and the Imnaitchiak Chert of Mull and others (1987) and have yielded radiolarians of Pennsylvanian to Early Permian (Atokan? to Leonardian) age (Mayfield and others, 1984, table 2, locs. 8A, 17, 20, and 29; Murchey and others, 1988)

**Lisburne Group (Pennsylvanian and Mississippian)**

PMkv **Volcaniclastic rocks (Pennsylvanian? and Mississippian?)—**Predominantly light-gray to green-gray, light-brown- to rusty-weathering felsic tuff containing abundant feldspar and sparse biotite phenocrysts; typically has calcareous cement and disseminated sulfide minerals. Commonly associated with tuffaceous sandstone, coarse-grained limestone containing disseminated light-green chloritic minerals, and thick-bedded to massive calcareous rocks containing volcanic fragments. The felsic rocks are equivalent to units Mft, Mmt, Mct, and Mke of Nokleberg and Winkler (1982) in the Drenchwater Creek area, where their thickness ranges from 80 to 250 m. Also included in this unit are sparsely distributed and strongly altered mafic andesite, and keratophyre. The mafic rocks are equivalent to the Mma and Mke units of Nokleberg and Winkler (1982) in the Drenchwater Creek area, where their thickness is as much as 80 m, and a K-Ar age on biotite of 325.6 Ma (recalculated using decay constants of Steiger and Jager, 1977) was reported by Tailleur and others (1966). This unit is equivalent to unit PMvc of Mayfield and others (1984), who recognized it only east of upper Picnic Creek in the Misheguk Mountain quadrangle. Biotite from similar alkaline intrusive rocks associated with Sedex and vein-breccia mineralization in this unit in the

Drenchwater Creek area yielded $^{40}Ar/^{39}Ar$ plateau ages of 335–337 Ma (Werdon, 1999), indicating a Carboniferous age of mineralization

ⅣMk **Kuna Formation (Lower Pennsylvanian and Mississippian)—**Predominantly black siliceous mudstone and sooty, carbonaceous shale, including minor gray carbonate interbeds and concretions. Includes Mc (bedded chert) unit and various limestone units (Mls, Mko, and Mu) of Nokleberg and Winkler (1982) in Drenchwater Creek area. Siliceous beds are rich in sponge spicules and radiolarians. Thin carbonate layers are chiefly dolomitic mudstone and calcitized radiolarite. Some intervals of carbonate in Drenchwater Creek area are at least 20 m thick and may be (at least in part) carbonate turbidites derived from a shallow-water Lisburne Group source (Werdon, 1999). Sedimentologic and faunal evidence suggest that the Kuna was deposited in a deep-water setting in which anoxic or dysaerobic bottom-water conditions generally prevailed. Conodonts from carbonate layers near base of type section in Howard Pass B–3 quadrangle are early middle Osagean (lower part *S. anchoralis-D. latus* Zone); uppermost carbonate beds could be as young as Meramecian (Dumoulin and others, 1993, 1994) (table 1, locs. 21, 61, 146, 147; table 4, loc. 125). Carbonate layers also contain rare cephalopods of Osagean and Meramecian ages (table 5, locs. 174–175). Siliceous beds in the uppermost Kuna yield radiolarians of Late Mississippian–Early Pennsylvanian age (table 2, loc. 115; less diagnostic ages were obtained from locs. 17 and 21); similar ages are reported from this stratigraphic interval west of the map area in the De Long Mountains quadrangle (C.D. Blome, written commun., 2000). The lithology and fauna of these highest siliceous beds are locally gradational into those of the lower Etivluk Group. Depositional contact on underlying Kayak Shale and beneath overlying Siksikpuk Formation exposed in places, but top is generally faulted. Maximum thickness about 70 m

Mlb **Bupto facies (Upper and Lower Mississippian)—**Thin-bedded to massive dolostone, chert, and subordinate limestone; locally parallel- and cross-laminated. Mapped only at Mt. Bupto and two small areas about 10 km to the north. Well-exposed upper part of the section at Mt. Bupto is 195 m thick; entire succession may be as much as 360 m thick (Armstrong, 1970). Upper section has three subunits. Upper and lower subunits are chiefly chert; middle subunit mostly dolostone (this dolostone-rich middle unit was not recognized by early workers; see for comparison Dumoulin and Harris, 1993, p. 46). Relict textures indicate that most chert was limy bioclastic wackestone, packstone, and grainstone prior to silicification; bioclasts include sponge spicules, crinoid ossicles, bryozoans, and brachiopods. Dolostone was mainly crinoidal packstone and (or) grainstone; some intervals contain 1–15 percent moldic and intercrystalline pores, locally lined with solid hydrocarbons. Lowest beds are limestone (skeletal grainstone and packstone) with partings of noncalcareous black shale; lithofacies and biofacies of these rocks resemble those of the Rough Mountain Creek unit (table 1, locs. 67, 68). Uppermost beds are organic-rich, locally phosphatic and (or) petroliferous black shale, chert, and dolostone. Sedimentary structures and faunal evidence suggest most of section formed in an open-marine, outer shelf or platform setting. Dolostone subunit accumulated in shallower water (middle shelf?) shoals; some northern strata (table 1, locs. 37, 41) were deposited in very shallow-water environments. Conodonts indicate that uppermost 60 m of unit is late Meramecian, middle part of section is middle-late Osagean, and lowest beds may be as old as late Kinderhookian (table 1, locs. 33, 37, 41, 58, 66–72). Also contains Osagean-Meramecian megafossils and possibly Meramecian endothyrid foraminifers (Armstrong, 1970). Similar in lithology, age, and depositional environment to correlative sections to the northeast at Lisburne Ridge and in the Ivotuk Hills (Dumoulin and Harris, 1993).

Mlr **Rough Mountain Creek unit of Dumoulin and Harris, 1997 (Lower Mississippian)—**Predominantly light- to dark-gray limestone interbedded with subordinate black fissile shale and blocky mudstone. Limestone mainly poorly sorted to well-sorted, medium-grained to very coarse grained skeletal grainstone and packstone; cherty and spiculitic in part. Some beds are graded; others parallel-laminated or bioturbated. Late Kinderhookian age indicated by conodonts in the eastern Howard Pass quadrangle and by brachiopods in underlying Kayak Shale (Dumoulin and Harris, 1997; Mull, Harris, and Carter, 1997); contains Kinderhookian conodonts in central and eastern parts of map area (table 4, locs. 131, 144, 148–50, 155). In eastern Misheguk Mountain quadrangle, rocks provisionally included in this unit contain foraminifers of late Osagean (late Early Mississippian) age (Mayfield and others, 1984; table 2, locs. 8B, 14B). Lithologic and faunal data indicate deposition mainly in shallow-water, inner- to middle-shelf settings. Thickness generally 8–17 m

**Endicott Group (Lower Mississippian and Upper Devonian)**

**Key Creek facies**

Mk **Kayak Shale (Lower Mississippian)—**Dark-gray to black, fissile clay shale containing conspicuous yellowish-brown-weathering, thin, fossiliferous limestone interbeds near the top and greenish-gray siltstone and sandy siltstone in the lower part. Sideritic concretions are characteristic in places. Locally contains felsic to intermediate intrusive, extrusive, and volcaniclastic rocks. Contains Kinderhookian (locally late Kinderhookian; early Early Mississippian) conodonts and brachiopods within the map area (Dumoulin and Harris, 1997; Mull, Harris, and Carter, 1997) (table 4, locs. 116, 118, 119, 142, 143, 148, 153, 154). Mayfield and others (1984) reported brachiopods and corals of Early Mississippian age (table 2, locs. 38, 40, 42, and 44) from this unit in the eastern Misheguk Mountain quadrangle. Minimum thickness 45 m; typically complexly folded and pervasively sheared, especially near the structural base, where phyllitic textures and detachment from underlying rocks are common

Mkl **Limestone unit of Kayak Shale (lower Lower Mississippian)—**Orange-weathering, gray fossiliferous limestone in beds 0.1–5 m thick, interbedded with dark gray to black shale. Crinoid ossicles, corals, and other bioclasts locally abundant. Mapped separately only north of Safari Creek window. Lithologically similar beds commonly occur in the upper part of the Kayak Shale elsewhere in the map area but are too thin and (or) discontinuous to map separately; these beds contain Kinderhookian (early Early Mississippian) conodonts and brachiopods (Dumoulin and Harris, 1997; Mull, Harris, and Carter 1997).

Mik **Isikut unit of Mull and Werdon (1994) and Kayak Shale, undivided (lower Lower Mississippian)—**Conodonts of early Early Mississippian age (table 4, locs. 123–126, 132, 133, 145) were reported by Dumoulin and others (1997) and Mull, Harris, and Carter (1997). See table 3 (loc. 125) for additional megafossil data

Mikv **Volcanic-rich part of Isikut unit of Mull and Werden (1994) and Kayak(?) Shale, undivided (lower Lower Mississippian)—**Isikut unit as described below, but representing a part of the Isikut containing more abundant volcanic components than is typical. Conodonts of early Early Mississippian (Kinderhookian; locally, middle to late Kinderhookian) age are reported by Dumoulin and others (1997) and Mull, Harris, and Carter (1997) (table 4, locs. 120, 122)

MDkn **Kanayut Conglomerate and Noatak Sandstone, undivided (Lower Mississippian? and Upper Devonian)**

MDk **Kanayut Conglomerate (Lower Mississippian? and Upper Devonian)—** Gray to brown, tannish-brown-weathering, quartzitic sandstone and subordinate quartz- and chert-pebble conglomerate. Lower part contains gray to black shale, siltstone, sandstone, and conglomerate. Weathered surfaces characterized by black lichen growth. Forms resistant ledges and steep slopes of coarse, blocky talus. Thickness may vary across map area, but about 800 m was reported east of Etivluk River by Mull and Werdon (1994); distinctly thicker than equivalent rocks in the Aniuk River facies south and west of the Howard Hills thrust (Mull and Werdon, 1994)

Dn **Noatak Sandstone (Upper Devonian)—**Light-gray to tan, fine- to medium-grained, thick-bedded sandstone containing abundant siltstone and shale interbeds; sandstone is typically cross-bedded. Contains abundant limonitic spots and scattered to abundant detrital muscovite. Contains Late Devonian–Early Mississippian brachiopods in the Misheguk Mountain part of the map area (Mayfield and others, 1984, table 2, loc. 48) and Late Devonian brachiopods to the southwest in the Baird Mountains quadrangle (Karl and others, 1989). Thickness of 500 m or more reported east of Nigu River by Mull and Werdon (l994); distinctly thicker than equivalent rocks in the Aniuk River facies south and west of the Howard Hills thrust (Mull and Werdon, 1994)

**Aniuk River facies**

Mi **Isikut unit of Mull and Werdon (1994) (Lower Mississippian)**—Reddish-tan to grayish-green, tan- to reddish-brown-weathering, thin- bedded to platy siltstone and phyllitic shale; bioturbation and flaser structure common. Locally contains quartzitic sandstone interbeds at the base and thin, sandy limestone interbeds higher in the section. Includes interbeds typical of the Kayak Shale in places. Contains Kinderhookian (locally late Kinderhookian; early Early Mississippian) conodonts and brachiopods (Mull, Harris, and Carter, 1997) (table 4, locs. 101, 106, 155, 156). Minimum thickness about 200 m. Pervasively folded and typically displays prominent axial-plane cleavage

MDka **Kanayut Conglomerate (Lower Mississippian? and Upper Devonian)—** Gray to brown, gray-weathering, fine- to coarse-grained, quartzitic sandstone, and minor quartz- and chert-pebble conglomerate; commonly has gray to black mudstone, shale, and phyllitic shale partings and interbeds as much as a few meters thick. Forms coarse, blocky talus having weathered surfaces characterized by black lichen growth. Interfingers downward with Noatak Sandstone. Southeast of the map area (Howard Pass A–2 quadrangle), contains plant axes (lycopod trunks) of probable Mississippian age (S.H. Mamay, unpub. USGS fossil data, 1976). Thicknesses of about 183 m and 112 m measured at Isikut Mountain and along Aniuk River, respectively (T.E. Moore, written commun., 1994); distinctly thinner than equivalent rocks in the Key Creek facies north and east of the Howard Hills thrust (C.G. Mull, written commun., 1995)

Dna **Noatak Sandstone (Upper Devonian)—**Light-gray to tan, fine- to medium-grained, thick-bedded sandstone with abundant siltstone and shale interbeds; sandstone typically cross-bedded and ripple marked. Contains abundant limonitic spots; commonly has scattered to abundant detrital muscovite. In the Key Creek facies this unit contains Late Devonian–Early Mississippian brachiopods. Thicknesses of 138 and 215 m measured at Isikut Mountain and along Aniuk River, respectively (T.E. Moore, written commun., 1994); distinctly thinner than equivalent rocks in the Key Creek facies north and east of the Howard Hills thrust (Mull and Werdon, 1994)

## PICNIC CREEK SEQUENCE
## (LOWER CRETACEOUS TO MISSISSIPPIAN )

KMp **Rocks of the Picnic Creek sequence, undivided (Lower Cretaceous (Neocomian) to Mississippian)—**Mapped tentatively in areas of limited or isolated exposure not examined in the field or identifiable by photo interpretation; unit assignment based on structural position of general sequence inferred from geologic relations mapped in surrounding areas

Kop **Okpikruak Formation (Lower Cretaceous (Valanginian))—**Dark-gray to grayish-tan mudstone, siltstone, and graywacke sandstone. Contains isolated pelecypods (*Buchia* spp.) of early and middle to late Valanginian ages in the map area (table 5, locs. 162 and 184) and in the De Long Mountains quadrangle to the west (Elder and others, 1989). Intensely deformed and base structurally detached in many places. Thickness unknown

JIPip **Imnaitchiak Chert of Etivluk Group (Jurassic to Pennsylvanian)—**Gray to greenish-gray bedded chert or siliceous mudstone in beds 2–15 cm thick, intercalated with greenish-gray to distinctive maroon, siliceous, silty mudstone partings and interbeds. In Picnic Creek sequence, distinguish-able from Imnaitchiak Chert of Ipnavik River sequence only by stratigraphic association with underlying Akmalik Chert. Contains mainly Pennsylvanian to Late Triassic radiolarians (Mull and others, 1987); but a few samples yielded Early Jurassic radiolarians in the map area (table 2, loc. 80) and to the east (Mull, Glenn, and Adams, 1997). Unit typically structurally contorted; thickness probably 75 m or less. Radiolarian collections from this unit (table 2, locs. 6, 10, 11, 25, 26, 34, 36, 39, 45, 53, 78–80, 85, 94, 95, 102, 135, 136, 159; table 4, loc. 100; and Mayfield and others, 1984, table 2, locs. 9, 10, 15) include ages of Permian (possibly middle and Late Permian), Middle and Late Triassic (probably Ladinian, Carnian, and early to middle and middle to late Norian), and Early Jurassic (Hettangian or Sinemurian)

IPMap **Akmalik Chert of Lisburne Group (Pennsylvanian and Mississippian)—**Black bedded chert in beds as much as 10 cm thick, with thin, black siliceous shale partings; locally contains barite deposits (b) in Cutaway Basin window (Kelley and others, 1993) and rare interbeds of calcareous radiolarite. Chert contains abundant radiolarians and lesser sponge spicules. In the Howard Pass C–5 quadrangle (table 1, locs. 7, 10), unit includes abundant interbeds 2–7 cm thick of brownish-black dolostone; these beds are probable turbidites made up of graded skeletal packstone rich in echinoderm debris. Locally includes subordinate red and green chert (table 2, loc. 84). Radiolarians are chiefly Late Mississippian but locally may be as old as late Early Mississippian (Osagean) and are as young as Early or Middle Pennsylvanian (Morrowan or Atokan) (table 2, locs. 4, 8, 9, 12, 20, 25, 28, 57, 76, 77, 84, 102, 128, 129; table 4, locs. 48 and 160; Mayfield and others, 1984, locs. 11, 12, and 16); the youngest ages come from beds lithologically gradational into the overlying Imnaitchiak Chert. Within the map area conodonts are Osagean (late Early Mississippian) and Meramecian (probably middle Meramecian; early Late Mississippian) (Dumoulin and others, 1993) (table 1, locs. 7, 10; table 4, locs. 30, 32, 40, 48). Osagean conodonts and radiolarians of middle Osagean to probably late Meramecian age are reported from the type section of the Akmalik to the east (Blome and others, 1998). These rocks formed in a deep-water, basinal setting. Type section 70 m thick, but in the map area unit generally is a few tens of meters thick at most. Dolostone-rich sections are as much as 100 m thick.

## KELLY RIVER SEQUENCE
## (CRETACEOUS TO DEVONIAN)

Kok **Okpikruak Formation (Lower Cretaceous (Valanginian and Berriasian))—**Dark-gray to grayish-tan mudstone, siltstone, graywacke sandstone, and local conglomerate; contains rare pelecypods (various species of *Buchia*) of Berriasian and early and late Valanginian age in the western Misheguk Mountain quadrangle (Elder and others, 1989; Curtis and others, 1984). Intensely deformed and base structurally detached in places. Thickness unknown. Mapped only in one locality within a small structural window in the south-central part of the Misheguk Mountain C–1 quadrangle

**Lisburne Group (Mississippian)**

Mko **Kogruk Formation—**Light-gray-weathering limestone containing black chert nodules and lenses. Common fossils are Late Mississippian corals, crinoids, brachiopods, and foraminifers. To the west in the Misheguk Mountain and De Long Mountains quadrangles, unit contains conodonts and foraminifers of chiefly Meramecian (early Late Mississippian) age; in the Baird Mountains and Noatak quadrangles, the base of the unit may be as old as late Osagean (late Early Mississip-pian) (Dumoulin and Harris, 1992). Thickness variable and base gradational with underlying Utukok Formation in Misheguk Mountain quadrangle (Mayfield and others, 1984)

Mu **Utukok Formation—**Buff-weathering limestone and locally calcareous, fine-grained sandstone. Contains brachiopods, crinoids, and corals. In the map area the unit has produced conodonts of early Early Mississippian (middle to early late Kinderhookian) age (table 4, loc. 14; Dumoulin and Harris, 1997; see also table 1, loc. 35) as well as Early Mississippian brachiopods (Mayfield and others, 1984; table 2, loc. 39). Conodonts of Kinderhookian and Osagean age occur to the west and southwest; top of unit probably middle Osagean in the Baird Mountains quadrangle but late Osagean in the De Long Mountains quadrangle (Dumoulin and Harris, 1992; A.G. Harris, written commun., 1999). May represent a thin, discontinuous tongue below the Kogruk Formation, and may not have been deposited in some places within this sequence. Depositional thickness probably ranges from 0 to 80 m (Mayfield and others, 1984; Dumoulin and Harris, 1997). Base is probably gradational into Devonian limestone

Dlk **Limestone (Devonian)—**Light-gray limestone and dark-gray dolostone. Common fossils in and just west of the map area are Middle and Late Devonian brachiopods, stromatoporoids, and corals (Mayfield and others, 1984; table 2, locs. 37, 43, 45, 52). Thickness is less than 700 m in outcrops to the west. Occurs depositionally beneath the Utukok Formation in the Misheguk Mountain quadrangle (Mayfield and others, 1984). Called Baird Group by previous workers (for example, Mayfield and others, 1984, 1988) but differs from Baird Group in its type area in the Baird Mountains quadrangle in age, metamorphic grade, and stratigraphic and structural position. Type Baird Group is chiefly or entirely older (Ordovician to early Middle Devonian; mostly Early Devonian and older), metamorphosed (conodont CAI values greater than or equal to 5), grades upward into Devonian and Mississippian siliciclastic rocks (Endicott Group), and is nowhere contiguous with unit Dlk. Because depositional continuity of these rocks with type Baird Group has not been established, we here exclude them from that unit

## IPNAVIK RIVER SEQUENCE
## (CRETACEOUS TO MISSISSIPPIAN)

KMi **Rocks of the Ipnavik River sequence, undivided (Cretaceous to Mississippian)—** Mapped tentatively in areas of limited or isolated exposure not examined in the field or identifiable by photo interpretation; unit assignment based on structural position of general sequence inferred from geologic relations mapped in surrounding areas

Koi **Okpikruak Formation (Lower Cretaceous (Valanginian and Berriasian))—**Dark-gray to grayish-tan mudstone, siltstone, graywacke sandstone, and local conglomerate containing cobbles and boulders of gabbro, fine-grained mafic igneous rocks, light-gray diorite or granodiorite, light-gray micritic limestone, and gray to black chert. Contains various species of the pelecypod *Buchia* of Berriasian and middle and late Valanginian age in and just west of the map area (table 5, locs. 170–172, 178, 179, 181; Mayfield and others, 1984, table 2, loc. 54), in the eastern Howard Pass quadrangle, and in the central and western Misheguk Mountain quadrangle. Intensely deformed and base structurally detached in places. Thickness unknown

Kot **Tuff (Cretaceous)—**Light-gray-weathering tuffaceous beds of clay, plagioclase and quartz; occurs as thin, discontinuous beds 4 m or less thick within the Okpikruak Formation. Mapped by Mayfield and others (1984) only in several small layers in the southwest corner of the map area; thickness exaggerated on map

JMmi **Mafic sills and dikes (Jurassic? to Mississippian?)—**Typically dark- greenish-gray, mostly diabasic to gabbroic sills and dikes; composed mainly of plagioclase and augite. Abundant and locally voluminous within the Lower Mississippian Rim Butte unit of the Lisburne Group of Dumoulin and others (1993), and locally intrude rocks of the Etivluk Group. Comprises a characteristic component of the Ipnavik thrust sequence, but similar mafic rocks locally intrude rocks of the Etivluk Group in the Picnic Creek and Endicott thrust sequences. Generally altered; age uncertain, but permissible age range based on intrusive relations with rocks of the Lisburne and Etivluk Groups

JIPii **Imnaitchiak Chert of Etivluk Group (Jurassic to Pennsylvanian)—**Gray to greenish-gray bedded chert or siliceous mudstone in beds 2–15 cm thick, with greenish-gray to distinctive maroon, siliceous, silty mudstone partings and interbeds. Distinguishable from Imnaitchiak Chert of Picnic Creek sequence only by stratigraphic association here in the Ipnavik sequence with underlying Rim Butte unit of the Lisburne Group of Dumoulin and others (1993). Contains mainly Pennsylvanian to Late Triassic radiolarians (Mull and others, 1987), but a few samples contain Jurassic radiolarians (C.D. Blome, written commun., 1994); ages obtained in the map area include middle Permian (probably Guadalupian), Late Triassic (Norian), and Early Jurassic (probably Pliensbachian or Toarcian) (table 2, locs. 46, 63, 81–83, 90, 93, 189; table 4, loc. 158; and Mayfield and others, 1984, table 2 locs. 7, 18, 19, 27, 30). The unit has also produced Early Triassic conodonts (Mayfield and others, 1984, table 2, loc. 30) and a Late Triassic (Norian) monotid bivalve (table 5, loc. 180). Typically is intensely deformed; commonly occurs as rubble. Thickness probably 75 m or less

Mlri **Rim Butte unit of Lisburne Group of Dumoulin and others (1993) (Mississippian)—** Generally thin-bedded and distinctively color-banded succession composed of lighter layers of limestone turbidite, interbedded with darker layers of siliceous, spiculitic mudstone like that in the Kuna Formation and lesser chert. Limestone, in beds 3–80 cm thick, makes up 15–70 percent of sections studied. Chert interbedded with limestone is mostly gray but locally red or green. Turbidites are mostly complete or incomplete Bouma sequences with the base missing, composed of abundant reworked and redeposited bioclasts (derived from shallow- and deep-water settings), sedimentary lithic clasts, and as much as 15 percent detrital quartz. Redeposited conodonts are mainly of late Kinderhookian age but include forms as old as Famennian (Late Devonian) and as young as Osagean. Much of unit appears to have a depositional age of early middle Osagean (lower part of *S. anchoralis–D. latus* Zone) but at least one section is no older than late Meramecian (Dumoulin and others, 1993), and the base of another section may be as old as early Early Mississippian (Kinderhookian) (table 1, locs. 2, 3, 24, 27, 29, 44, 52, 56, 59, 60, 64, 75, 89, 91, 92; table 4, locs. 29, 47, 49–51, 54, 55, 105). Early Mississippian ammonoid cephalopods from one locality were reported (table 5, loc. 163). Radiolarians from bedded chert in the uppermost part of the unit are Mississippian (Osagean to Meramecian and Meramecian to Chesterian; table 2, loc. 1), and locally as young as late Meramecian(?)–Morrowan (Mayfield and others, 1984, table 2, loc. 28; Murchey and others, 1988, p. 705). At least 70–85 m thick in the map area. Base of unit generally faulted or not exposed; at two localities (in the Howard Pass C–5 and C–2 quadrangles), appears to overlie shale, siltstone, and quartz pebble conglomerate that contains late Late Devonian (upper Famennian) spores (table 5, loc. 161). Gradational upper contact with gray chert of the Etivluk Group observed locally

Mki **Kayak Shale of Endicott Group (Lower Mississippian)—**Dark-gray to black fissile clay shale containing subordinate but conspicuous yellowish-brown-weathering, thin, fossiliferous limestone interbeds near the top, and greenish-gray siltstone and sandy siltstone in the lower part. Mayfield and others (1984; table 2, loc. 31) reported a single conodont collection of latest Devonian–Early Mississippian (late Famennian–middle Osagean) age from this unit. Minimum thickness 45 m; typically complexly folded and pervasively sheared, especially near the structural base, where phyllitic textures and detachment from underlying rocks are common

SEQUENCE AFFINITY UNCERTAIN

Dl **Limestone (Devonian)—**Limestone and dolostone structurally detached from surrounding rocks; occurs most commonly at the base of the Ipnavik thrust sequence. Uncertain stratigraphic affinity. Most likely limestone detached from the Kelly River sequence and dragged along the base of the overriding Ipnavik River sequence during its tectonic emplacement, but could represent correlative rocks originally deposited under the Rim Butte unit of the Lisburne Group of Dumoulin and others (1993) within the Ipnavik River sequence. Chief rock types are peloidal supportstone, lime mudstone with locally well-developed fenestral fabric, and skeletal grainstone and packstone; megafossils are locally abundant and include brachiopods, corals, pelmatozoans, and stromatoporoids. Megafossils (table 3, locs. 23, 73, 74, 86, 87) and conodonts (table 1, locs. 23, 73, 74, 87, 88), where most tightly dated, are of Middle and early Late Devonian age. Sections are generally fault-bounded and less than 130 m thick

NUKA RIDGE SEQUENCE
(CRETACEOUS TO MISSISSIPPIAN)

KMn **Rocks of the Nuka Ridge sequence, undivided (Cretaceous to Mississippian)—**Mapped tentatively in areas of limited or isolated exposure not examined in the field or identifiable by photo interpretation; unit assignment based on structural position of general sequence inferred from geologic relations mapped in surrounding areas

Kon **Okpikruak Formation (Lower Cretaceous (Valanginian))—**Gray mudstone and minor greenish-gray, medium- to fine-grained lithic wacke, containing distinctive cannon-ball concretions in the Nuka Ridge area (Mayfield and others, 1984); intensely deformed and base structurally detached in places. Contains isolated specimens of the pelecypod *Buchia crassicollis solida* (middle to late Valanginian) in the map area (table 5, loc. 169). Thickness unknown

Jℙen **Etivluk Group (Middle Jurassic to Pennsylvanian)—**Assemblage of variegated but mostly black, gray, or greenish-gray bedded chert containing partings and subordinate interbeds of shale and siliceous shale. Typically is nintensely tectonically disrupted. Radiolarians, foraminifers, and conodonts of Carboniferous-Permian age from this unit were reported (Mayfield and others, 1984; table 2, locs. 56–58)

ℙMn **Nuka Formation (Pennsylvanian and Mississippian)—**Light-gray- to buff-weathering, coarse- to medium-grained arkose, arkosic limestone, and limestone. Contains locally abundant glauconite and rare hematite-cemented beds. Arkose consists of quartz with potassium and plagioclase feldspars apparently derived from a southern source. The upper part of the Nuka was previously dated by brachiopods identified as Permian (Tailleur and others, 1973), but more recent collections of conodonts from the top of the structurally highest beds at Nuka Ridge are no younger than Early Pennsylvanian (A.G. Harris, written communication, 1982, cited in Mayfield and others, 1984). Late Mississippian–Early Pennsylvanian conodonts and foraminifers occur in the map area (Mayfield and others, 1984; table 2, locs. 55–58) and throughout the western Brooks Range. Depositional thickness is estimated to range from a few meters to 300 m. Base is gradational into Kayak Shale

Mkn **Kayak Shale of Endicott Group (Lower Mississippian)—**Dark-gray shale, interbedded with orange-weathering limestone, siltstone, and minor fine-grained sandstone. Contains Mississippian foraminifers and brachiopods. Maximum stratigraphic thickness estimated by Mayfield and others (1984) to be 350 m. Basal contact is a thrust fault, along which the unit is cut out completely in many places

COPTER PEAK SEQUENCE
(CRETACEOUS? TO DEVONIAN)

KJmv **Volcaniclastic rocks of Memorial Creek (Cretaceous? and Jurassic?)—** Predominantly volcaniclastic rocks and subordinate associated mafic to intermediate volcanic rocks, mapped only in the Memorial Creek area along the east-central edge of the map area. Unit has some lithologic similarities to the Okpikruak Formation in other thrust sequences and a similar degree of induration. Contains Early(?) Jurassic (Sinemurian? or Pliensbachian?) radiolarians at one locality (table 2, loc. 134)

JDbc **Basalt (Jurassic? to Devonian?)—**Greenish-gray, vesicular, and amygdaloidal, locally pillowed basalt; also contains minor volcanic breccia, tuff, and volcaniclastic rocks, as well as lenses or interpillow intercalations of radiolarian chert and fossiliferous limestone. In Memorial Creek area, chert contains Middle and Late Triassic, Permian(?), and pre-Permian (Mississippian?) radiolarians (table 2, locs. 137–139, 141), and limestone contains early Early Mississippian (Kinderhookian) conodonts (table 4, loc. 140). At Siniktanneyak Mountain, limestone and volcaniclastic rocks contain Permian brachiopods (table 3, loc. 103; table 4, loc. 97); other limestone pods yielded megafossils and conodonts of chiefly early Late Devonian (Frasnian, locally middle Frasnian) age (table 1, locs. 111,112; table 4, locs. 111–114; table 5, loc 186; Nelson and Nelson, 1982). Chert (locally interpillow?) on the east and west sides of Siniktanneyak contains Triassic and Early(?) Jurassic radiolarians (table 2, locs. 96, 104, 108–

110). Assignment of the Siniktanneyak and Memorial Creek basalt exposures to one long-lived unit is tentative and based on similarities in petrologic character and structural occurrence, and because the age distribution of the unit is poorly known in both areas

PDlc **Limestone (Permian and Devonian)—**Mapped mainly west and northwest of Siniktanneyak Mountain. Brownish- to light-gray, fine-grained limestone, correlative with small limestone lenses included in unit JDbc. One occurrence contains numerous prisms apparently derived from shells of the Permian bivalve *Atomodesma* sp. (table 3, loc. 98); the other yields early Late Devonian (Frasnian) conodonts (table 4, loc. 99)

MISHEGUK SEQUENCE
(MIDDLE? JURASSIC)

Jsu **Igneous complex of Siniktanneyak Mountain, undivided (Middle? Jurassic)—**Predominantly mafic and ultramafic rocks considered by most workers to represent an essentially complete ophiolite sequence; grades upward from tectonized and serpentinized mantle peridotite, dunite, harzburgite, and lherzolite at the base, through a crustal sequence of cumulate ultramafic rocks and layered gabbro, massive gabbro, high-level felsic igneous differentiates, and sheeted diabase dikes, and capped by basalt and minor silicic tuffs (Nelson and Nelson, 1982; Bickerstaff, 1994). The mantle sequence has petrologic, geochemical, and geophysical characteristics of the upper part of oceanic mantle; a Middle Jurassic U-Pb age of 170±3 Ma was reported by Moore and others (1993). Crustal rocks have petrochemical signature transitional between MORB and an island-arc setting. Bickerstaff (1994) suggested a cogenetic tholeiitic origin within an active intra-arc basin for the igneous complex of Siniktanneyak Mountain.

Six map units, listed from high-level to deep-level intrusive settings, are distinguished in places:

Jsb **Basalt—**Predominantly brown to greenish, vesicular and amygdaloidal basalt containing broken pillow breccia in places; bedded silicic tuff containing soft-sediment deformation features found at one locality

Jsf **Felsic intrusive rocks—**Typically ranges from diorite to hornblende-plagiogranite in composition; alaskite dikes also common. Formed above, and by differentiation from, massive gabbro (unit Jsg). Locally intruded by late-stage diabase dikes. Nearly 2 km thick in places

Jsd **Diabase—**Occurs as localized swarms of subparallel dikes as much as 2 m thick and having chilled margins; two distinct generations of dikes reported by S.W. Nelson (written commun., 1994)

Jsg **Massive gabbro—**Predominantly grayish-weathering, medium- to coarse-grained, hypersthene-bearing hornblende-pyroxene-gabbro having generally directionless texture but well-developed mineral banding in places. Grades downward into layered gabbro (unit Jslg)

Jslg **Layered gabbro—**Predominantly gray-green cumulate gabbro that includes interlayered ultramafic rocks in the lower part; banding typically expressed by melanocratic and leucocratic layers. As much as 4 km thick

Jsdh **Dunite and harzburgite—**Orange-weathering dunite predominates, but harzburgite common in places; also includes lesser amounts of lherzolite, serpentinized peridotite, and olivine pyroxenite; most lithologies typically tectonized and foliated, especially near the structural base of the complex

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## BIOSTRATIGRAPHIC DATA FROM THE WEST-CENTRAL PART OF THE HOWARD PASS QUADRANGLE

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Numerous biostratigraphic collections, mainly conodonts and radiolarians, were made during the 1990's to support geologic mapping in the west-central Howard Pass quadrangle. These collections tightly constrain ages of many of the map units, and they provide additional data on topics ranging from depositional environments to thermal history and tectonic disruption of the rocks in this area. This section presents previously unpublished biostratigraphic data from 128 localities and summarizes previously published data from an additional 61 localities.

### DATA SOURCES

Most of the fossil specimens tabulated herein were collected, examined, and identified (chiefly by paleontologists of the U.S. Geological Survey) during the past 20 years; these data are presented in tables 1–4. Data not previously published appear in tables 1 (conodonts), 2 (radiolarians), and 3 (megafossils); previously published data—chiefly conodonts but also some radiolarian and megafossil data—are summarized in table 4. Data in these tables are mostly limited to collections made and identified since 1978, and published since 1982. Primary published sources are Nelson and Nelson (1982), Murchey and others (1988), Dumoulin and others (1993, 1994), Kelley and others (1993), Baxter and Blodgett (1994), Dumoulin and Harris (1997), and Mull and others (1997). Mayfield and others (1984; table 2) summarized paleontologic data from the eastern Misheguk Mountain quadrangle; these data are referred to where appropriate under unit descriptions for the geologic map but are not reprinted below.

About 100 fossil collections (chiefly megafossils) were made during previous mapping efforts in the west-central Howard Pass quadrangle, mainly during the 1950's. The sites of many of these older collections can be only approximately located on modern topographic maps, and the rock units sampled by some collections are uncertain. Table 5 presents the most useful of these early collections that could be accurately located by using original field station maps; most of the fossils were identified by paleontologists of the U.S. Geological Survey during the 1950's and have not been re-examined since that time. About half of the collections have never been previously published. Sixteen collections are Mesozoic pelecypods that were included in a regional data base compiled by Elder and others (1989); these authors did not re-examine the collections to verify the original identifications.

Fossil data from the west-central Howard Pass quadrangle published prior to 1982 are limited. Several Mississippian cephalopod collections were described by Gordon (1957), a few Mississippian coral collections were listed by Armstrong (1970, 1975), several localities yielding fragments of Triassic vertebrate fossils were mentioned by Tailleur and others (1973), and a single Jurassic pelecypod collection was described by Imlay and Detterman (1973). Where original collection localities could be verified, data from these publications are included in table 5.

All tables presenting previously unpublished fossil data (tables 1–3, 5) include lithologic descriptions of the rocks that contained the fossils if these data were available. Petrographic descriptions based on thin section examinations of the sampled lithologies (by J.A. Dumoulin) are also provided for most of the conodont and a few of the radiolarian collections (tables 1, 2). Table 1 also includes weights of most of the samples processed for conodonts and any unusual features noted in the heavy mineral residues. Localities of virtually all fossil collections presented here were verified using original field maps and notes of the geologists that collected them; the verified points were then digitized and latitudes and longitudes of the locations were generated. In some cases, previously published latitudes and longitudes and (or) map locations were incorrect; corrected locations are noted by an asterisk in tables 4 and 5.

## IMPLICATIONS OF DATA

It is beyond the scope of this text to discuss all the implications of the fossil data contained in these tables, but a few key findings concerning depositional environments, biogeography, and thermal and tectonic history are summarized here. Conodonts and radiolarians in particular provide information on depositional environments of the rocks in which they occur. Conodonts in the Howard Pass quadrangle have been found chiefly in carbonate rocks of Devonian and Mississippian age. Biofacies of Devonian conodonts indicate shallow-water carbonate platform settings, but Mississippian biofacies reflect a wide range of depositional environments. These include high-energy shallow marine (Isikut unit), carbonate platform (Bupto facies, Rough Mountain Creek unit), and deep-water slope and basin (Kuna Formation, Akmalik Chert, Rim Butte unit) (Dumoulin and others, 1993, 1994; Dumoulin and Harris, 1997; Mull and others, 1997) and imply a complex paleogeography for this area during Mississippian time. In the west-central Howard Pass quadrangle, Mississippian shallow-water carbonate build-ups are short-lived (Rough Mountain Creek unit) and (or) areally restricted (Bupto facies) and occur only locally within the Endicott sequence. Coeval neritic carbonate rocks are much more abundant west of the map area, in the Kelly River sequence, and to the east, in the Endicott sequence.

Mississippian through Jurassic rocks in the Picnic Creek and Ipnavik River sequences consist mainly of chert and siliceous mudstone, but tightly-dated radiolarian faunas recovered from these rocks represent relatively restricted time intervals. Faunas are mainly of Late Mississippian, middle Permian, and Middle and Late Triassic ages; the oldest faunas are late Early–early Late Mississippian (Osagean-Meramecian; table 2, locs. 1, 9, 28; table 4, loc. 160) and the youngest are late Early Jurassic (Pliensbachian or Toarcian; table 2, locs. 81, 82). Radiolarian distribution throughout the Brooks Range (for example, Murchey and others, 1988) shows similar patterns and may have had both global (oceanographic) and local (tectonic and paleogeographic) controls. Radiolarian-rich strata in Paleozoic and Mesozoic oceans formed beneath high-productivity zones with little siliciclastic dilution (Murchey and others, 1988). Thus, intervals not represented by radiolarian faunas in the map area (middle Pennsylvanian–early Early Permian; Early Triassic) could reflect times of increased siliciclastic input due to uplift and erosion of adjacent landmasses and (or) reduced nutrient availability caused by changes in oceanic circulation. Closely spaced biostratigraphic samples through chert-rich sections are needed to address these questions.

Chert sequences throughout the Brooks Range record a pronounced lithologic change during Carboniferous time. Black or dark-gray chert interbedded with pelagic limestone (Akmalik Chert, upper parts of the Kuna Formation and Rim Butte unit) are overlain by medium- or light-gray, green, and locally maroon chert interbedded with noncalcareous mudstone (Siksikpuk Formation, Imnaitchiak Chert). Radiolarian data from the west-central Howard Pass quadrangle support the contention of Murchey and others (1988) that this lithologic change is diachronous and occurs earlier in structurally higher allochthons (sequences). Gray, green, and red chert as old as late Early–early Late Mississippian is found locally in the Picnic Creek and Ipnavik River sequences (for example, table 2, locs. 1, 20, 28, 128), whereas in the Endicott sequence, this lithologic transition generally takes place in rocks no older than latest Mississippian or Early Pennsylvanian (table 2, loc. 115).

Paleozoic fossils elsewhere in Alaska have yielded abundant biogeographic data; for example, lower Paleozoic strata from the southern Brooks Range contain microfossils and megafossils characteristic of both Siberian and Laurentian (North American) biotic provinces (Blodgett, 1998; Dumoulin and others, 2002). The Howard Pass fossils documented here yield only limited data of this type. Deep-water faunas, and most conodont faunas of Devonian and Carboniferous age, are relatively cosmopolitan. Megafossils from the map area do provide some evidence of the “mixed” biogeographic affinities seen in southern Brooks Range faunas. Middle Devonian brachiopods (table 3, loc. 74) have Siberian affinities (Baxter and Blodgett, 1994), but Early Devonian (Pragian?) corals (table 3, loc. 23) are known elsewhere only from cratonal North America (Road River Formation, Yukon Territory; W.A. Oliver, written commun., 1993). Mississippian plants found in chert and sandstone of the Kelly River and Picnic Creek sequences east and west of the map area have Angaran (Siberian) affinities (Spicer and Thomas, 1987).

Biogeography of Mesozoic fossils from the map area has been little studied, but some forms do provide useful data. Late Triassic bivalves (various species of *Monotis*) found in the Howard Pass quadrangle and in coeval strata throughout the Brooks Range represent middle, possibly high-middle, northern paleolatitudes (Silberling and others, 1997). Jurassic ammonites (Pliensbachian and younger) found west of the map area and in the northeastern Brooks Range belong mostly to the Boreal realm (Imlay and Detterman, 1973).

Conodonts provide data on thermal history of the rocks that contain them (Epstein and others, 1977). Values of conodont color alteration indices (CAI) for Devonian and Carboniferous strata in the west-central Howard Pass quadrangle range from 1 to 4, and have a bimodal distribution; about half of the ≈100 values determined fall in the range 1–2, and the other half have values of 3–4. Howard Pass CAI values include some of the lowest reported for Paleozoic strata in the western and central Brooks Range; Paleozoic CAI values < 2 are rare west of the eastern Misheguk Mountain quadrangle and east of the western Killik River quadrangle. A CAI value of 1 indicates a temperature range of <50–80° C; a CAI value of 4 indicates a range of 190–250° C (the temperature ranges for CAI values were determined from the Ahrrenius plot of the experimental data of Epstein and others, 1977). CAI temperature values can be converted to equivalent burial depths for a given vertical geothermal gradient; for example, in the Appalachian basin, overburden of <1,220 m produced CAI values of 1 in Ordovician rocks whereas overburden of 5,490–7,930 m produced CAI values of 4 (Harris and others, 1987). Total stratigraphic thickness of the Pennsylvanian through Lower Cretaceous section overlying Mississippian strata in the Howard Pass area has been estimated as generally less than 1,500 m, although locally (in the Ipnavik River sequence) thicknesses as great as 3,200 m may have been reached (Mayfield and others, 1988).

Harris and others (1987) interpreted CAI values for the western parts of the Misheguk Mountain and Baird Mountains quadrangles as related to tectonic burial and not to prethrust burial metamorphism, because CAI values for coeval rocks in these areas increase downward through the stack of thrust sheets. CAI data from the Howard Pass quadrangle appear to show no such pattern; conodont CAI values for Mississippian rocks are not generally higher in lower thrust sheets. Both low (1–1.5) and high (3–4) values have been determined for conodonts from thrust sheets interpreted by Mayfield and others (1988) as representing low and high structural levels. For example, conodonts from the Kuna Formation (Endicott sequence; presumed low structural level) have CAI values of 1.5–2 at locality 21 (table 1) but CAI values of ≈3 at locality 146 (table 1). Conodont CAI values for the Rim Butte unit (Ipnavik River sequence, high structural level) range from 1 (table 1, loc. 27) to 3–4 (table 4, loc. 50). Conodont CAI values for the map area do appear to reflect a rough geographic gradient; values for a given unit in the same sequence are generally higher in the south and lower to the north-northwest. Igneous activity may have produced anomalously high CAI values locally (for example, Rim Butte unit samples near mafic sills, table 4, loc. 47; limestone intercalated with basalt in the Copter Peak sequence, table 4, loc. 112) and may indicate regional increases in the geothermal gradient during certain time intervals.

Paleontologic data from the west-central Howard Pass quadrangle also bears on the tectonic history of this area. For example, Mississippian conodonts from the Ipnavik River sequence support the hypothesis of large-scale transport of thrust sheets. The Rim Butte unit represents a large volume of carbonate turbidites of middle Osagean age that also contain redeposited Kinderhookian and Famennian conodonts; conodonts of all three ages are (at least in part) derived from a shallow-water setting. But there are few shallow-water rocks of appropriate age presently exposed in the map area that could have been a source for these abundant turbidites. The Kelly River sequence, however, widely exposed west of the Howard Pass quadrangle, contains strata of suitable age, biofacies, and lithofacies to produce the Rim Butte turbidites (Dumoulin and others, 1993). Because the easternmost exposures of the Rim Butte unit in the map area are at least 75 km east of the easternmost exposures of the Kelly River sequence, this interpretation of the provenance of the Rim Butte unit supports the idea of significant (and at least partly east-directed) thrust sheet movement.

Mesozoic bivalves also have implications for tectonic reconstruction of rocks in the Howard Pass area. *Buchia* species—widely distributed in Upper Jurassic and Lower Cretaceous strata throughout the northern Brooks Range—are useful stratigraphic markers in rocks of late Oxfordian through late Valanginian age (Imlay, 1955, 1961). *Buchia* species of Late Jurassic, Berriasian, and early and middle to late Valanginian ages have been found in the Okpikruak Formation in the west-central Howard Pass quadrangle (table 5, locs. 162, 167–172, 178, 179, 181–185, 188) and in the Misheguk Mountain and De Long Mountains quadrangles to the west

(Elder and others, 1989). A preliminary comparison of *Buchia* species distribution (Elder and others, 1989) in the Okpikruak Formation of various thrust sheets in these quadrangles (Curtis and others, 1984; Ellersieck and others, 1984, 1990; Mayfield and others, 1984; 1990) suggests some interesting patterns. *Buchia* species of Berriasian and Valanginian age occur in thrust sheets of the Endicott Mountains, Kelly River, and Ipnavik River sequences; only Valanginian species are reported in samples from the Picnic Creek and Nuka Ridge sequences. Pelecypods that may be as old as Jurassic are reported from thrust sheets of the Endicott sequence in the Howard Pass quadrangle (table 5, loc. 188; Imlay and Detterman, 1973; Elder and others, 1989), and also from thrust sheets of uncertain structural position to the west (for example, Mayfield and others,1990, table 3, loc. 5). Within thrust sheets of the same sequence, however, younger species of *Buchia* generally occur to the north and east.

Mayfield and others (1988, p. 166) stated that the lowermost part of the Okpikruak Formation appears to be older in structurally higher thrust sheets and younger in structurally lower sheets. The data outlined above do not support this contention, although it must be noted that stratigraphic position of most of the pelecypod collections we considered was not specified, and species identification (and thus age assignment) of some of the older collections is uncertain. Jones and Grantz (1964) suggested that some *Buchia* specimens previously identified as late Valanginian forms may actually be Berriasian species, and species assignment of some specimens that may be as old as Jurassic is uncertain (for example, table 5, loc. 188). A thorough study of the composition and stratigraphic and structural position of the *Buchia* faunas in the western Brooks Range would be very useful in establishing regional patterns of distribution and age, and more precise timing of deformation.

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# TABLES 1–5