Chapter BR (Basement Rocks)

# PRE-MISSISSIPPIAN ROCKS BENEATH THE ARCTIC COASTAL PLAIN OF THE ARCTIC NATIONAL WILDLIFE REFUGE, ALASKA

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## ABSTRACT

The geologic framework of pre-Mississippian rocks in the 1002 area comprises three east-west-striking and north-dipping structural-lithologic units. The first and structurally lowest unit crops out in the Sadlerochit and Shublik Mountains and extends under the southern 1002 area. Although a north-dipping structural-lilthologic unit, the first unit is composed of south-dipping imbricated blocks of Precambrian to Lower Devonian shelf carbonate that are truncated along an angular unconformity beneath Mississippian and younger rocks. The second structural-lithologic unit, which overlies the first unit under the coastal plain, also unconformably underlies Mississippian and younger rocks under the coastal plain. Seismic reflectors within the second unit are homoclinal and dip to the north. Where penetrated in a drillhole west of the Canning River, rocks of the second unit are similar to the Neroukpuk Schist of Leffingwell (1919) exposed at Lake Peters south of the Sadlerochit Mountains and likely are Early to early Middle Cambrian in age. The third structural-lithologic unit appears to be a clastic wedge that thickens to the north and depositionally overlies the second unit; it is unconformably overlain by younger rocks north of where the second unit underlies these same unconformities. The age and composition of the third unit are uncertain, but comparison with rocks under the central Arctic Coastal Plain and in the northeastern Brooks Range suggest two possible correlations: (1) the third unit could be similar to fill in the Umiat, Ikpikpuk, and Meade basins in which case it would likely be composed of Middle Devonian to Early Mississippian clastic rocks that lie on metamorphosed pre-Mississippian rocks, or (2) the third unit could be similar to pre-Mississippian rocks younger than the Neroukpuk Schist which are characterized by large thickness variations, in particular Cambrian volcaniclastic rocks recognized along the Canada-U.S. border.

The first and third structural-lithologic units may compose a pre-Mississippian antiformal duplex that formed during north-directed thrusting in Early to Middle Devonian time. The first unit consists of south-dipping horse blocks in this duplex. The second unit likely lies above a roof thrust to unit one. The floor thrust of the duplex likely lies in Precambrian argillite present beneath the shelf carbonates of the first unit. Brookian thrusting, which was also north-directed, reoccupied earlier-formed thrust faults in unit one and accentuated an antiformal character of the duplex.



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Whether or not the third unit was involved in the postulated Early to Middle Devonian thrusting is uncertain. Only Brookian thrusting is recognized in the third unit. This thrusting has resulted in structural inversion of depocenters within the third unit and generation of the Aurora and Niguanak domes.

## INTRODUCTION

This chapter outlines the geologic framework of rocks that primarily lie beneath the pre-Mississippian unconformity in the1002 area of ANWR. These rocks are variously referred to as "basement", "pre-Mississippian basement", or "pre-Mississippian rocks" in previous work (Bird and Molenaar, 1987).

The pre-Mississippian, Lower Cretaceous, and basal Tertiary unconformities overlie rocks discussed in this chapter. As successively younger unconformities overstep one another northward across the 1002 area, Lower Mississippian, Lower Cretaceous, and lower Tertiary rocks lie on rocks that originally underlay the pre-Mississippian unconformity. Lower Cretaceous rocks overlie rocks that originally underlay the pre-Mississippian unconformity where rocks of Early Mississippian and younger age wedge out beneath the Lower Cretaceous unconformity and Paleocene rocks overlie rocks that originally underlay the pre-Mississippian unconformity where rocks of Early Cretaceous and younger age wedge out beneath the base of Tertiary unconformity.

The pre-Mississippian unconformity crops out in the northeastern Brooks Range and is present under most of the Arctic Coastal Plain (Fig. BR1). In the northeastern Brooks Range, the unconformity separates rocks of Early Mississippian age that lie in angular discordance on rocks as young as Early Devonian age. The unconformity is evident in the Prudhoe Bay and Lisburne fields where rocks above the unconformity lie in angular discordance on penetratively deformed rocks. But in the Endicott field, Umiat, Ikpikpuk, Meade, and Utukok basins, and the Hanna trough, thick accumulations of Early Mississippian and older rocks are present and angular discordance is absent. Some of these accumulations are as much as 15,000 feet thick and likely include Upper and Middle Devonian rocks. Wedges of Middle and Upper Devonian and Lower Mississippian clastics are present in the eastern, central, and western

Brooks Range (Fig. BR1); the pre-Mississippian unconformity is not prominent if present in these areas.

The Lower Cretaceous unconformity crops out in the Sadlerochit and Shublik Mountains, northeastern Brooks Range (Plate BR1), and east-central Brooks Range and is recognized under the Arctic Coastal Plain. In the Sadlerochit and Shublik Mountains, northeastern Brooks Range, and the east-central Brooks Range, the unconformity shows little discordance between Lower Cretaceous and underlying Mesozoic rocks. Under the coastal plain and where relations between Lower Mississippian rocks and underlying rocks were angular prior to removal of Lower Mississippian rocks by erosion, relations between Lower Cretaceous rocks and rocks that originally underlay the Lower Mississippian rocks are angular. Where the pre-Mississippian unconformity was not angular under the coastal plain and most Lower Mississippian rocks have been removed by erosion, distinguishing clastic rocks that lay below the pre-Mississippian unconformity from erosional remnants of Lower Mississippian clastic rocks that overlay the pre-Mississippian unconformity is problematical in reflection seismic data.

Under the coastal plain, the basal Tertiary unconformity locally brings Paleocene rocks into contact with rocks that underlay the pre-Mississippian unconformity where rocks that lay above the pre-Mississippian and Lower Cretaceous unconformities have been removed by erosion. As with the Lower Cretaceous unconformity, the stratigraphic position of rocks below the basal Tertiary unconformity relative to the pre-Mississippian unconformity is problematical where either the position of the pre-Mississippian unconformity was problematical or erosional remnants of basal Ellesmerian clastic rocks could be present below the basal Tertiary unconformity.

## PREVIOUS WORK

Attempts to deduce the geologic framework of pre-Mississippian rocks in the 1002 area arose from a previous assessment of the oil and gas potential of the 1002 area (U.S. Department of the Interior, 1986). Bird and Molenaar (1987) summarized the stratigraphy of pre-Mississippian rocks that could be present under the 1002 area based on information from the northeastern Brooks Range (Reiser and others, 1980; Dutro and others, 1972; Norris, 1985; Sable, 1977).

From reflection seismic data from the 1002 area, Fisher and Bruns (1987) concluded that the structure of pre-Mississippian rocks is much simpler than in coeval rocks in the northeastern Brooks Range and that there are two domains under the western part of the 1002 area. Their southern domain is composed of rocks that are either horizontal or dip gently south and their northern domain consists of rocks that dip monoclinally north except along the coast where the rocks could retain large-scale sedimentary structures. Kelley and Foland (1987) recognized large anticlines cored by pre-Mississippian rocks under the 1002 area, similar in size and trend to the anticlines exposed in the Sadlerochit and Shublik Mountains. Kelley and Molenaar (1985, 1989) recognized that the Weller and Hue thrusts, faults that dip south and underlie the anticlines in the Sadlerochit and Shublik Mountains (Plate BR1), are influenced by a fabric in pre-Mississippian rocks but were uncertain of the nature of that fabric; they inferred that similar relations could exist under the coastal plain.

Work in the northeastern Brooks Range subsequent to the 1987 assessment (Dolton and others, 1987) influences the interpretations presented here. Kelley and others (1995a) used forward seismic modeling of a cross section in pre-Mississippian rocks to demonstrate that outcrop-scale complexities would not be imaged in reflection seismic data like those collected in the 1002 area; this forward model imaged large shallow-dipping structures, similar to those observed in reflection seismic data from the 1002 area. From this, Kelley and others (1995a) concluded that pre-Mississippian rocks imaged under the coastal plain could be as deformed as those in the mountain belt. Based on meso- and microfabric studies in selected localities, Oldow and others (1987) inferred that a south-directed thrusting event pre-dates the pre-Mississippian unconformity. Lane and others (1991), Kelley and others (1992), Lane and others (1995), and Kelley and others (1995b) conclude that the pre-Mississippian rocks along the Alaska-Yukon border are a succession of Precambrian(?) to Lower Devonian(?) basinal rocks depositionally continuous with rocks elsewhere in the northeastern Brooks Range rather than an assemblage of tectonostratigraphic terranes as implied by Moore and others (1987). Hanks (1993) inferred from mesoscopic structural analysis that at least one north-directed pre-Mississippian folding and thrusting event resulted in most of the mesoscopic penetrative structures recognized in pre-Mississippian rocks. Lane and others (1995) and Kelley and others (1995b) report a large north-transporting thrust fault that juxtaposes contrasting pre-Mississippian lithofacies. This fault cuts Silurian and Lower Devonian(?) rocks and is cut by the pre-Mississippian unconformity and implies that the micro- and mesofabric data reported by Oldow and others (1987) may not reflect the principal transport direction of Late to Middle Devonian thrusting.

Synthesis of these observations and interpretations subsequent to the 1986 assessment provide some basic assumptions for the present work. Forward seismic modeling (Kelley and others, 1995a) implies that rocks similar to the complexly deformed argillite, turbidites, limestone, and chert present in the Franklin Mountains could be present under the coastal plain. Recognition of the lower Paleozoic succession along the US/Canada border (Clarence and Malcolm Rivers area, Plate BR1) (Lane and others, 1991; Kelley and others, 1992; Lane and others, 1995; Kelley and others, 1994; Kelley and others, 1995b) confirms interpretations of regional workers (Reiser and others, 1980; Dutro and others, 1972; Norris, 1985) that rocks in the Franklin Mountains are a stratigraphically complex depositional succession rather than an assemblage of fault-bounded tectonostratigraphic terranes (Moore and others, 1987). Facies transitions between Proterozoic and lower Paleozoic platform carbonate rocks present in the Sadlerochit and Shublik Mountains and the contrasting succession of lower Paleozoic rocks present in the Franklin Mountains reported by Dutro (1970), James Clough (oral comm., 1997), and William Brosgé (oral comm., 1997) imply that similar relations could exist between rocks in the Sadlerochit and Shublik Mountains and rocks under the coastal plain. Recognition of north-directed thrusting during Late to Middle Devonian time (Hanks, 1993; Lane and others, 1995; Kelley and others, 1995b) implies that the Weller and Hue thrusts are Late to Middle Devonian thrusts that were truncated along the pre-Mississippian unconformity and locally reactivated by north-directed Brookian thrusting and that similar features are likely present under the coastal plain.

**PRESENT WORK**

The purpose of this study is to deduce a geologic framework for pre-Mississippian rocks under the 1002 area. This framework is shown in a paleogeologic map that shows the distribution of rocks that lay beneath the pre-Mississippian unconformity as they approximately appeared prior to deposition of Ellesmerian rocks (Fig. BR1); these pre-Mississippian rocks are not restored for



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Cretaceous and Tertiary folding and thrusting. Three sections also show this framework (Figs. BR2, BR3, and BR4). Two of these are north-south and approximately parallel the transport direction during Early to Middle Devonian thrusting and subsequent Cretaceous and Tertiary thrusting (Figs. BR2 and BR4); one these cross sections (Fig. BR4), shows an example of the reflection seismic data (from Kelley and Foland, 1987) used to construct the cross sections and map (Plate BR1). The third profile is east-west (Fig. BR3).

The framework in this study is deduced from seismic reflection profiles, geologic relations in the Sadlerochit, Shublik, and Franklin Mountains, and drillhole data. The top of pre-Mississippian rocks is identified on unmigrated seismic profiles from the 1984 and 1985 data sets; geometric patterns below this surface are mapped. These geometric patterns are then interpreted by comparison to structural and stratigraphic styles for fold and thrust belts and extensional and transtensional basins (Bally, 1983a, b, and c). The resulting framework model is rationalized in terms of geologic relations recognized in outcrops and during previous work. The framework model then is compared to drillhole information described by Dumoulin (Chap. CC) to determine whether or not the framework model is consistent with rocks penetrated adjacent to the 1002 area.

Seismic reflection data used in this work and the lack of drillhole data from the 1002 area impose limitations on age determination of rocks mapped in this chapter. The age of rocks can be problematical where thick clastic wedges are present and clear angularly unconformable relations are not present across the pre-Mississippian unconformity. This difficulty is compounded where the Lower Cretaceous or basal Tertiary unconformities lie on rocks that presumably originally lay beneath the pre-Mississippian unconformity; erosional remnants of Mississippian rocks could be present beneath these unconformities. Hence the term "pre-Mississippian rocks" is expanded to include lowest Mississippian rocks for purposes of this chapter.

Although this report focuses on pre-Mississippian geology, the effect of subsequent history cannot always be clearly distinguished from earlier geologic history. This is especially acute in the eastern part of the 1002 area where structural complexities produce an especially high noise to signal ratio in seismic reflections from pre-Mississippian rocks. Also, intense Brookian deformation overprints earlier-formed structures in pre-Mississippian rocks. For these reasons, units used in this report are projected into the eastern part of the 1002 area based on trends in the western part of the 1002 area and minimal information from the southwestern part of the 1002 area.

The geologic framework of the northwestern part of the 1002 area is unresolved (Plate BR1). Available information does not permit clear and unequivocal assignment of rocks in this area to one of the three units identified in this report.

Rocks in the southwesternmost part of the 1002 area also are unresolved (Plate BR1). The transition between Precambrian and lower Paleozoic shelf carbonate rocks exposed in the Sadlerochit and Shublik Mountains and coeval argillite, sandstone, chert, and volcanic rocks exposed in the Franklin Mountains is not imaged in the seismic data.

Undivided structural/lithologic units are used in this report because of limitations in the resolution of seismic reflection data which are used to map pre-Mississippian rocks. These units are arrays of seimic reflections related to one or more structural or lithologic characteristics; these arrays can be produced by a particular structural style, a particular succession of rocks, or most likely a combination lithologic response to seismic waves and structural style. One unit for example, consists of rocks that are divided into formations, members, and unnamed units in the Sadlerochit and Shublik Mountains. Neither are these lithostratigraphic units well imaged in seismic reflection profiles nor are most of the structures in this unit well imaged; collectively however, these rocks and their structures do have seismic expression that can be tracked from outcrops into the subsurface and is distinct enough to discriminate this structural/lithologic unit from other units recognized under the coastal plain. The age of rocks in structural/lithologic units can be inferred with differing degrees of confidence from superimposition relative to one another, crosscutting relations relative to the pre-Mississippian unconformity, data from drillholes, and correlation.

**Geologic Framework.** The three structural/litologic units underlie the 1002 area and are arranged in three east-west-trending belts (Plate BR1). The first unit makes up the southern belt, the second unit makes up the central belt, and the third unit makes up the northern belt.

**First Unit.** The first structural/lithologic unit consists of the subsurface extension of rocks exposed in the Sadlerochit and Shublik Mountains and underlies the southern part of the 1002 area. It extends from the Canning River to the Aichilik River.

This unit consists of imbricate blocks of mostly carbonate rocks that are exposed in the Sadlerochit and Shublik Mountains. In the Sadlerochit and Shublik Mountains, the carbonates are part of a depositional succession that consists of Precambrian argillite and quartzite, Precambrian pillowed and volcaniclastic greenstone, the Precambrian Katakturuk Dolomite, the Precambrian, Cambrian, and Ordovician Nanook Limestone, and the Lower Devonian Copplestone Limestone in ascending order. This succession is present in south-dipping homoclines that are truncated along the pre-Mississippian unconformity (Plate BR1) and are present in the cores of anticlines that underlie the Sadlerochit and Shublik Mountains. These homoclines are hanging wall blocks of the south-dipping Weller and Hue thrust faults which were also truncated along the pre-Mississippian unconformity but were locally reactivated by Cretaceous and/or Tertiary thrusting; where this has occurred, segments of the Weller and Hue thrusts have been reactivated as south-dipping faults that cut the pre-Mississippian unconformity.

Seismic reflection profiles that terminate in or near bedrock exposures on the north flank of the Sadlerochit Mountains provide the means to track the northward extension of the first unit (Fig. BR4). Eastward extension of this unit is tracked in seismic profiles that cross the eastward extension of the Sadlerochit Mountains under the coastal plain in the southeastern part of the 1002 area.

South-dipping seismic reflections characterize the first unit. Although a few north-dipping reflectors are present in the unit, these reflectors are typically small and subordinate to south-dipping reflectors; they generally represent thrust faults that cut the overlying unconformity with little offset and typically cannot be traced to depth. Most reflectors are inclined in moderate to low angles relative to the overlying unconformity. Some packages of coherent reflectors dip more steeply at depth than near the bounding unconformity suggesting hanging wall cut offs.

Thrust faults similar to the Weller and Hue thrusts, in that they were reoccupied during Brookian thrusting, are recognized in seismic reflection profiles in the western part of the 1002 area and are especially useful in identifying the first unit north of the Sadlerochit Mountains (Plate BR1). Tertiary thrusting obscures pre-Mississippian structures in the eastern part of the 1002 area and makes tracking the first unit east of the Sadlerochit Mountains uncertain. Overall, the direction of dip of reflectors below the pre-Mississippian unconformity west of the Sadlerochit Mountains is south, consistent with dips of reflectors north of the Sadlerochit Mountains.

Rocks of the first unit were penetrated in the Exxon Canning River A-1 drillhole. These rocks consist mostly of dolomite similar to that present in the Katakturuk Dolomite and the lower part of the Nanook Limestone and imply that rocks exposed in the Sadlerochit Mountains extend west of the Sadlerochit Mountains.

**Second Unit.** The second unit extends from the Canning River to the Aichilik River and borders the first unit on the north. In the northwestern part of the 1002 area, the boundary of the second unit is uncertain (Plate BR1). It is composed of metamorphic rocks where penetrated along the western boundary of the 1002 area.

North-dipping reflectors characterize the second unit. In general, reflectors are straight, parallel to one another, and generally without strong contrasts in amplitude. Reflection characteristics within the unit that are not suggestive of sedimentary processes, such as onlaps or downlaps and abrupt termination of reflectors in geometrically regular patterns suggestive of faults are not apparent. Curvilinear reflectors are obscure or not imaged in the especially poor data quality typical of this unit.

Thrust faults that dip north and are upthrown southward are present in the second unit and help to characterize the unit. These faults are only clearly identifiable where they cut and offset the overlying unconformity. They parallel homoclinal reflectors within the second unit that may represent compositional layering that has been selectively broken. This fabric would predate the pre-Mississippian unconformity but, in contrast to the first unit, no clear examples of reactivated thrust faults similar to Weller or Hue thrusts were recognized.



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Rocks that make up the second unit do not crop out but are present in the Leffingwell drillhole. Rocks penetrated in this well are white mica quartz schist, mica schist, schistose sandstone, and semischist. Thin sections from some of these rocks contain equant grains composed of books of white mica. These grains appear in strain shadows within a matrix composed of strongly oriented white mica and finely granulated grains. These larger grains, possibly porphyroclasts of potassium feldspar that survived the granulation that generated the enclosing matrix, are now composed of white mica.

Rocks penetrated in the Leffingwell drillhole are unlike any rocks in the first unit but similar to the Neroukpuk Schist of Leffingwell (1919) as mapped by Reiser and others (1980) and described by Reed (1968). Rocks in the Leffingwell drillhole are more like those described in thin section by Reed (1968) in the Lake Peters area than those along the U.S./Canada border (Reiser and others, 1980; Lane and others, 1995; Kelley and others, 1995b). In the Lake Peters area (Fig. BR1), the Neroukpuk consists of more than 6,000 feet of monotonous, homoclinally dipping turbidites and possible grain-flow deposits (P.J. Phillips and J.S. Kelley, personal observation). Sandstone is composed of mostly quartz, plagioclase feldspar, and muscovite; matrix in these rocks ranges from 10 to 70 per cent of the rock (Reed, 1968, p. 13). Reed (1968, p. 16) reports clots of sericite that could have been clasts of potassium feldspar that were replaced by white mica. Sedimentary rocks in the Lake Peters area have been metamorphosed to greenschist facies and range from sandstone with little evidence of foliation to quartz semischist, phyllite, slate, and metachert. Bedding planes, foliation, and compositional layering are parallel and most of the sedimentary structures such as lamination, ripple cross bedding, dish structures, graded bedding, and flute casts are obscured. The section has an overall monotonous character consistent with the parallel and homoclinal character of reflections in unit 2.

The Neroukpuk Schist of Leffingwell (1919) along the U.S./Canada border (Reiser and others, 1980; Lane and others, 1995; Kelley and others, 1995b) consists of sandstone, argillite, limestone, cherty argillite, and chert. These rocks lack the degree of degree of schistosity clearly evident in the Lake Peters area. Sandstones consist of quartz, plagioclase feldspar, potassium feldspar, white mica, and matrix that makes up as much as 20 per cent of the rock (Kelley and others, 1995b).



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Products of the alteration of potassium feldspar and other framework grains appear to be a major contributor to the matrix in these rocks (Kelley and others, 1995b).

The age of the second unit in the 1002 area is uncertain. Rocks in the Leffingwell drillhole are more similar to the Neroukpuk Schist of Leffingwell (1919) in the Lake Peters area (the type area) than the Neroukpuk along the U.S./Canada border. The Neroukpuk at Lake Peters is not dated by fossils but the Neroukpuk along the U.S./Canada border contains trace fossils that are thought to be Early or early Middle Cambrian in age (Lane and others, 1995).

**Third Unit.** This unit underlies the northern part of the 1002 area. It extends from the western part of Camden Bay, east of Figure BR2, to the Aichilik River (Plate BR1). The western boundary of the unit is uncertain where it is thin and indistinct beneath the pre-Tertiary and Lower Cretaceous unconformities.

The third unit likely is a sedimentary wedge that is as much as 12,000 feet thick (assuming an interval velocity of 16,000 feet/second) in the 1002 area. The unit becomes thicker under the Beaufort Sea shelf north of the 1002 area. The unit wedges out along its southern and western boundaries where it appears to onlap, and locally appears to be discordant to reflectors within, the second unit and possibly the first unit.

Deformation in rocks that make up the third unit consists of extensional faults, faults and folds that formed during Tertiary folding and thrusting, and poorly understood deformation (Fig. BR3). Extensional faults along the bottom of the wedge that could have formed during deposition strike north-northwest and north, parallel to trends in thickness of the third unit (Plate BR1). They cut the rocks that make up the wedge and the rocks that underlie the wedge. Clastics that likely make up the wedge thicken across these faults implying differential subsidence during deposition (Fig. BR3). Some of the more prominent faults appear to flank depocenters. In cross section (Fig. BR3), the down-stepping nature of the faults on the flanks of depocenters and changes in thickness of the third unit across these faults is apparent, but these faults are not apparent in Figures BR2 and BR4 probably because the faults intersect these sections at acute angles which would make them poorly imaged in reflection siesmic data.

There is a pronounced west to east progressive change in degree of Tertiary deformation of the third unit. The western part of the unit is not affected by Tertiary deformation whereas Tertiary deformation in the eastern part of the unit is intense. Tertiary deformation detaches the third unit from underlying rocks and structurally thickens the third unit. A few prominent thrusts sole in the second unit and cut up section into the third unit (Fig. BR3) . In Figure BR4, the third unit is detached from the underlying second unit and thrust upward and southward. In profiles that parallel structural transport (Fig. BR4), fault-floored anticlines are present. In profiles perpendicular to structural transport (Fig. BR3), Tertiary deformation is reflected in Niguanak and Aurora domes. This deformation consists of warping upward of the unconformities that overlie the third unit and obscure repetitions of the third unit within these domes. These domes are associated with depocenters within the third unit and likely are the result of structural inversion of subbasins.

Some poorly understood structures are present in the third unit. These structures were active during Tertiary time but could have evolved from earlier-formed structures. An example of one these structures is the prominent concave-upward curvilinear fault near the central part of Figure BR3. The fault soles near the base of the third unit and cuts across the entire unit but only minimally offsets the unconformity that bounds the third unit. The down-dip persistence of this fault appears out of proportion to the amount of offset of the unconformity and beds immediately below the unconformity. It is possible that the fault could be a pre-Mississippian structure that was truncated by the unconformity and reactivated during Tertiary time. It is also possible that the fault is a lateral ramp that formed during Tertiary time in which case the greater component of offset implied by the length of the feature would be northward and would not be imaged in the east-west profiles. Because the fault does not extend much above the unconformity, and if this structure is a lateral ramp, it should merge with a roof thrust above the unconformity; no roof thrust is clear from the seismic records.

Ages of underlying and overlying rocks loosely constrain the age of the rocks that make up the third unit. Underlying rocks likely include rocks of Early to early Middle Cambrian age and overlying rocks could be as old as Early Mississippian in age



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Correlation with rocks elsewhere in northern Alaska further constrains the likely age of the rocks that make up the unit. Although only rocks similar to the Neroukpuk Schist of Leffingwell (1919) are tentatively identified in the second unit, the Neroukpuk Schist of Leffingwell (1919) is part of a succession of rocks that range from Precambrian(?) or Early Cambrian in age to Early Devonian(?) in age, suggesting that the youngest rocks in unit 2 could be as young as Early Devonian. One possible correlation are rocks in the eastern Brooks Range and along the continental divide; a sedimentary wedge of Middle and Upper(?) Devonian chert-quartz sandstone and conglomerate overlain by Upper Devonian and/or Mississippian limestone, sandstone, and mudstone. These rocks lie unconformably on Lower Devonian rocks and beneath the Kayak Shale (Anderson, 1993; Anderson and others, 1994) (Fig. BR1). Thick clastic wedges of Lower Mississippian and Upper Devonian rocks underlie Lower Mississippian rocks in the central and western Brooks Range (Fig. BR1). Thick clastic wedges also underlie Lower Mississippian rocks in the Ikpikpuk, Meade, Umiat, and Utukok basins under the central and western Arctic coastal plain (Fig. BR1). This correlation suggests that unit 3 likely is Middle and/or Late Devonian in age and could contain rocks as young as earliest Mississippian in age. Alternatively, another possible correlation is with rocks that lie above the Neroukpuk Schist of Leffingwell (1919) along the U.S./Canada border. Cambrian volcanic and volcaniclastic rocks along the border thicken radically over a distance of 25 miles (Lane and others, 1991; Kelley and others, 1994). Rocks similar to these volcanics and volcaniclastic rocks could make up the third unit; if so, the third unit could consist of rocks that are Cambrian to Early Devonian(?) in age.

**Rocks of Uncertain Affinity.** An enigmatic assemblage of rocks appears on the north end of Figure BR2. Although they appear to lie on the second unit, they cannot be shown in the seismic data to be part of the third unit east of Figure BR2. These rocks are described by Dumoulin (Chap. CC).

These rocks have features in common with the second and third units. They are similar to the third unit in that they appear to be a wedge that lies on the second unit. They differ from the third unit in that they appear to have been involved in deformation (Fig. BR2), possibly south-directed thrusting prior to the pre-Mississippian unconformity.



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Pre-Mississippian rocks penetrated in the Point Thompson wells appear to bottom in the upper part of these rocks of uncertain affinity (Fig. BR2; Dumoulin, Chap. CC). Limestone in these wells is similar to Precambrian(?) or Lower Cambrian limestone in the Franklin Mountains and is unlike Middle and Upper Devonian and earliest Mississippian chert and quartz sandstone and conglomerate exposed in the Brooks Range. Sandstone in these wells is described by Dumoulin (Chap. CC) and includes varieties rich in feldspar and similar to the Neroukpuk Schist of Leffingwell (1919) along the U.S./Canada border of Early to early Middle Cambrian age.

**Framework Model.** Pre-Mississippian rocks in the 1002 area likely make up an antiformal duplex. The duplex formed during north-transporting thrusting in Early to Middle Devonian time. Horses in this duplex are south-dipping repetitions of the Katakturuk Dolomite, Nanook Limestone, Copplestone Limestone and unnamed rocks exposed in the Sadlerochit Mountains and Shublik Mountains. The south-dipping antiformal aspect of this duplex is expressed in the progressive exposure of younger to older rocks below the pre-Mississippian unconformity and in the Fourth Range, Third Range, Shublik Mountains, and Sadlerochit Mountains (Plate BR1); the crestal part of the duplex is in the Sadlerochit Mountains where Precambrian argillite and quartzite that underlie the Katakturuk Dolomite subcrop the pre-Mississippian unconformity. The north-dipping antiformal aspect of this duplex is expressed in the north dip of the contact between units 1 and 2 under the 1002 area.

The roof thrust that separates the horses from rocks that overlie these imbricate blocks dips north and separates unit 1 from unit 2 under the 1002 area. The horses that underlie the roof thrust have moved northward relative to the rocks above the thrust.

Rocks above the roof thrust likely are clastic and metaclastic rocks similar to the succession of rocks that include the Neroukpuk Schist of Leffingwell (1919) in the Franklin Mountains. Rocks above the roof thrust likely are Early to early Middle Cambrian in age and lithologically similar to the Neroukpuk Schist of Leffingwell (1919) in the type area south of the 1002 area. Hence rocks above the roof thrust in the 1002 area likely are turbidites, limestone, chert, and argillite deposited in deeper water than the platform carbonate rocks in the Sadlerochit and Shublik Mountains with which they are time equivalent.

Erosion during Early Mississippian time stripped off rocks above the roof thrust of the antiformal duplex exposing the horses in the Sadlerochit and Shublik Mountains and Third and Fourth Ranges. This erosion cut deepest into the crest of the antiformal duplex exposing rocks that underlie the Katakturuk Dolomite in the Sadlerochit Mountains but did not strip off rocks above the roof thrust north of the Sadlerochit Mountains. These relations could imply that the roof thrust cut down section in the direction of structural transport because rocks above the roof thrust in the 1002 area (unit 2) likely are age equivalent to Early to early Middle Cambrian carbonate rocks in the horse blocks in the Sadlerochit and Shublik Mountains. If this is the case, the roof thrust probably propagated along this facies transition between carbonate and clastic rocks rather than a particular stratigraphic horizon.

The rocks that make unit 3 accumulated in response to normal faults that strike north-northwest and north-south in the northern part of the 1002 area. These normal faults likely began to form during early stages of sedimentation; it is unknown whether these faults predate or post date the folding and thrusting that produced the underlying antiformal duplex. Although locally clear near the base of unit 3, growth faults are subtle if present at all in the upper part of the unit.

Rocks that make up unit 3 probably are similar to the rocks present in basins under the central and eastern Arctic coastal plain and exposed in a belt that extends the length of the Brooks Range. Successions of clastic rocks as much as 15,000 feet thick composed of rocks of earliest Mississippian age and presumably rocks of Middle and Late Devonian age are present in the Umiat, Ikpikpuk, Meade, and Utukok basins under the Arctic coastal plain west of the 1002 area. Successions of marine and nonmarine clastic rocks ranging from Middle Devonian to earliest Mississippian age and as much as 15,000 feet thick crop out: examples are the Ulungarat and Mangaqtaaq Formations of Anderson and others (1994) in the eastern Brooks Range, the Kanayut Conglomerate and Hunt Fork Shale in the central Brooks Range, and the Noatak Sandstone in the western Brooks Range.

Alternatively, rocks that make up unit 3 could be older than Middle Devonian. Other than their age relative to rocks that make up unit 2, the age and composition of rocks that make up unit 3 are poorly documented.

If unit 3 is older than Middle Devonian, the rock types that could make up this unit are ambiguous. Along the U.S./Canada border, two units in outcrop are known to thicken radically, possibly similar to rocks that make up unit 3. One is the Neroukpuk Schist of Leffingwell (1919) (Lane and others, 1995; Kelley and others, 1995b); which yields dates similar to those age likely in unit 2. The other is a volcaniclastic unit correlated with the Whale Mountain Volcanics (Lane and others, 1991; Kelley and others, 1994). This volcaniclastic unit depositionally overlies rocks that likely are early Middle Cambrian in age and which contain the same fossils as those present in the Neroukpuk Schist of Leffingwell (1919) in the border area.

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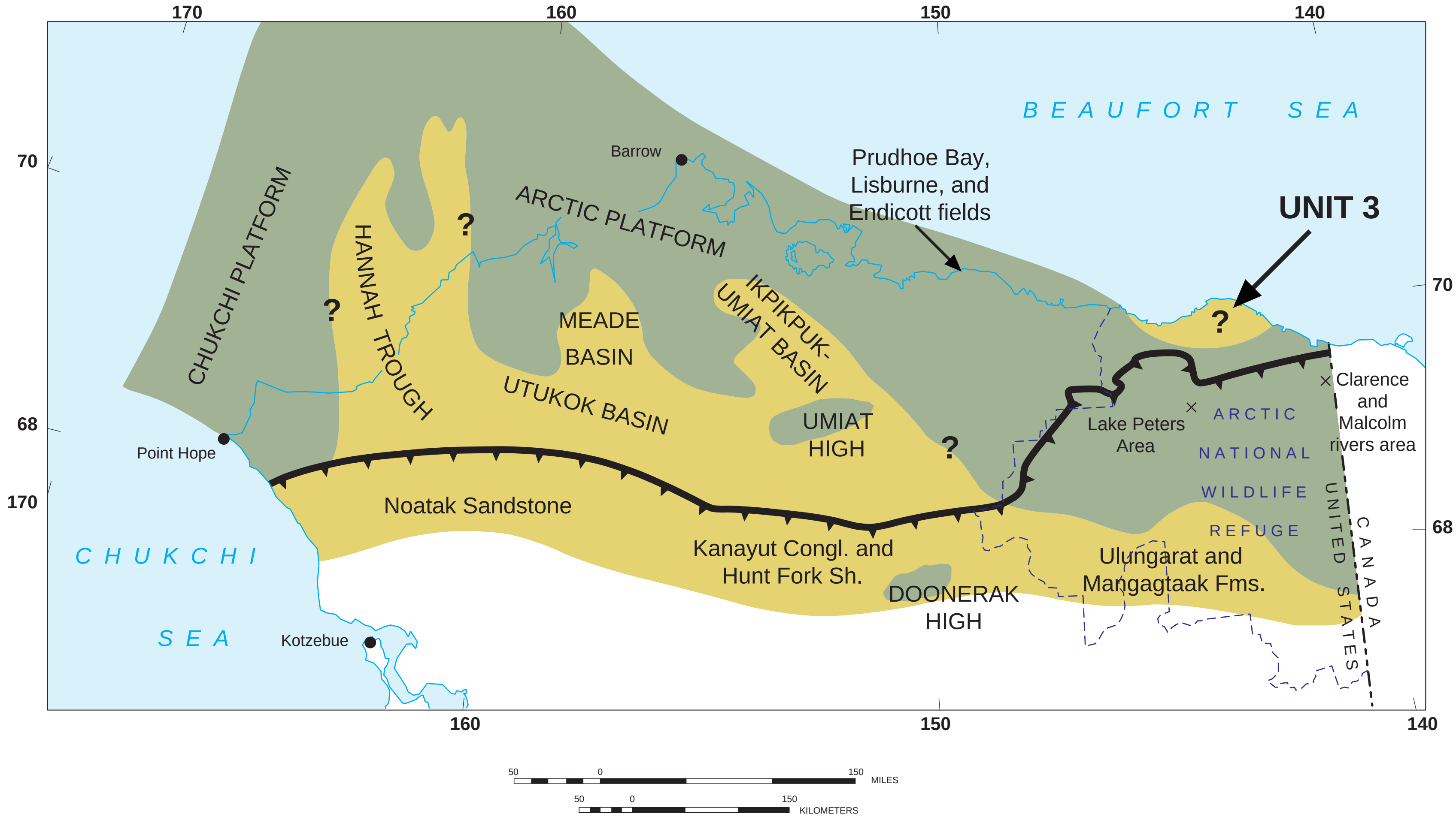


## EXPLANATION

Areas where seismic data indicate that Mississippian rocks conformably overlie Devonian clastic rocks within Middle to Late Devonian transtensional rift basins superposed upon a heterolithic deformed complex of Middle Devonian and older strata.

Areas where seismic, outcrop, or well data indicate that Mississippian or younger rocks conformably overlie a heterolithic deformed complex of Middle Devonian and older strata.

Brooks Range front

Figure BR1.–Map of northern Alaska showing distribution of the pre-Mississippian unconformity and areas where Mississippian rocks lie conformably on Devonian clastic rocks and selected localities discussed in the text.



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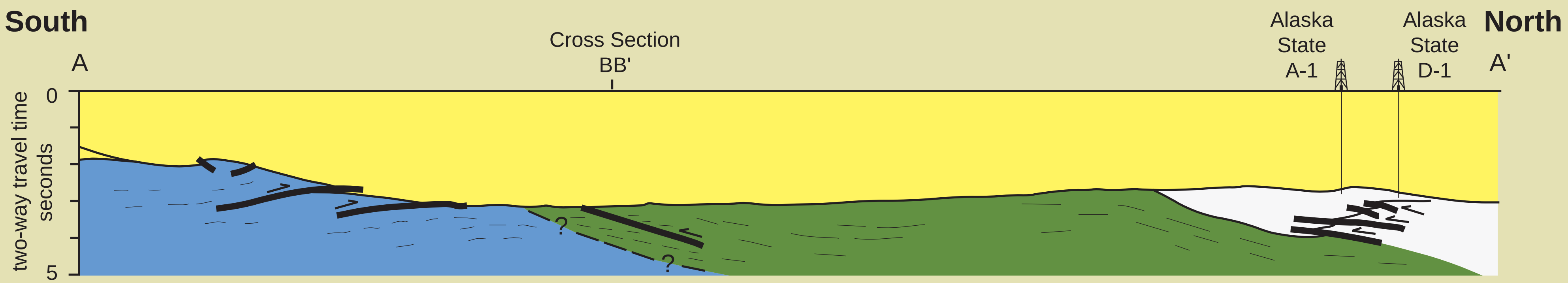
in the toolbar to return.




**EXPLANATION**

- ROCKS OVERLYING BASEMENT
- STRUCTURAL–LITHOLOGIC UNIT 1
- STRUCTURAL–LITHOLOGIC UNIT 2
- ROCKS OF UNCERTAIN AFFINITY

Figure BR2.–Cross section AA' showing relations between structural/lithologic units 1 and 2 and rocks of uncertain affinity in the western part of the 1002 area.

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in the toolbar to return.



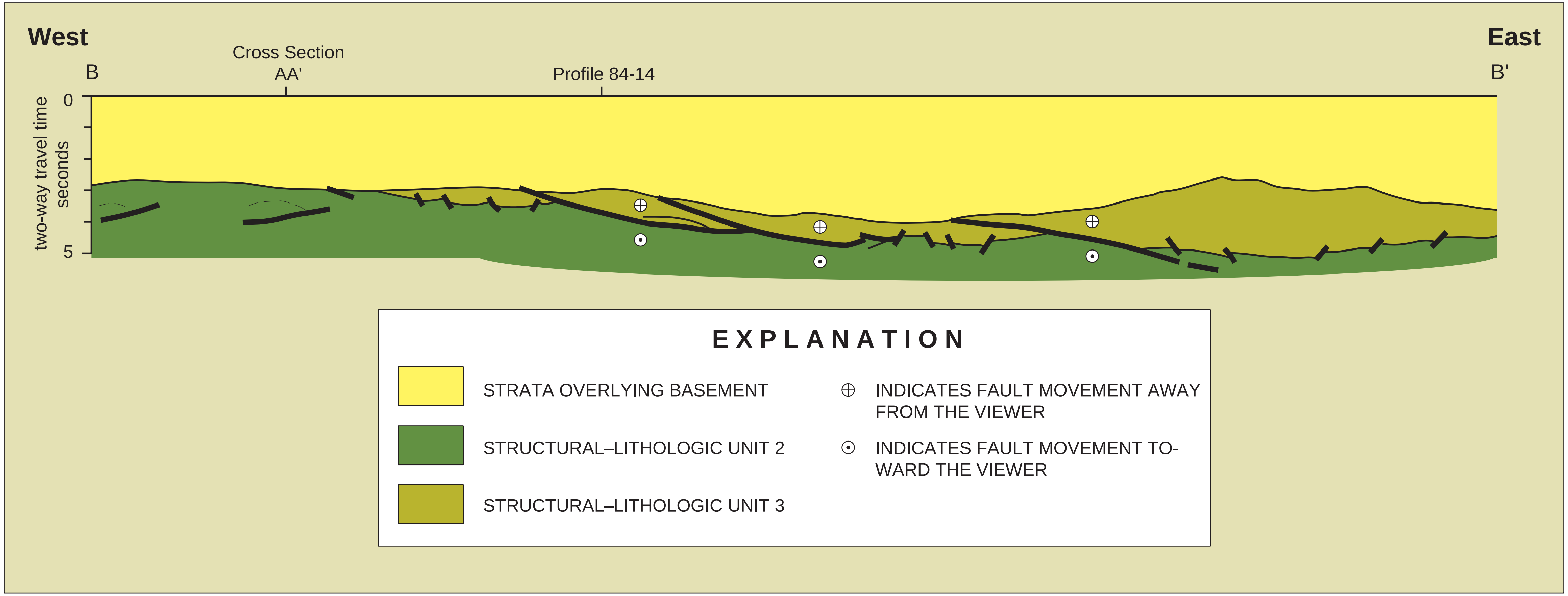


Figure BR3.–Cross section BB' showing relations between structural/lithologic units 2 and 3 in the northern part of the 1002 area.

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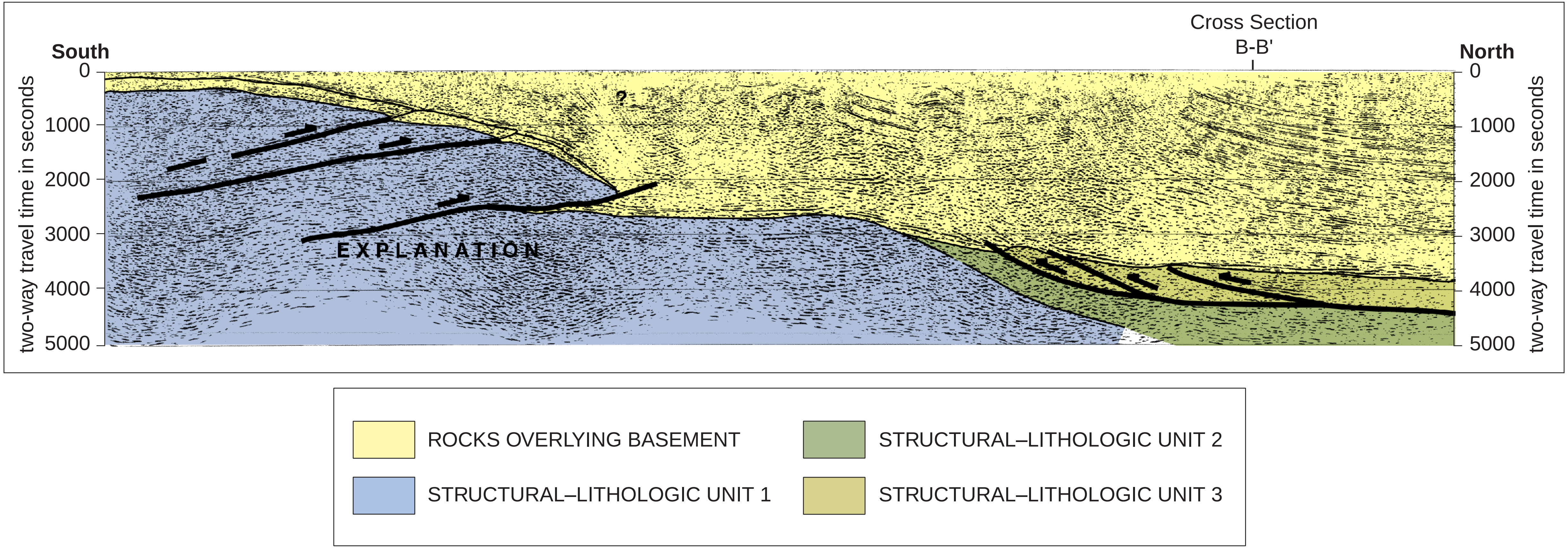


Figure BR4–Seismic profile 84-14 showing relations between structural/lithologic units 1, 2, and 3 in the central part of the 1002 area.

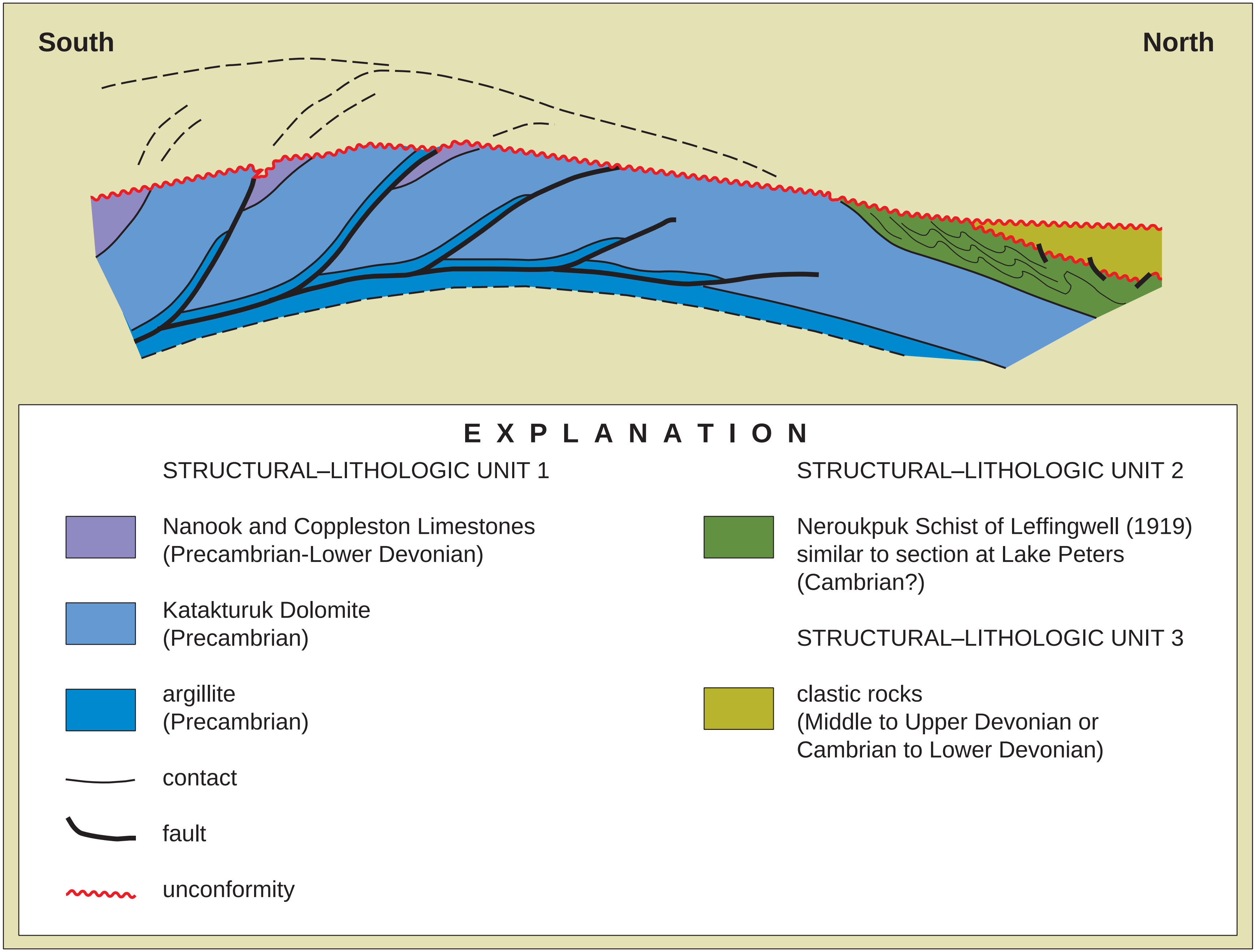


Figure BR5.–Diagrammatic north-south cross section across the 1002 area showing the pre-Mississippian antiformal duplex inferred in the text, relations between structural/lithologic units 1, 2, and 3, and rocks that likely make up the structural/lithologic units 1, 2, and 3.

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U.S. DEPARTMENT OF THE INTERIOR
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OPEN-FILE REPORT 98-34
PLATE BR1


SCALE 1: 250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

ALASKA

MAP LOCATION

# PRE-MISSISSIPPIAN ROCKS UNDER THE 1002 AREA

By
John S. Kelley
1998

Map Projection UTM Zone 6

Surface outcrop patterns based on Bader and Bird (1986) with modifications from field studies 1986-1997.

EXPLANATION

FIRST STRUCTURAL/LITHOLOGIC UNIT

SECOND STRUCTURAL/LITHOLOGIC UNIT

THIRD STRUCTURAL/LITHOLOGIC UNIT

ROCKS OF UNCERTAIN AFFINITY

Cross-sections and seismic profile

Isopachs of seismic interval in two-way travel time in seconds.

Faults; red line indicates that fault offsets the pre-Mississippian unconformity. Blue line indicates that unconformity truncates fault. Filled triangles mark hanging-wall cutoff. Open triangles indicate foot-wall cutoff.