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BALANCED CROSS SECTIONS OF THE AICHILIK RIVER AND OKPILAK BATHOLITH REGIONS, NORTHEASTERN BROOKS RANGE, ALASKA

by

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Abstract

The range front of the northeastern Brooks Range in the Arctic National Wildlife Refuge (ANWR) is defined by pre-Mississippian-cored anticlinoria that are interpreted as the surface expression of horses in a northward-propagating regional duplex. Lateral variations in the geometry of these range-front anticlinoria are influenced by changes in lithology and deformational style of the pre-Mississippian rocks and their Mississippian and younger cover.

Two distinct geometries are displayed in different parts of the range front in northeastern ANWR. To the east, stratified, slightly metamorphosed pre-Mississippian clastic, carbonate, and volcanic rocks were deformed into an anticlinal stack during Cenozoic thrusting. The presence of multiple potential detachment horizons permitted these rocks to deform as discrete thrust slices above a detachment with an original depth of less than 15 km. The overlying Mississippian and younger cover sequence deformed separately from the pre-Mississippian rocks above a detachment in the Mississippian Kayak Shale. Shortening within the cover sequence was by a combination of thrust duplication and detachment folding.

In contrast, to the west the pre-Mississippian rocks include the structurally homogeneous Devonian Okpilak batholith. The batholith was transported northward during Cenozoic thrusting and now forms a major topographic and structural high near the range front. The batholith probably shortened via a combination of closely spaced thrust slices with intervening ductile shear zones and penetrative simple shear above a detachment at greater than 15 km depth. The Kayak Shale is absent or very thin in the vicinity of the batholith. Consequently, Mississippian and younger rocks remained attached to the batholith and also shortened via small-scale imbrication and penetrative strain.

Total shortening in both transects as determined from these cross sections is approximately 45-47%. However, the overall amount of shortening in either transect is governed by: 1) the depth to the basal detachment surface at the pin line in the foreland; 2) the structural topography of the transect; 3) the slope of the basal detachment surface with respect to the pre-Mississippian unconformity and 4) the depth to the brittle/ductile transition, where the basal detachment surface would be expected to flatten. Factors 1 and 2, and to a lesser extent 3, can be reasonably constrained by seismic data from the coastal plain and by structural studies in exposed rocks. More information on the geothermal gradient at the time of deformation is required to obtain an accurate estimate of the influence of factor 4.

Introduction

The northeastern Brooks Range is a relatively well-exposed example of a Cenozoic foreland fold-and-thrust belt. Both the style of deformation and the rocks involved are thought to continue northward into the subsurface of the coastal plain of the Arctic National Wildlife Refuge (ANWR). Balanced cross sections through key areas of the northeastern Brooks Range should lend new insights into the structural geometry of this relatively young fold-and-thrust belt.

This report summarizes some preliminary results of a Ph.D. study currently in progress at the University of Alaska Fairbanks. Fieldwork and geologic mapping that form part of the basis for these interpretations were conducted during the summers of 1986, 1987, 1988 and 1989 and encompassed a large percentage of the range front east of the HulaHula River. These data, combined with regional data, previous detailed studies, and publicly available seismic data from the coastal plain, form the basis for the following discussion.

Regional Setting

The northeastern Brooks Range is an arcuate northern salient of the Brooks Range of northern Alaska. The main axis of the Brooks Range formed by shortening of 100's of kilometers of allochthonous rocks during Middle Jurassic to Early Cretaceous time (Mayfield and others, 1983). In contrast, thrusting in the northeastern Brooks Range is Cenozoic in age, resulted in less shortening (<100 km) and has involved para-autochthonous rocks similar to those of the North Slope subsurface (Wallace and Hanks, in press and this study). These rocks consist predominantly of non-crystalline, pre-Mississippian rocks unconformably overlain by Mississippian and younger carbonate and clastic rocks of the Ellesmerian sequence (Reiser, 1970).

Cenozoic shortening in the northeastern Brooks Range was accommodated by the formation of a regional, north-directed duplex, with a floor thrust in the pre-Mississippian rocks and a roof thrust in the overlying Mississippian Kayak Shale. The northeastern Brooks Range can be divided into three structural provinces based upon regional variations in the Cenozoic structural style of both the pre-Mississippian rocks and the Ellesmerian sequence (Figures 1 and 2; Wallace and Hanks, in press). Throughout the northeastern Brooks Range, thrusting resulted in the formation of a series of east-west trending regional anticlinoria cored by pre-Mississippian rocks. In the western structural province, regional anticlinoria are formed by single horses within the pre-Mississippian sequence, with the overlying Mississippian and younger carbonate and clastic rocks deforming primarily via detachment folds above a major detachment horizon in the Mississippian Kayak Shale. In the eastern structural province, regional anticlinoria are formed by multiple horses within the pre-Mississippian rocks, and the overlying Ellesmerian sequence is deformed primarily by thrust duplication with minor detachment folding. In the intervening Okpilak batholith structural province, the pre-Mississippian rocks consist, in part, of the Devonian Okpilak batholith.

During Cenozoic thrusting, the batholith was transported northward above a basal detachment surface at depth and deformed internally by displacement on shear zones and penetrative strain (Hanks and Wallace, in press). The Mississippian Kayak Shale is thin or missing in the vicinity of the batholith (Sable, 1977; Watts and others, 1988). Consequently, the overlying carbonate and clastic rocks remained structurally attached to the batholith during thrusting, and deformed primarily by the development of penetrative structures and small-scale folds and faults.

The remainder of this report will discuss balanced cross sections through the eastern and Okpilak batholith structural provinces. These balanced cross sections provide some constraints on the amount of shortening accommodated during Cenozoic thrusting in the northeastern Brooks Range, as well as illustrate the variations in the structural geometry between the two provinces.

Eastern structural province--the Aichilik River transect

The line of the balanced cross section across the eastern structural province (Figure 1 and Sheet 1) extends from north of the Niguanak high south through Leffingwell Ridge, Whale Mountain and Bathtub Ridge into the northern part of Table Mountain quadrangle.

Detailed mapping in the northern half of the transect (Hanks, 1987, 1988, 1989) was used to develop a working model of the deformational style of both the pre-Mississippian and Mississippian through Jurassic rocks during Cenozoic thrusting, as well as to provide detailed structural data for that part of the transect. Detailed mapping immediately north of Bathtub Ridge by Wallace and Hanks during 1988, and by Wallace south of Bathtub Ridge (Wallace and others, 1988) provided detailed structural information and/or general concepts on the dominant structural style in those areas. Regional structure contour maps on the exposed and projected surface of the pre-Mississippian unconformity helped constrain the Cenozoic structural geometry of the pre-Mississippian rocks (Figure 3; Wallace and Hanks, in press). Regional mapping at 1:250,000 (Reiser and others, 1980) provided constraints for the remaining areas of the transect where detailed maps are not available.

Publicly available seismic reflection data from the coastal plain of ANWR (Bird and Magoon, 1987) provided some general information on the geometry and depth of structures in the subsurface of the northern portion of the cross section. In particular, line 85-50 provided information on the geometry of the pre-Mississippian unconformity surface in the subsurface. The maximum interpreted structural relief on the pre-Mississippian unconformity along this line can be converted to depths by using the available time-depth curve (Bruns and others, 1987). The minimum depth to the basal detachment horizon under the coastal plain can be determined by assuming that this structural relief is due to structural duplication in a fault-bend fold-style structure (Suppe, 1983). This depth is a critical value, since it determines the absolute minimum depth to the basal detachment horizon for the entire cross section. In the Aichilik River transect, the depth to the basal detachment surface under the coastal plain is interpreted to be 20,000 ft (6.1

km).

GENERAL STRUCTURAL GEOMETRY

Pre-Mississippian rocks

In general, the large, pre-Mississippian-cored anticlinoria exposed in the eastern structural province were formed by Cenozoic emplacement of multiple horses in the pre-Mississippian rocks, as illustrated on the cross section for the Aichilik River transect (Sheet 1). These horses formed in the regional, north-vergent duplex between a floor thrust at depth in the pre-Mississippian rocks, and a roof thrust in the Mississippian Kayak Shale. This geometry is especially evident in the northern exposed anticlinorium, the Aichilik River anticlinorium, where the pre-Mississippian rocks consist of heterogeneous interlayered carbonates and shales. In several places, Cenozoic faults cutting these rocks have emplaced pre-Mississippian rocks over Mississippian rocks of the Ellesmerian sequence. There is little current evidence from this anticlinorium that Cenozoic deformation was pervasive and not limited only to these fault zones (Hanks, 1989).

The southern anticlinorium (Whale Mountain anticlinorium) is formed by only two horses (Sheet 1). This geometry is inferred based on the structure contour map of the pre-Mississippian unconformity (Figure 3) and on the mapped lithologies and faults (Reiser and others, 1980). Changes to this geometry might be needed as more detailed geologic information from the pre-Mississippian rocks of the Whale Mountain anticlinorium becomes available.

In contrast, the pre-Mississippian-cored anticlinoria in the subsurface in the northern portion of the transect are interpreted to be formed by only single horses (Sheet 1). This simple geometry is suggested by the structural topography of those anticlinoria as interpreted from the published seismic data, as well as reflecting the lack of geologic information on the pre-Mississippian rocks of the subsurface.

In this cross section, there is a progressive increase towards the south in the thickness of the horses within the pre-Mississippian sequence. This results from an effort to keep the number of horses per anticlinorium at a minimum while honoring the available geologic data, and the necessity to reflect the change in structural elevation of the deformed pre-Mississippian unconformity at Leffingwell Ridge and Whale Mountain. These changes in the thickness of Cenozoic horses within the pre-Mississippian rocks may reflect a progressive decrease in the depth to the basal detachment horizon as the fold-and-thrust belt migrated northward.

Ellesmerian sequence rocks

In this cross section, the Ellesmerian sequence rocks are shown to thin to the north. This interpretation is based partially on the regional stratigraphic thinning of the Ellesmerian section from south of Bathtub Ridge north to Leffingwell Ridge, particularly in the Mississippian to Pennsylvanian Lisburne Group (Watts, pers. comm.). The Ellesmerian section may also thin north of Leffingwell Ridge due to erosion on one or more unconformities, particularly the Lower Cretaceous unconformity (LCu), as is seen to the northwest and east. However, the presence of Jurassic rocks at the Niguanak high suggests that the Ellesmerian sequence has been at least locally preserved beneath the LCu in the subsurface of the coastal plain north of Leffingwell Ridge.

In the subsurface of the coastal plain, the Ellesmerian sequence is portrayed as remaining structurally attached to the underlying pre-Mississippian rocks and deforming with them as a single structural unit (Sheet 1). This interpretation is based partially on published seismic data, which although of relatively poor quality, does not show any obvious thrusting or detachment folding of the Ellesmerian sequence above the pre-Mississippian rocks. Exposures of the Mississippian Kayak Shale at Leffingwell Ridge suggest that the Kayak Shale may lose its effectiveness as a detachment horizon to the north, possibly because of both depositional thinning and deposition of a higher proportion of limestone to shale within the unit.

At the range front, the Ellesmerian rocks for the most part have remained structurally attached to the underlying pre-Mississippian rocks, with only minor detachment folding. Along Leffingwell Ridge, between the Aichilik and Ekaluakat Rivers, the Ellesmerian section between the Mississippian Kayak Shale and the Jurassic to Lower Cretaceous Kingak Shale has been duplicated by thrusting and is preserved in the Egaksrak River klippe (Hanks, 1987; Hanks and Wallace, 1987). Superficial similarities between the stratigraphy of the klippe and that of the underlying Ellesmerian sequence suggest that the klippe may not be displaced very far. This is the interpretation used in this version of the balanced cross section.

The Ellesmerian sequence is poorly exposed over much of the remainder of the cross section, with outcrop belts limited to the flanks of the regional anticlinoria. Detailed and regional mapping in these areas supports the interpretation that the Ellesmerian sequence has deformed primarily via a combination of thrust duplication and detachment folding, as illustrated on the cross section. This is probably due, in part, to a southward increase in the effectiveness of the Kayak Shale as a detachment horizon south of Leffingwell Ridge.

Okpilak batholith structural province--the Okpilak batholith transect

The Okpilak batholith transect (Figure 1 and Sheet 2) extends from just south of the shoreline of the coastal plain, through the northern margin of the batholith between the Okpilak and Jago Rivers, south through the Romanzof Mountains of Demarcation Point quadrangle to the northernmost exposed Ellesmerian sequence rocks in Table Mountain quadrangle.

Detailed mapping along the northern margin of the batholith (Hanks and Wallace, 1989; Hanks and Wallace, in press; Pavia, 1987; Sable, 1977) provided data on how the batholith deformed during Cenozoic thrusting. Regional mapping (Reiser and others, 1980) and local detailed mapping (Sable, 1977) provided the information needed to constrain the general geometry and structural style of the remaining exposed portions of the transect.

As in the Aichilik River transect, published seismic data from the coastal plain of ANWR (Bird and Magoon, 1987) provided some general constraints on the geometry and depth of structures in the subsurface of the northern part of the cross section. There was no seismic data available immediately north of the batholith, so the closest available line, line 84-20, was used. Using this information, the published time/depth curve (Burns and others, 1987), and making assumptions regarding the geometric relationship of faults to the observed folds, a minimum depth to the basal detachment horizon under the coastal plain north of the batholith was deduced. In the Okpilak batholith cross section, the depth to the basal detachment surface under the coastal plain is interpreted to be 32,000 ft (9.8 km), considerably deeper than that under the coastal plain of the Aichilik River transect.

GENERAL STRUCTURAL GEOMETRY

Franklinian sequence rocks

The pre-Mississippian rocks along the Okpilak batholith transect can be divided into two gross lithologic packages that have different structural character. South, and probably north, of the batholith, the pre-Mississippian rocks consists of heterogeneous stratified rocks with multiple potential detachment horizons. As in the Aichilik River transect, the Cenozoic map-scale structures of these rocks have a geometry suggesting that they deformed via duplication on thrust faults with a ramp/flat geometry.

In contrast, the batholith is a mechanically homogeneous, relatively rigid crystalline body with no obvious internal mechanical layering to serve as detachment horizons. Detailed mapping along the northern margin of the batholith (Hanks and Wallace, 1989 and in press; Sable, 1977) suggests that the batholith has deformed via a combination of thrust duplication on ductile to semi-ductile shear zones, and the development of penetrative fabrics between shear zones. Penetrative strain may play an increasingly important role with increasing temperature and pressure deeper in the batholith.

Ellesmerian sequence rocks

The Mississippian Kayak Shale has behaved as the roof thrust of the regional duplex, but is thin to absent in the vicinity of the batholith (Sable, 1977; Watts and others, 1988). Consequently, the overlying carbonate and clastic rocks of the Ellesmerian sequence have remained structurally attached to the batholith during Cenozoic thrusting. During this deformational event, the Ellesmerian sequence has deformed along with the rocks of the batholith via a combination of penetrative strain and resulting mesoscopic structures, and larger-scale folding and faulting. This structural behavior has resulted in an increase in mesoscopic fabrics within the Ellesmerian sequence with proximity to the batholith.

Little data is available on the structural behavior of the Ellesmerian sequence north of the batholith. Consequently, the same assumptions made for the subsurface segment of the Aichilik River transect were applied here. The Kayak Shale is assumed to be thin, absent or not an effective detachment horizon. The overlying carbonate and clastic rocks would therefore deform with the underlying pre-Mississippian rocks as a single structural unit.

Regional and detailed mapping (Reiser and others, 1980; Sable, 1977) suggest that the Kayak Shale becomes considerably thicker south of the batholith and that, where exposed, the Mississippian and younger rocks of the Ellesmerian sequence have deformed primarily via detachment folding. However, the lack of exposure of Ellesmerian rocks over much of the area immediately south of the batholith provides little information regarding the structural behavior of the Ellesmerian sequence immediately south of the batholith, and little indication of where the Kayak Shale becomes thick enough to be an effective detachment horizon. Consequently, that portion of the transect has been interpreted as being similar to the Canning River transect of the western structural province, where the Ellesmerian sequence has deformed primarily via detachment folding (Namson and Wallace, 1986; Wallace and Hanks, in press).

Boundary between the Okpilak batholith and eastern structural provinces

The boundary between these two provinces occurs along the Jago River. This boundary is marked by a major change in structural relief from the Okpilak batholith to the west (at elevations of >8000' (2.4 km)) to the stratified pre-Mississippian rocks immediately to the east (elevations <4000' (1.2 km)). This change in structural relief is also evident on the contour map of the pre-Mississippian unconformity (Figure 3; Wallace and Hanks, in press).

Direct field study of the nature of this boundary has been hampered by poor exposure. The balanced cross sections suggest that the change in structural relief reflects a lateral ramp in the basal detachment surface. The thickness of the thrust sheets in the deformed cross sections increases from the east (Aichilik River transect) to the west (Okpilak batholith transect). This change in thickness reflects a corresponding increase in the depth to the basal detachment from east to west in the undeformed sections (Sheets 1 and 2, restorations). This lateral difference in the thickness of the thrust sheets resulted in an abrupt east to west increase in structural relief when the thrust sheets were displaced northward over a frontal ramp and onto a shallower basal detachment. Some dip-slip or strike-slip motion probably occurred on transverse faults associated with this lateral ramp. However, this displacement must be relatively minor since there is no visible offset of Leffingwell Ridge where it crosses the Jago River.

Constraints on shortening

These two sections were drawn along approximately parallel transects that begin and end in laterally equivalent structures. The following table summarizes the shortening values for the two transects as measured in different parts of the cross-sections.

Aichilik River transect

Part of section measured	deformed length	undeformed length	shortening
northern pin line to range front (Leffingwell Ridge)	31.2 miles (50.2 km)	52 miles (83.7 km)	20.8 miles (33.5 km) or 40.0%
Leffingwell Ridge to south of Bathtub Ridge	42.8 miles (68.9 km)	84.6 miles (136.2 km)	41.8 miles (67.3 km) or 49.4%
TOTAL	74 miles (119.1 km)	136.6 miles (219.9 km)	62.6 miles (100.8 km) or 45.8%

Okpilak batholith transect

Part of section measured	deformed length	undeformed length	shortening
northern pin line to range front (north of north margin of batholith)	40.4 miles (65 km)	76 miles (122.4 km)	35.6 miles (57.3 km) or 46.8%
range front to south end of section	39.6 miles (63.8 km)	77.4 miles (124.6 km)	37.8 miles (60.9 km) or 48.8%
TOTAL	80 miles (128.8 km)	153.4 miles (247 km)	73.4 miles (118.2 km) or 47.9%

The amount of shortening represented in these two balanced cross sections depends greatly on the constraints and assumptions used in building the cross sections. A range in shortening values can be achieved by varying critical constraints and/or assumptions. Of critical importance is the depth to and slope of the basal detachment horizon. In both of these cross sections, the depth to the basal detachment surface was constrained in the foreland by the published seismic data and velocity/depth curve. This constraint is subject to changing interpretations, the availability of new data and/or better processing. In addition, there presently is no direct information on the depth to the basal detachment beneath the exposed portions of the fold-and-thrust belt. Consequently, the depth and slope of the basal detachment south of where it is 'known' in the foreland is subject to conjecture. In both of the cross sections, the slope of the basal detachment horizon is interpreted to be 0°, based on the relatively constant elevation of the deformed pre-Mississippian unconformity surface under the coastal plain. Where this surface displays an abrupt change in elevation, such as at the northern margin of the batholith or at Leffingwell Ridge, a corresponding ramp in the detachment surface has been postulated. Smaller amounts of shortening would have resulted if a gradually sloping detachment surface had been used. However, the relatively constant structural relief of the pre-Mississippian unconformity surface south of the range-front in both transects suggests that the depth to the basal detachment surface is also relatively constant south of the frontal ramps.

Another critical constraint on the amount of shortening is the depth to the brittle/ductile transition. Regardless of the slope of the basal detachment surface, it is assumed that where that surface reached the depth of the brittle/ductile transition, the detachment horizon would flatten and become horizontal. This would, in effect, put a lower limit on the amount of shortening one could expect with a basal detachment horizon of a specific slope. The depth to the brittle/ductile transition depends on the composition of the crust and the geothermal gradient, with the depth to the brittle/ductile transition decreasing with an increase in geothermal gradient (Suppe, 1985). The depth to the brittle/ductile transition could range from <10 km to 18-20 km, corresponding to a range in geothermal gradients of >30°C to 15°C/km (Suppe, 1985).

Unfortunately, there is presently very little information on the geothermal gradient at the time of thrusting for either transect. The depth to the basal detachment horizon in southern end of both transects was constrained primarily via the large-scale structural geometry of the pre-Mississippian rocks. In the southern part of the Aichilik River transect, the depth to the brittle/ductile transition is 31,000 ft (9.5 km), corresponding to a geothermal gradient of 28-30°C/km. This value does agree well with what little data on the thermal history are available, specifically apatite fission-track data from Bathtub Ridge (O'Sullivan, 1988) and preliminary conodont alteration indices from north of Bathtub Ridge (Anita Harris, pers. comm.). At the southern end of the Okpilak batholith transect, the depth to the brittle/ductile transition is 48,000 ft. (14.6 km), corresponding to a geothermal gradient of approximately 18°C/km. There is, at present, no geothermal data for this transect.

Conclusions

Variations in the structural style between the eastern and Okpilak batholith structural provinces of the northeastern Brooks Range and within each province are controlled by lateral variations in the lithology and consequent structural behavior of both the pre-Mississippian rocks and its Mississippian and younger cover. Deformation of heterogeneous, stratified pre-Mississippian rocks above a basal detachment horizon has resulted in map-scale structures with ramp/flat thrust geometries and associated folds. Cenozoic deformation in pre-Mississippian rocks appears to be restricted to Cenozoic faults and is not pervasive. Where pre-Mississippian rocks are mechanically homogeneous crystalline rocks (i.e. the Okpilak batholith), deformation above the basal detachment horizon has been via thrust duplication on ductile shear zones and the development of penetrative fabrics throughout the entire crystalline body.

The deformational style of the Mississippian and younger cover rocks appears to be linked to the presence and effectiveness of the Mississippian Kayak Shale as a detachment horizon. Where the Kayak Shale is thick and shaly, the overlying carbonate and clastic rocks deform primarily via detachment folding. Where the Kayak Shale begins to thin and/or become siltier or more calcareous, deformation of overlying rocks is via thrust duplication and detachment folding. Where the Kayak Shale is thin or absent, the Ellesmerian sequence rocks deform with the underlying pre-Mississippian rocks as a single structural unit. This has resulted in the development of penetrative mesoscopic structures in the Mississippian and younger rocks overlying the Okpilak batholith.

The amount of shortening in each of the balanced cross sections depends upon certain assumptions made regarding the behavior of the basal detachment horizon, including its depth, slope and the presence of any ramps. The depth to the brittle/ductile transition is also important. Extrapolation of regional structural, stratigraphic and thermal data can serve to constrain these to some extent, as can theoretical models on the range of possible slopes on the basal detachment, the range of possible geothermal gradients and the relationship between geothermal gradient, fluid pressure and depth to the brittle/ductile transition.

For a more constrained balanced cross-section, several additional data are necessary, including: additional and/or reprocessed seismic reflection data from the coastal plain; seismic reflection or refraction data in the mountains (not realistically feasible); a more constrained geothermal gradient at the time of thrusting; and detailed information on the behavior of the pre-Mississippian rocks in the parts of the transects that were not covered by detailed mapping.

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TECTONIC MAP OF THE NORTHEASTERN BROOKS RANGE

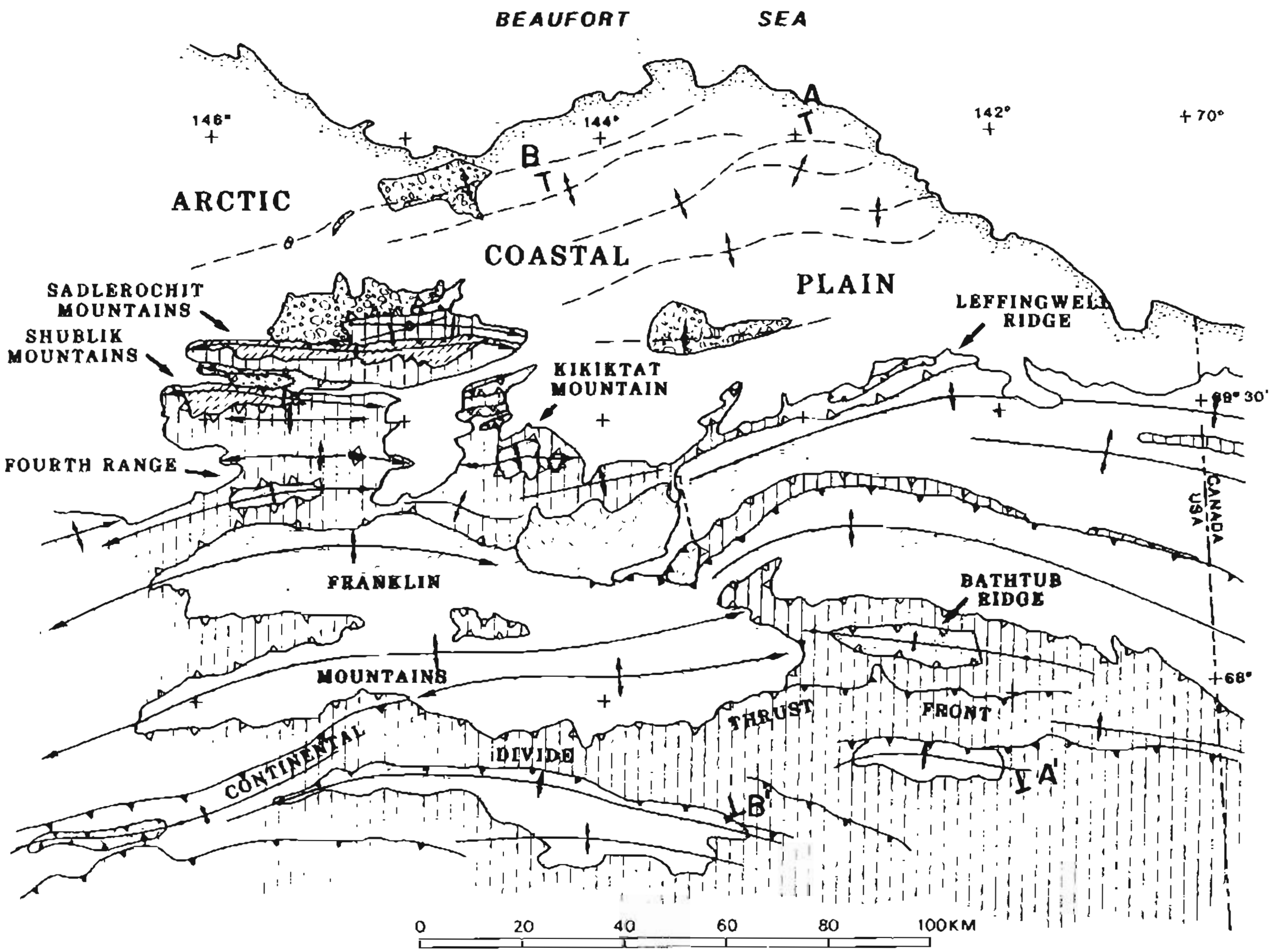

FIGURE 1. Tectonic map of the northeastern Brooks Range. Cross section A-A': Aichilik River transect; B-B': Okpilak batholith transect.

modified from: Wallace & Hanks, in press.

EXPLANATION

Quaternary deposits

Structural unit 4:
Hue Shale, Canning Formation, Jago River Formation, and Sagavanirktok Formation (Upper Cretaceous to Tertiary)

Detachment unit 4:
Pebble shale unit (Lower Cretaceous)
Structural unit 3:
Ignek unit of Kemik Sandstone (Lower Cretaceous)
Also includes Arctic Creek facies north of Okpilak Batholith and Kongakut Formation at Bathtub Ridge (both Lower Cretaceous)

Detachment unit 3:
Kingak Shale (Jurassic to Lower Cretaceous)
Structural unit 2:
Lisburne Group, Sadlerochit Group, Shublik Formation, Karen Creek Sandstone, and Marsh Creek unit of Kemik Sandstone (Mississippian to Lower Cretaceous)

Detachment unit 2:
Kayak Shale (Mississippian)
Structural unit 1A:
Undifferentiated pre-Mississippian rocks (Proterozoic to Devonian) (Exclusive of Katakturuk Dolomite, Nanook Limestone, and Okpilak batholith), and Kekiktuk Conglomerate (Mississippian)

Detachment unit 2:
Kayak Shale (Mississippian)
Structural unit 1B:
Katakturuk Dolomite and Nanook Limestone (Proterozoic to Devonian), and Kekiktuk Conglomerate (Mississippian)

Detachment unit 2:
Kayak Shale (Mississippian)
Structural unit 1C:
Okpilak batholith (Devonian), and Kekiktuk Conglomerate (Mississippian)

Klippe near Porcupine Lake:
Allochthonous Mississippian to Lower Cretaceous rocks

FIGURE 1. (cont)

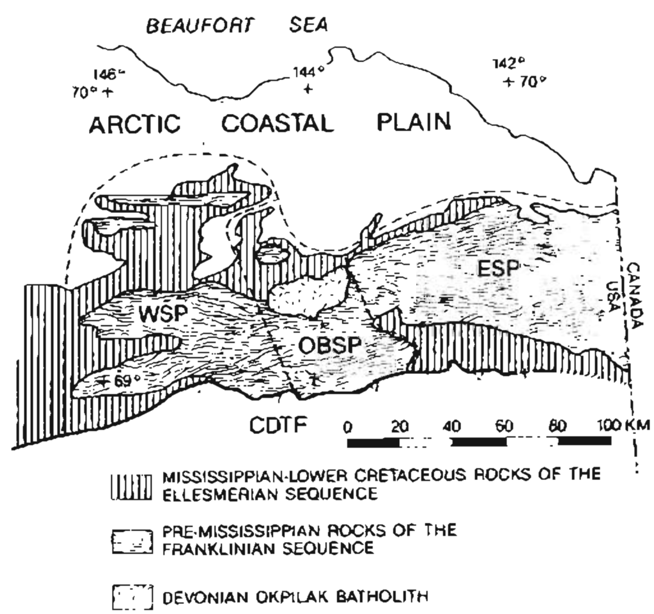

FIGURE 2. Structural Provinces of the northeastern Brooks Range.
WSP: Western structural province;
OBSP: Okpilak batholith structural province;
ESP: Eastern structural province.

<u>from</u>: Wallace and Hanks, in press.

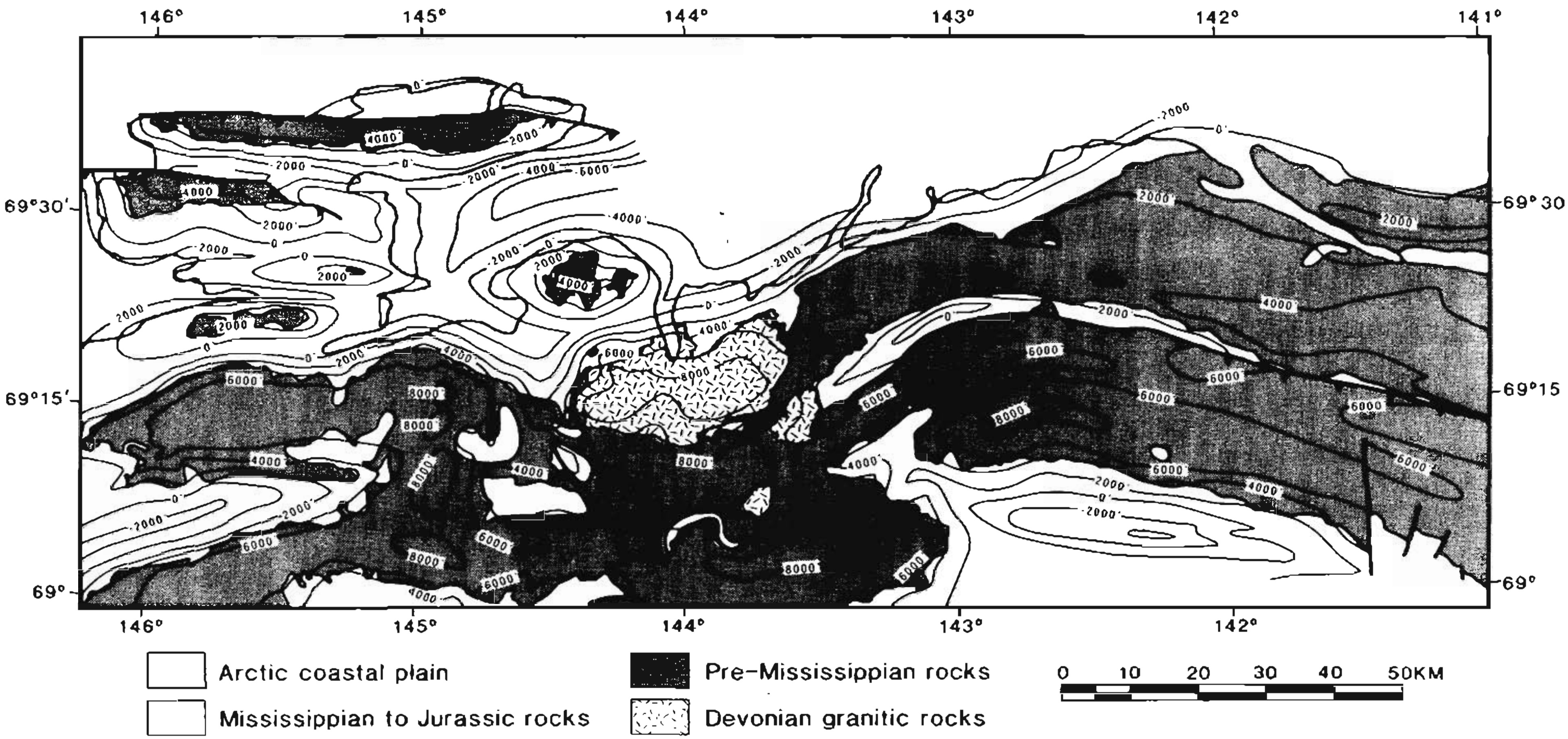

FIGURE 3. Structure contour map of the pre-Mississippian unconformity.

from: Wallace and Hanks, in press