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PRELIMINARY GEOLOGIC MAP OF THE NORTHERN MARGIN OF THE OKPILAK BATHOLITH BETWEEN MCCALL CREEK AND THE OKPILAK RIVER, NORTHEASTERN BROOKS RANGE, ALASKA

By

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Abstract

Regional and local geologic observations suggest that the Devonian Okpilak batholith of the northeastern Brooks Range has been structurally elevated and thrust northward during Cenozoic regional fold-and-thrust deformation. The batholith defines a major structural high with respect to mid-Cretaceous and younger foredeep deposits exposed nearby to the north. Range-front structures east and west of the batholith continue relatively uninterrupted north of the batholith. In this range-front region, the intensity of penetrative axial-planar cleavage increases both across and along strike toward the north flank of the batholith. A large thrust-related anticlinorium north of the batholith exposes rocks probably equivalent to those it has intruded. Northward slip on a detachment surface beneath the batholith is the simplest explanation for these structures.

Between McCall Creek and the Okpilak River, the northern front of the batholith is defined by a ductile shear zone that emplaces granitic rocks of the batholith over the Mississippian Kekiktuk Conglomerate, the Mississippian-Pennsylvanian Lisburne Limestone, and the Permian-Triassic Sadlerochit Group. This sequence retains its stratigraphic continuity, but is in the overturned and attenuated limb of a footwall syncline. Protomylonitic to mylonitic structures are well developed in the shear zone, with S/C fabrics, sheath folds, and stretching lineations all suggesting top-to-the-north tectonic transport. Near the Okpilak River, a thrust slice of granite with its overlying Mississippian to Permian sedimentary cover has been thrust over an upright sequence of Sadlerochit Group and older rocks.

Shortening within the batholith during Cenozoic thrusting was probably accommodated by the development of ductile shear zones and associated penetrative structures. The regional detachment horizon at the base of the Ellesmerian sequence, the Kayak Shale, is depositionally thin or absent immediately adjacent to the batholith. The Kekiktuk Conglomerate and Lisburne Limestone thus remained structurally coupled to the batholith during thrusting and developed similar penetrative structures, especially where shear zones cut up-section from the granite into the overlying sediments.

Introduction

The Devonian Okpilak batholith of the northeastern Brooks Range has a complex structural relationship with depositionally overlying Mississippian and younger sedimentary rocks of the Ellesmerian sequence. Although demonstrably Devonian in age, the batholith is structurally elevated with respect to nearby younger rocks. A satellite stock of the batholith has yielded a 59 Ma cooling age, suggesting uplift at that time (Dillon and others, 1987). Mississippian and younger rocks in the vicinity exhibit a strong dynamo-thermal overprint that appears to be spatially associated with the batholith.

This report summarizes the results of a pilot field study conducted during the summer of 1988. The goal of this study was to investigate the hypothesis that the batholith was structurally involved in the Cenozoic thrusting event that affected the remainder of the northeastern Brooks Range and, if so, if this involvement could explain both the relative uplift of and structures associated with the batholith. The study area is located on the northern margin of the batholith, between McCall Creek and the Okpilak River (Demarcation Point quadrangle B5).

Regional setting

The northeastern Brooks Range is a Cenozoic fold and thrust belt involving para-autochthonous rocks equivalent to those of the North Slope subsurface (figure 1and 2; Reiser, 1970). The dominant structures of the region are large anticlinoria cored by pre-Mississippian rocks, with Mississippian and younger rocks of the Ellesmerian sequence defining the limbs (Bader and Bird, 1986). These anticlinoria are thought to be fault-bend folds related to a regional-scale duplex, with a floor thrust at depth in the pre-Mississippian rocks and a roof thrust in the Mississippian Kayak Shale (figure 3; Namson and Wallace, 1986; Wallace and Hanks, in review).

The Devonian Okpilak batholith and its satellite stocks are the only large intrusive bodies in the northeastern Brooks Range (Bader and Bird, 1986). The batholith is exposed immediately south of the range front of central ANWR (figure 1), and rises to elevations over 9000 ft, over 7000 ft higher than adjacent Cretaceous and Tertiary foredeep deposits that underlie the adjacent coastal plain to the north. The batholith is rugged, glaciated and inaccessible, so geologic studies of the batholith and the immediately adjacent rocks have been few (Reed, 1968; Sable, 1977; Pavia, 1986). U-Pb zircon age determinations indicate an age of 380 ± 10 Ma for the Okpilak batholith and the nearby Jago stock (Dillon and others, 1987). This data also indicates a 60 Ma lead-loss event. A 59 Ma biotite cooling age was also obtained from the Jago stock using conventional K/Ar techniques (Dillon and others, 1987).

Mississippian and younger sedimentary rocks of the Ellesmerian sequence similar to those in the subsurface of the North Slope unconformably overlie the batholith around its margins, but have been removed by erosion over most of the batholith (Sable, 1977; Dillon and others, 1987). Where the Ellesmerian sequence is preserved, the Kayak Shale is depositionally thin or absent and the Lisburne Limestone directly overlies either the Kekiktuk Conglomerate, or the batholith itself, suggesting that the batholith was a topographic high at the time of deposition (Watts and others, 1988).

Evidence for Cenozoic thrusting of the Okpilak batholith

Regional observations

Several regional geologic relationships suggest that rocks of the Okpilak batholith were involved in the Cenozoic thrusting and related folding seen throughout the northeastern Brooks Range. The batholith is a major topographic high, reaching elevations of over 9000 ft., making it one of the highest portions of the entire Brooks Range. The batholith is structurally higher than immediately adjacent rocks of the Ellesmerian sequence along its northern margin (figure 4). These Ellesmerian sequence rocks are in turn structurally higher than the deformed Cretaceous and Tertiary foredeep deposits that underlie the ANWR coastal plain to the north. Uplift of the batholith with respect to these young, deformed rocks implies that the batholith itself must have been involved in the Cenozoic deformation.

To the east of the batholith, Leffingwell Ridge marks the northern limb of an anticlinorium that formed as a result of Cenozoic thrusting (figure 1; Reiser and others, 1980). This range-front structure continues uninterrupted north of the batholith, implying that the batholith is also underlain by a thrust fault. Pre-Mississippian rocks are exposed in the core of a thrust-related anticlinorium north of the batholith (Kikiktak Mt, figure 1; Bader and Bird, 1986), again implying that there is a detachment at depth in the pre-Mississippian rocks which must pass through or beneath the batholith.

Isotopic ages and intrusive and depositional relationships indicate that the Okpilak batholith is Devonian in age and pre-dates the pre-Mississippian unconformity at the base of the overlying Ellesmerian sequence (Dillon and other, 1987). However, there is an apparent increase in the intensity of mesoscopic folding and axial planar cleavage in Triassic and older rocks of the Ellesmerian sequence approaching the northern margin of the batholith, suggesting a post-Triassic dynamo-thermal event spatially associated with the batholith. 60 Ma metamorphic and cooling ages (Dillon and others, 1987) may reflect structural emplacement and uplift of the batholith that led to the formation of these structures.

Field observations

In the study area, the northern margin of the batholith is a ductile shear zone that dips moderately to the south. Between McCall Creek and the Okpirourak River, a complete but northward-overturned stratigraphic sequence is exposed north of the batholith, including the Kekiktuk Conglomerate, Lisburne Limestone and Echooka Formation of the Ellesmerian sequence (see map and cross section B-B'). Although stratigraphic continuity is preserved, the granite, Kekiktuk Conglomerate and Lisburne Limestone all display penetrative fabrics indicative of high strain. These penetrative fabrics decrease both to the north and up stratigraphic section. Penetrative mesocopic structures include well-developed schistosity parallel to subparallel to bedding, possible S/C protomylonitic to mylonitic penetrative fabrics and north-trending stretching lineations. All of these fabrics suggest top-to-the-north transport directions. The intensity of the penetrative mesoscopic deformation increases westward as this overturned section exhibits progressively greater structural attenuation. Where the structural thinning is greatest, bedding appears to be totally transposed, and north-trending sheath folds have developed in the Lisburne Limestone.

This northward-overturned sequence forms the attenuated south limb of a major overturned syncline (see map and cross sections). The Lisburne Limestone and Echooka Formation locally form tight overturned folds in the core of the syncline. To the north of the overturned syncline, rocks of the Sadlerochit Group display folds of comparable scale, but they are upright and increase in interlimb angle and wavelength northward. Smaller and tighter upright folds occur above a detachment in the Kavik Shale of the Sadlerochit Group.

Between the headwaters of the Okpirourak River and the Okpilak River in the western part of the study area, a thin and areally restricted thrust sheet containing granite, Kekiktuk Conglomerate, Lisburne Limestone and Echooka Formation has been thrust northward over rocks of the Sadlerochit Group (see map and cross-section A-A'). This thrust sheet may be an out-of-the-syncline thrust related to the overturned footwall syncline seen farther to the east on the northern margin of the batholith.

Mapping by Sable (1977) indicates that the northern margin of the batholith steps northward approaching and west of the Okpilak River. Similar shear zones to that described in this report occur along the batholith's margins to the west (Sable, 1977). This suggests that the batholith is cut by multiple shear zones north of the one described here, and that there is a westward increase in displacement on one or more of these, resulting in location of the batholith front farther to the north.

South-dipping foliations and planar zones of high strain also occur across the width of the batholith south of the study area (Sable, 1977; personal observation). This suggests that there has been significant shortening within the batholith, and that displacement on shear zones is not restricted to the northern margin of the batholith.

Discussion

Regional and detailed field evidence indicates that the Devonian Okpilak batholith was intimately involved in the Cenozoic thrusting that formed the latest regional structures of the northeastern Brooks Range. Deformation in the vicinity of the batholith is characterized by penetrative strain, as indicated by the development of mylonitic fabrics within shear zones associated with thrusting of the batholith, and by the extensive development of pervasive fabrics in Mississippian to Triassic rocks adjacent to the batholith. Although these structures suggest that deformation may have occurred at elevated temperatures and/or pressures, there is no evidence that this deformation was related to a Cenozoic magmatic event.

This style of Cenozoic deformation contrasts markedly with that seen both west and east of the batholith. In these areas, the pre-Mississippian sequence consists primarily of lithologically heterogeneous sedimentary rocks that have been deformed in a regional duplex between a floor thrust at depth and a roof thrust in the overlying Mississippian Kayak Shale (figure 3; Wallace and Hanks, in review). However, the Kayak Shale is depositionally thin or absent over the batholith. Therefore, thrusts ramping up from depth would climb up-section and flatten in higher detachment horizons, such as the Triassic Kavik Shale or Jurassic-Cretaceous Kingak Shale. This would require that the batholith, Kekiktuk Conglomerate and Lisburne Limestone remain structurally coupled during Cenozoic thrusting and deform as a single structural unit.

Because of its structurally homogeneous and very competent nature, the batholith lacks well-developed internal incompetent layers or zones that would serve as structural detachment horizons. Consequently, thrusting may have been delayed in the vicinity of the batholith with respect to surrounding pre-Mississippian sedimentary rocks. The northward-concave arcuate trend of structures around the southern margin of the batholith (Bader and Bird, 1986) suggests that it acted initially as a structural buttress. Displacement of and shortening within the batholith was accommodated by internal stain localized in ductile to semi-ductile shear zones. Due to the lack of an intervening detachment horizon, shortening within the overlying Kekiktuk Conglomerate and Lisburne Limestone was also accommodated largely by the development of penetrative fabrics, as opposed to detachment folding or thrust faulting as is observed where the Kayak Shale is present (Wallace and Hanks, in review). However, tight asymmetrical folds (fault-propagation folds?) do occur where these ductile shear zones cut up-section into the Ellesmerian cover sequence.

Implications for the coastal plain of ANWR

The high strains reflected by penetrative fabrics related to Cenozoic thrusting of the batholith probably resulted in destruction of the reservoir potential of the sedimentary rocks immediately adjacent to the batholith. However, the zone of destroyed reservoir potential probably is limited to the region where the batholith has been involved in the thrusting, or where a good detachment horizon is absent near the base of the Ellesmerian sequence.

The objective of this and planned studies is to determine the rate, timing and conditions associated with thrusting of the batholith using radiometric dating, thermal studies, fabric and petrologic analysis. This information may provide constraints on thermal history, uplift rates, the timing and rate of the development of structures in the coastal plain to the north, and the rate and timing of hydrocarbon generation and migration.

Acknowledgements

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Bibliography

Bader, J. W., and Bird, K. J., 1986, Geologic map of the Demarcation Point, Mt. Michelson, Flaxman Island, and Barter Island quadrangles, northeastern Alaska: USGS Map, I-1791, scale 1:250,000.

Dillon, J. T., Tilton, G. R., Decker, J. E., and Kelly, M. J., 1987, Resource implications of magmatic and metamorphic ages for Devonian igneous rocks in the Brooks Range, in Tailleur, I. L., and Weimer, P., eds., Alaskan North Slope geology: Pacific section, SEPM, and Alaska Geological Society, Book 50, p. 713-723.

Namson, J.S., and Wallace, W.K., 1986, A structural transect across the northeastern Brooks Range, GSA Abstracts with Programs, v. 18, no. 2, p. 163.

Pavia, E.A., 1986, Structure and stratigraphy of the northeastern Okpilak batholith and Jago River area, Romanzof Mountains, northeastern Brooks Range, Alaska: Alaska Divisions of Mining and Geological and Geophysical Surveys Public Data File Report 86-86g.

Reed, B.L., 1968, Geology of the Lake Peters area, northeastern Brooks Range, Alaska: USGS Bulletin 1236, 132 p.

Reiser, H.N., 1970, Northeastern Brooks Range--A surface expression of the Prudhoe Bay section: in Adkison, W.L., and Brosgé, M.M., Eds., Proceedings of the geological seminar on the North Slope of Alaska: AAPG Pacific Section Meeting, Los Angeles, p. K1-K13.

Reiser, H.N., Brosgé, W.P., Dutro, J.T., Jr., and Detterman, R.L., 1980, Geologic map of the Demarcation Point quadrangle, Alaska: USGS Map I-1133, scale 1:250,000.

Sable, E.G., 1977, Geology of the western Romanzof Mountains, Brooks Range, northeastern Alaska: USGS Professional Paper 897, 84 p.

Wallace, W. K. and Hanks, C. L., in review, Systematic vertical and lateral variations in structural geometry in the northeastern Brooks Range, Alaska: American Association of Petroleum Geologists Bulletin.

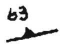
Watts, K. F., Carlson, R., Imm, T., Gruzlovic, P., and Hanks, C., 1988, Influence of pre-Mississippian paleogeography on the Carboniferous Lisburne Group, Arctic National Wildlife Refuge, northeast Alaska: AAPG Bulletin, v. 72, no. 2, p. 257.

Unit descriptions

Qal	Quaternary alluvium and glacial deposits
Trl	Triassic Ledge Sandstone. Dark-weathering sandstones that form resistant ridges. Poorly exposed, stratigraphic thickness unknown. Detachment folded above Kavik Shale.
Trk	Triassic Kavik Shale. Dark brown to black phyllitic slates and siltstones. Highly deformed, stratigraphic thickness unknown, possible detachment horizon.
Pe	Permian Echooka Formation. Rusty-weathering fossiliferous calcareous fine-grained sandstones and siltstones. Possibly highly strained and internally deformed, stratigraphic thickness unknown.
PMl	Pennsylvanian to Mississippian Lisburne Limestone. Grey-weathering mudstones and crinoidal grainstones. Highly deformed and internally strained, stratigraphic thickness unknown.
Mk	Mississippian Kekiktuk Conglomerate. Dark-grey quartzose medium- to coarse-grained sandstone to pebble conglomerate. Local dark chert and/or argillite clasts, local fossil hash. Thickness <10 meters.
Mks	Mississippian Kekiktuk Conglomerate (?), schistose. Yellow-weathering quartz schist with micaceous and/or clay matrix. Highly variable in thickness from <5 meters to 10 meters.
Dg	Devonian granite of the Okpilak batholith. Medium-grey weathering granite to quartz diorite. Local coarse-grained feldspar porphyry with K-spar phenocrysts up to 4 cm in diameter. Micaceous foliation locally well-developed.

GEOLOGIC MAP SYMBOLS

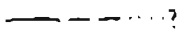
Strike and dip of beds



Strike and dip of foliation or cleavage


Trend and plunge of trace of fold axial surface, dashed where approximately located, dotted where concealed.


Trend of axial surface of flexure where dip changes magnitude but not direction.


Contact: solid where known, dashed where approximately located, dotted where covered, queried where questionable.

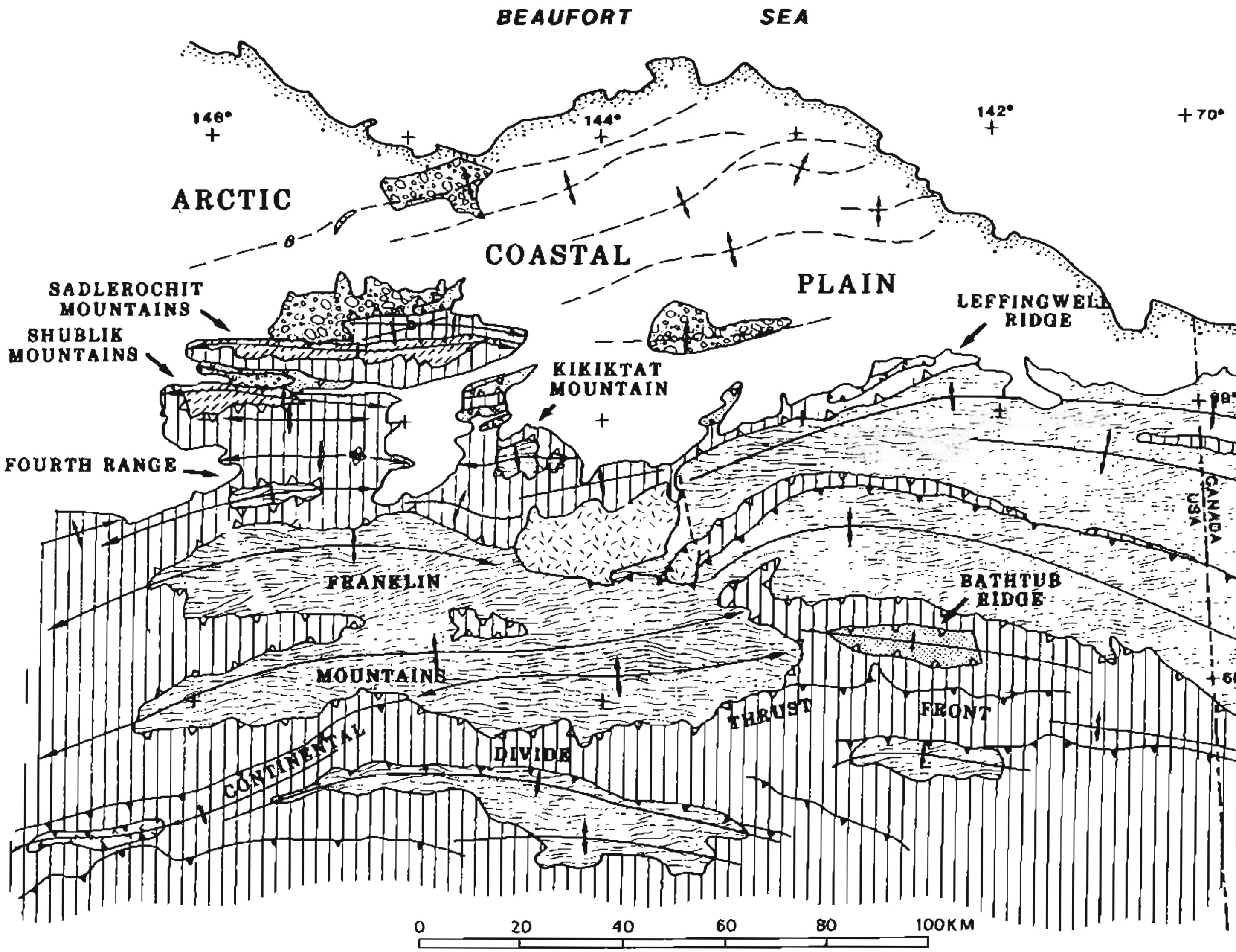

Thrust fault: solid where known, dashed where approximately located, dotted where covered, queried where questionable.


Detachment surface (surface of displacement, but stratigraphic order maintained): solid where known, dashed where approximately located, dotted where covered, queried where questionable.

Fault: solid where known, dashed where approximately located, dotted where covered, queried where questionable.


Zones of well-developed schistosity and/or protomylonitic fabrics

TECTONIC MAP OF THE NORTHEASTERN BROOKS RANGE



W.K.WALLACE OCTOBER,1987
MODIFIED FROM BADER & BIRD,1986
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FIGURE 1.

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

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FIGURE 1 (cont)

STRUCTURAL STRATIGRAPHY, NE BROOKS RANGE

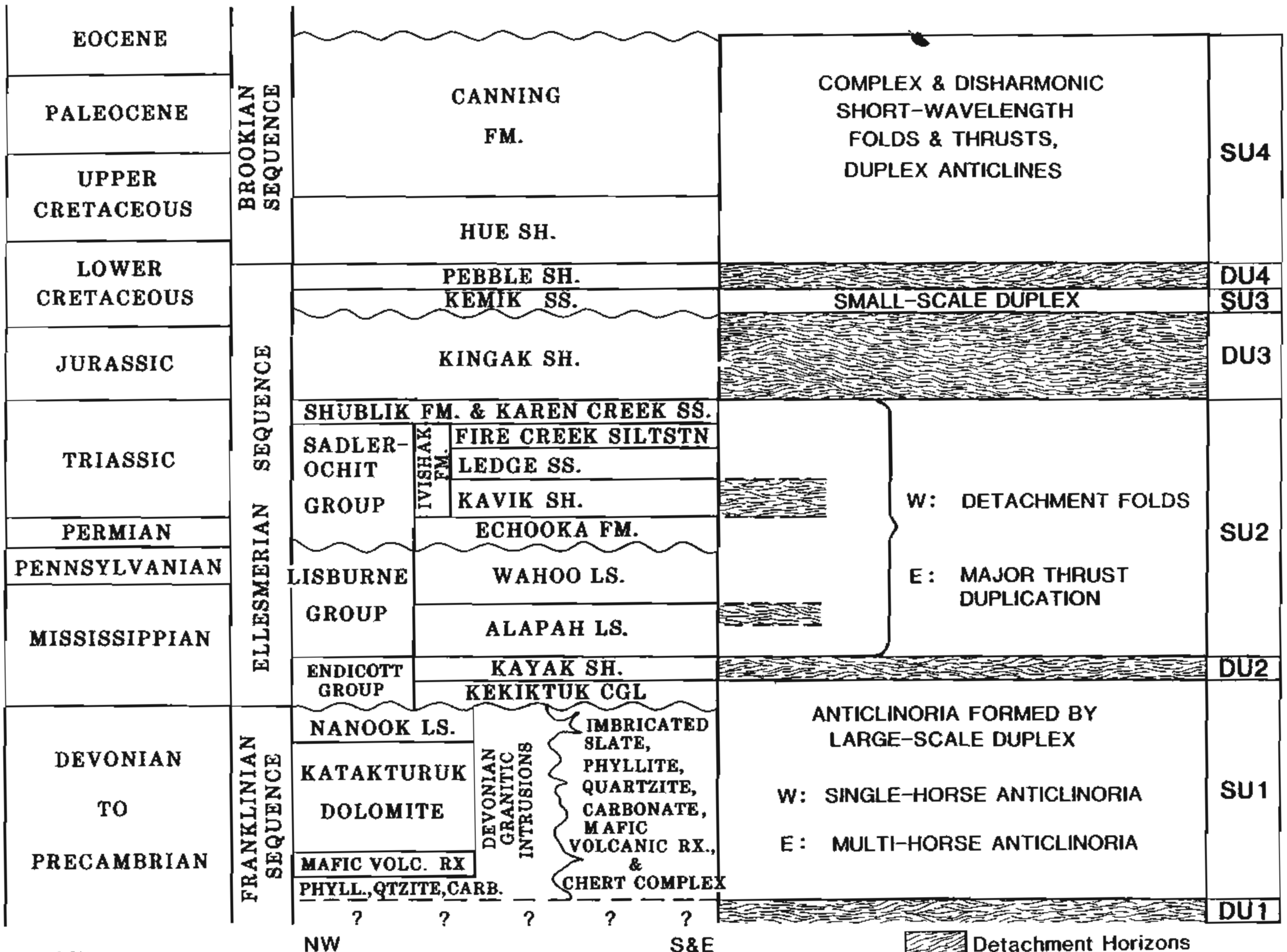

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FIGURE 2.

SCHEMATIC CROSS SECTIONS OF THE NORTHEASTERN BROOKS RANGE
(Not to Scale, Not Balanced)

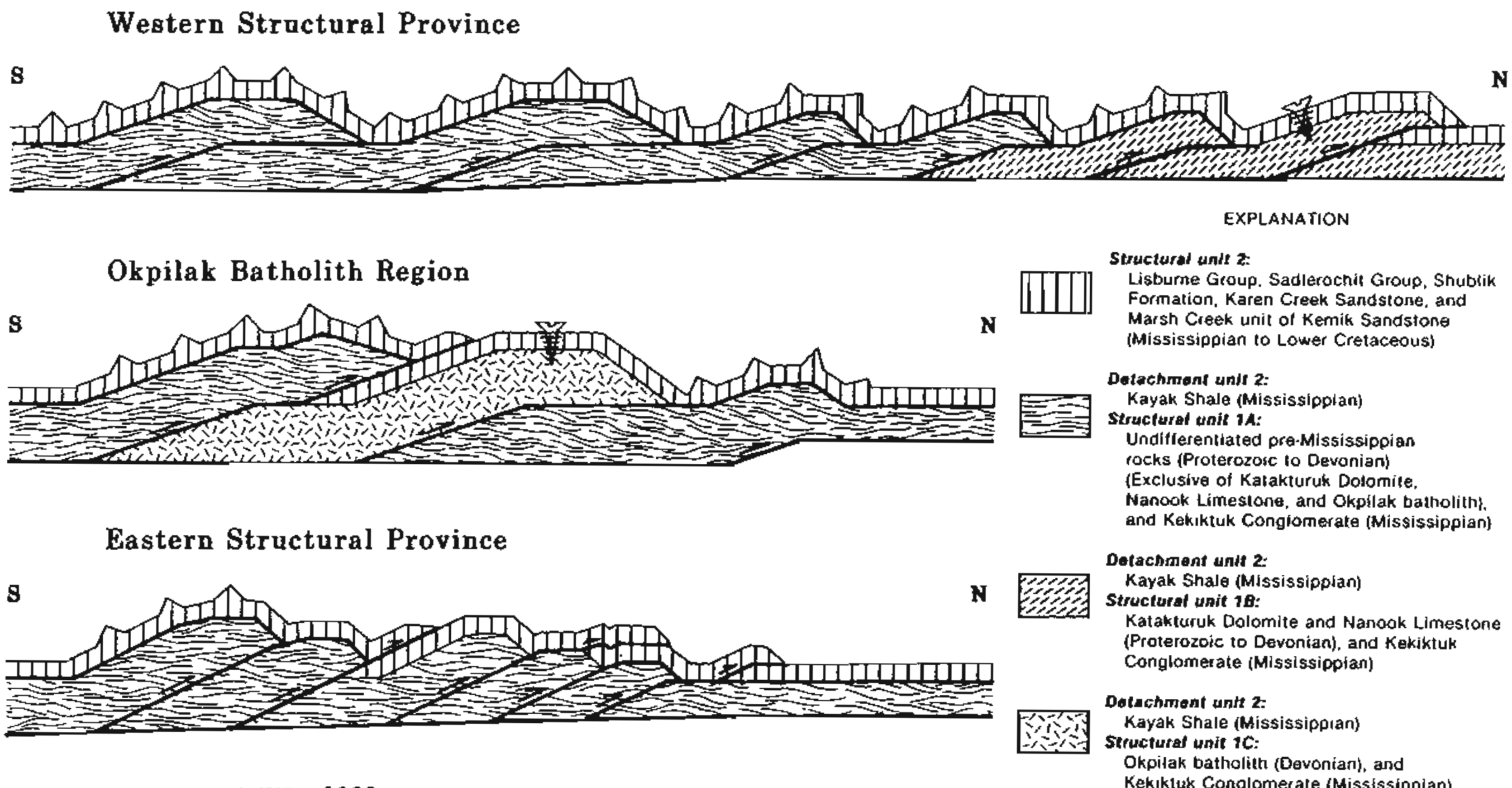

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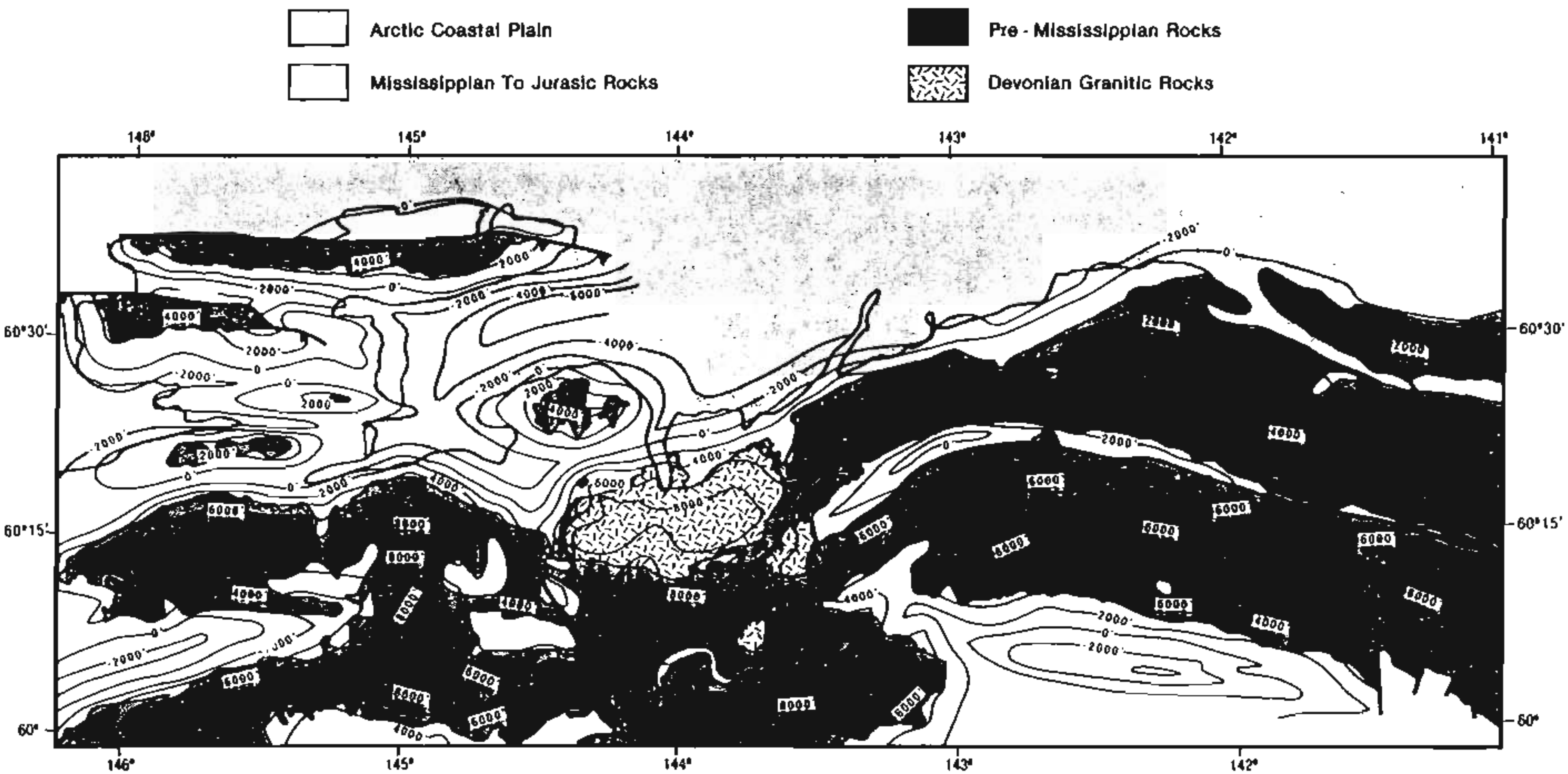
FIGURE 3



STRUCTURE CONTOUR MAP ON THE PRE - MISSISSIPPIAN UNCONFORMITY

FROM:
WALLACE AND HANKS, 1988

FIGURE 4.